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DISSERTATION

The Influence of Non-Invasive Brain Stimulation over the Primary Motor Cortex on the Interaction Between Gestures and Language

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List of Abbreviations

tDCS	transcranial direct current stimulation
M1	primary motor cortex
PMC	premotor cortex
IPL	inferior parietal lobe
ERP	event related potential
TMS	transcranial magnetic stimulation
MNS	Mirror Neuron System
IFG	inferior frontal gyrus
STS	superior temporal sulcus
STG	supratemporal gyrus
MTG	middle temporal gyrus
FEF	frontal eye fields
PF	prefrontal cortex
VLPFC	ventrolateral prefrontal cortex
SMA	supplementary motor area
EEG	electroencephalography
MEP	motor evoked potentials
ASD	Autism Spectrum Disorder
ICD	International Statistical Classification of Diseases and Related Health Problems
NMDA	N-methyl-D-aspartate
LTP	long-term potentiation
LTD	long-term depression
SD	Standard Deviation
mA	milliampere
kΩ	kilohm
ms	milliseconds
SEM	Standard Error of the Mean
fMRI	functional magnetic resonance imaging

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Abstract (English version)

Gestures are an essential component of social communication. Gesture comprehension is impaired in various clinical conditions. Thus, research of the mechanisms underlying gesture comprehension is essential. The role of the cerebral motor system and of the right hemisphere in understanding gestures has been a focus in recent research. In view of these findings, the present study aimed at assessing whether “dual” transcranial direct current stimulation (tDCS) improves gesture comprehension and semantic integration. Anodal, facilitatory tDCS was applied to the right primary motor cortex (M1) while cathodal, inhibitory tDCS was applied to the left M1. Two groups of subjects (n = 20 each), matched for age and sex, were included in a between-subject design (real tDCS vs. sham tDCS). During stimulation, a semantic task was presented to the subjects followed by a control task (working memory). The semantic task required subjects to judge whether videos displaying symbolic gestures, instrumental gestures or landscapes and subsequent phrases were congruent or incongruent in meaning.

Overall accuracy was found to be significantly lower in the real tDCS group than in the sham group. Accuracy on congruent gestures was significantly lower than on incongruent ones. Response times were significantly longer to instrumental gestures compared to symbolic gestures and landscape videos. Contrary to our hypothesis, dual tDCS decreased accuracy in the semantic task. Additionally, no improvement of response times was observed under tDCS.

The finding that accuracies and response times were not modified as hypothesized, could be attributed to left hemisphere cathode placement. This may have negatively affected interhemispheric interaction, thus hindering right hemispheric processing of affective aspects of speech. Additionally, anode placement over the right hemisphere could have led to stimulation of left hand reactions, although only right hand responses were allowed. The area of stimulation, the M1, may play a more crucial role in isolated action recognition than in semantic judgment. The fact that semantic priming was not observed may have resulted from the small number of gestures used and the fact that some gestures were ambiguously understood.

Future studies comparing the dual tDCS set-up with an anodal set-up, allowing for left hand responses, and implementing a greater amount of gestures, could shed further light on the role of the M1 regarding the comprehension of gestures. Additionally, dual tDCS over other cortical areas such as the premotor cortex (PMC) and inferior parietal lobe (IPL) could assist in finding treatments for gesture comprehension impairments.

Abstract (German version)

Gesten stellen einen essentiellen Bestandteil sozialer Kommunikation dar. Es existieren verschiedene klinische Zustände, in denen das Gestenverständnis gestört ist. Daher werden die zugrunde liegenden Mechanismen des Gestenverständnisses zunehmend erforscht, wobei die Rolle des zerebralen motorischen Systems sowie der rechten Hemisphäre in den Fokus des Interesses gerückt ist. Ziel der vorliegenden Studie war es, herauszufinden, ob duale transkranielle Gleichstromstimulation (tDCS) das Gestenverständnis sowie die semantische Integration verbessern kann. Hierzu wurde anodische, fördernde tDCS über dem rechten primären motorischen Kortex (M1) und kathodische, hemmende tDCS über dem linken M1 appliziert. Die Studie wurde an zwei bezüglich Alter und Geschlecht vergleichbaren Gruppen durchgeführt (n = 20 je Gruppe). Eine Gruppe erhielt echte Gleichstromstimulation, während die andere Gruppe Placebo Stimulation erhielt. Während der Stimulation wurde den Probanden zunächst die Studienaufgabe und daraufhin eine Kontrollaufgabe (Arbeitsgedächtnis) präsentiert. In der Studienaufgabe mussten die Probanden beurteilen, ob Videos, welche symbolische oder instrumentelle Gesten oder Landschaften darstellten, mit darauf folgenden kurzen Aussagen übereinstimmten oder nicht.

Die Treffgenauigkeit in der Gruppe, die echte tDCS erhielt, war signifikant niedriger als jene in der Placebogruppe. Zudem war die Treffgenauigkeit für übereinstimmende Gesten niedriger als jene für nicht übereinstimmende Gesten. Die Reaktionszeiten auf instrumentelle Gesten waren am längsten. Entgegen der Studienhypothese, verringerte echte Gleichstromstimulation die Treffgenauigkeit in der Studienaufgabe. Zudem konnte keine Verbesserung der Reaktionszeiten durch Gleichstromstimulation erzielt werden.

Diese Ergebnisse könnten auf die Platzierung der Kathode über dem linken M1 und einer daraus resultierenden Störung der interhemisphärischen Interaktion sowie der Verarbeitung affektiver Aspekte durch die rechte Hemisphäre zurückzuführen sein. Zudem könnte die Platzierung der Anode über der rechten Hemisphäre Reaktionen der linken Hand stimuliert haben. Diese wurden, da nur rechtshändige Reaktionen gestattet waren, nicht gemessen. Weiterhin könnte der M1, die Stimulationsregion unserer Studie, eine größere Rolle beim Erkennen isolierter Handlungen spielen als bei semantischer Beurteilung. Dass unsere Studie kein semantisches Priming zeigen konnte, könnte an der relativ geringen Anzahl von präsentierten Gesten sowie an missverständlichen Gesten liegen.

Zukünftige Studien, die duale Gleichstromstimulation mit anodaler Stimulation vergleichen, sowie linkshändige Reaktionen gestatten und eine größere Anzahl von Gesten präsentieren, könnten die Rolle des M1 im Gestenverständnis klären. Des Weiteren könnte duale Stimulation anderer zerebraler Strukturen wie dem PMC und dem IPL helfen, Therapiemöglichkeiten für Beeinträchtigungen des Verständnisses von Gesten zu entwickeln.

1. Introduction

1.1 The Interaction between Gestures and Spoken Language

Gestures are intrinsic to cultures throughout the world and are an essential component of social communication (1-4). Gestures are specific types of actions from the language domain (5). They occur spontaneously accompanying speech or independent of speech (6-8). There is an ongoing debate concerning the interaction between gestures and spoken language (8, 9). Two main theories pertaining to how these two entities are linked are the "integrated system hypothesis" and the "independent system hypothesis" (7, 8, 10, 11).

Research in support of the "integrated system hypothesis" maintains that gestures and speech form one communication system (7, 8, 10, 12). This hypothesis emphasizes the fact that speech can be enhanced by gestures (8). In addition, gestures are able to influence how a message is understood as well as contributing to speech comprehension (8, 12-15). Notably, gestures which require speech to be understood (co-speech gestures) may not be understood when presented alone (16). Research supporting the "integrated system hypothesis" has illustrated that gestures and speech activate similar brain areas (9, 16). A study by Beattie and Shovelton confirmed the connection between gesture and speech. In their study subjects answered more precisely on object sizes when perceiving gestures while listening to speech (11). Further evidence of the "integrated system hypothesis" is that gesture observation has a positive influence on semantic processing and lexical retrieval (4, 17). Özyürek et al. summarize the similarities between gesture and speech as follows: speech and gesture function in relating similar information; they are "temporally aligned to each other" and convey a message to the viewer (17, 18).

In contrast, the "independent system hypothesis" maintains that gesture and speech are two separate communication systems (12). In this hypothesis gestures are considered to have an adjuvant function when speech is briefly disturbed (6, 10). Support for this hypothesis stems from findings showing that gestures are more frequently produced when lexical retrieval is difficult (7, 11).

There are two cardinal theories concerning the role that gestures play in communication, the "Lexical Retrieval Hypothesis" and the "Information Packaging Hypothesis" (19, 20). According to the "Lexical Retrieval Hypothesis", gestures are essential for gaining access to words, especially those that have a "spatial content" (20). In fact, preventing subjects from gesturing leads to impeded lexical access (20, 21). The "Information Packaging Hypothesis" assumes that gestures assist in planning a message and rearranging “motor knowledge in verbal form” (19).

The strong link between gestures and speech is further supported by the fact that they are processed similarly (16, 22). The so-called N400 effect has been investigated to study this link. The N400 is a strong negative event related potential (ERP), starting 200-300 ms after presentation of a context and peaking at 400 ms (23). It is interpreted as resulting from semantic processing (16, 23, 24). As the N400 effect is elicited during observation of gestures, it has been concluded that gestures trigger semantic processing (16-18, 22, 25).

1.2 Gesture Categories

“Co-speech” gestures are defined as hand movements that are produced while speaking (16, 20). McNeill arranged different types of gestures in “Kendon’s Continuum” (see Figure 1) (8). The continuum ranges gesture categories from unconventionalized to conventionalized, and also depicts to what extent the gestures possess linguistic properties (least to most) (see Figure 1) (26).

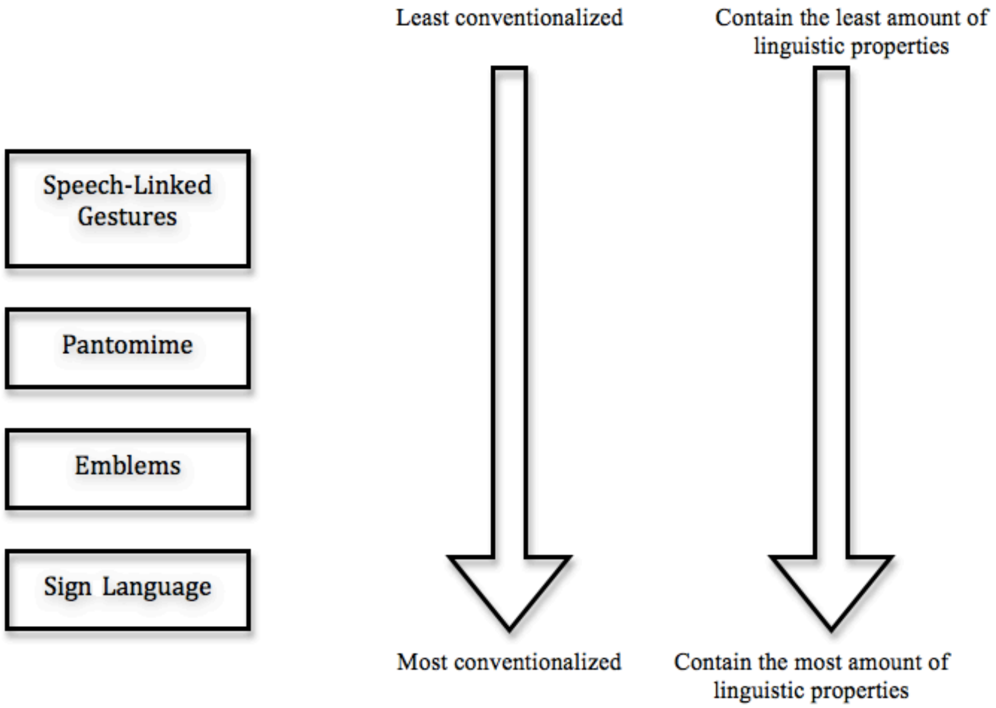

Figure 1. “Kendon’s Continuum” depicting different gesture categories as well as the degree of conventionalization and linguistic properties ranging from least to most (modified after McNeill 2000 (12)).

Gestures can be grouped into different classification systems (8). This paper will go into detail on McNeill's widely known classification system of gestures. McNeill defines "iconic", "metaphoric", and "deictic" gestures, as well as "beats" and "Butterworths" (8). Further, pantomimes are considered to be a type of gesture (12, 17, 18). McNeill notes, however, that other classification systems exist, such as those by Freedman and Hoffman as well as by Efron (8). In McNeill's system, "iconic" gestures are such gestures that carry meaning only when accompanied by speech; they deliver information about characteristics of events being described such as motion or size. (8, 11, 17, 18, 26). "Metaphoric" gestures, also known as emblematic or symbolic gestures or simply emblems, are culturally conventionalized symbols that can be understood with or without accompanying speech (7, 8, 16, 17). "Deictic" gestures indicate objects, people or directions and are most commonly formed using the index finger (8, 26). They can accompany speech, yet they can be understood alone as well (8). "Beat" gestures, also known as motor gestures or batons, do not possess one single meaning but rather accentuate rhythmic facets of speech (8, 17, 26). "Butterworths" are gestures that are employed when recollection of a word is impaired (8). Finally, pantomimes are more conventionalized gestures that present a specific action, event, or object without accompanying speech (27, 28).

1.3 The Role of Gestures in the Evolution of Language

The "gestural theory of language" supports the premise that gestures are essential in human communication (29-32). There are, however, researchers who contradict this premise (29, 31). According to Arbib, an advocate of the "gestural theory of language", language evolved on the basis of gesture in the following steps: grasping, evolution of a mirror system in order to understand actions of others, evolution of an imitation system, a communication form implementing signs and eventually a communication form based on speech (27). Arbib states that speech could evolve from gestures because "once an organism has an iconic gesture, it can both modulate that gesture and/or symbolize it […] by […] associating a word with it" (27). Correspondingly, as soon as the associated word had been learned, speech replaced gesture (27). It has therefore been hypothesized that if an evolutionary connection between speech and gestures exists, the perception of vocal gestures, i.e. speech, would lead to activation of the motor system (29). Support of this hypothesis stems from a study by Flöel et al. who examined whether motor evoked potentials (MEP) of hand muscles induced by transcranial magnetic stimulation (TMS) would be increased when subjects produced phonemes, read aloud, read silently, or spoke (29). In their study, Flöel et al. were able to establish that various linguistic tasks pre-activate the hand area of the M1 (29). A slightly different stance on the "gestural theory of language" is taken by McNeill et al., who argue that speech and gestures emerged together (33). Support for this point of view is based on the fact that gesture and speech typically occur simultaneously and transmit the same idea (33). McNeill et al. state that there is a possibility that pantomime was the actual protolanguage and in its place came gesture and speech (33). In fact, Rizzolatti and Craighero propose that words most likely evolved from combining sounds with pantomimes and actions (30). In contrast to the "gestural theory of language", MacNeilage and David propose that language evolved on the basis of a "mandibular frame", which includes, for example, lip-smacking and chewing (34). Such communicative signals, which are evident in several nonhuman primates as a form of communication, were progressively combined with phonation in the course of evolution until distinct words were formed (34).

1.4 Perception of Actions

The way in which actions, and specifically gestures, are perceived has been the focus of several studies. Gestures "require processing biologically relevant motion" (17). The Mirror Neuron System (MNS) is considered to be essential in understanding the actions of others (5, 9, 10, 31, 35). The MNS is composed of neurons that are both active when executing and when observing an action (36-39). Mirror neurons were first found in monkeys in area F5 of the PMC (27, 40). This system is thought to play an important role in enabling the transition from action execution to gesturing (10, 27, 41). In this way, it is essential in creating a link between the addressee and the sender of a message (30). The human MNS, unlike the monkey MNS, is activated when viewing intransitive and mimicked movements which include gestures (37, 42). Intransitive actions pertain to those that are unrelated to a particular object, for example clapping one's hands (10). The homologue of area F5 in the human brain is assumed to be Broca's area, specifically Brodmann's Area 44. However, the human MNS has been found to be composed of additional areas (27, 31, 36). These are the pars opercularis of the left inferior frontal gyrus (IFG) (corresponding to Brodmann's Area 45), the IPL, and the superior temporal sulcus (STS) (16, 43-46). Findings are divergent in regard to which hemisphere the MNS is located in. Some studies have shown that the MNS is distributed bilaterally, others have found that it is lateralized to the left hemisphere (30, 46, 47). Interestingly, Nishitani et al. suggest that although left-hemisphere dominance of the MNS was observed, this dominance could be attributed to presentation of movements mainly in the subjects' right visual field (47). An ample number of neuroimaging studies have demonstrated that action perception can lead to activation of several cerebral areas including the STS, the supratemporal gyrus (STG), the middle temporal gyrus (MTG), the IPL, the PMC, frontal eye fields (FEF), visual areas as well as the cerebellum (48-50). The STS has been found to be especially responsive to biological motion (48, 51, 52). Furthermore, it plays an important role in preparing for imitation and in converging the ventral and dorsal pathways (1, 45, 53). Observation of hand and arm action in particular, has been shown to activate the ventral PMC and the pars opercularis of the IFG (30). Decety et al. further demonstrated an activation of Broca's and Wernicke's areas when observing meaningful hand movements (54). Notably, viewing semantically unrelated hand movement and speech induces larger activation of the right hemisphere, especially of the IFG (17). Taken together, these findings indicate an activation and involvement of language areas during the perception of actions in general and in hand-related actions more specifically. These results further reinforce the evolutionary link between gestures and speech.

1.4.1 Perception of Gestures

The question that arises with respect to movements is whether gestures, a specific subtype of movement, are processed by similar cerebral areas as actions are. A neuronal network consisting of the posterior STS, the posterior STG, the MTG, the IPL, the PMC, and Broca's region is considered to be engaged in perceiving gestures (2, 9, 17, 54, 55). Furthermore, the amygdala and the prefrontal cortices (PF) have been shown to be involved in perceiving gestures (50). Observing expressive gestures leads to strong activity of the left ventrolateral prefrontal cortex (VLPFC), which is considered to be important for coding gesture valence (50). Interestingly, meaningful and meaningless gestures appear to be processed differently. Meaningful gestures lead to specific activation in left frontotemporal areas whereas meaningless gestures lead to specific activation in right occipitoparietal areas (54). Further evidence supporting the involvement of the right hemisphere in gesture comprehension was presented by Nakamura et al. In their study, viewing photographed hand signs and performing a semantic decision-making task resulted in activation predominantly in the right hemisphere (55). The authors suggested that the right hemisphere is more involved in social recognition, whereas the left hemisphere is more involved in language perception (55).

1.4.2 Involvement of the Motor System

The motor system is essential for producing movements; it “coordinates activities of individual muscles to generate sequences of movements that are integrated into behavioral responses appropriate to the environment” (56, 57). The cerebral motor areas comprise the M1 (Brodmann area 4), as well as secondary motor areas including the supplementary motor area (SMA) and the PMC, the brain stem, cerebellum, basal ganglia, and spinal cord (43, 56, 58). Strong connections between the subunits of the motor system are essential for proper functioning (56, 58). Furthermore, the subunits of the motor system are hierarchically organized: while the structures higher in the hierarchy include the cerebellum, basal ganglia and M1, those lowest in the hierarchy are the second motor neurons, which execute contraction of single muscles (56). Additionally, the motor system receives inputs from other cerebral areas such as the limbic system (56). Investigation as to the complex role of the cerebral motor system in comprehension of speech and gesture is still ongoing (59).

Understanding of language accompanying gestures is considered to depend on connections between areas involved in motor planning and production as well as anterior areas involved in language comprehension (4, 14). Jeannerod reported that action perception is based on the “motor simulation theory”, according to which action perception leads to motor cortex activation, as a remapping of the observed action onto one’s own motor system takes place (60, 61). Several studies showed that action observation leads to activation of the motor cortex (4, 16, 30, 36, 62). For example, studies that applied TMS over the left M1 while subjects observed actions, led to a facilitation of MEP amplitudes; these effects were specific for those muscles that are essential for the observed action (16, 36, 63). Moreover, a study was conducted which recorded neuromagnetic oscillations from the precentral cortex while stimulating the N. medianus of the right and left arm alternately (62). Here, a significant reduction of the electroencephalography (EEG) rebound was found both during action execution and during action observation (62). This effect, however, was stronger for execution than observation of actions and was not found for observation of objects (36, 62).

Evidence of the involvement of the M1 in action observation furthermore stems from studies on mu rhythms. Mu rhythms are oscillations over the rolandic areas with two frequencies: one at about 10 Hz and one at about 20 Hz (42, 64, 65). The 20 Hz frequency is regarded to be elicited by the M1 (42, 64, 65). This frequency is absent after median nerve stimulation both when a subject moves his/her fingers and when a subject views another person moving (62). Notably, this effect is also present when viewing iconic gestures (66).

1.4.3 Action and Gesture Comprehension Impairments

Studies on patients who display deficits in comprehension of observed actions and gestures further give insight into which cerebral mechanisms are activated by gestures. A study on patients who had suffered a unilateral stroke either in the left or right hemisphere revealed impairments in recognizing point-light displays of arm movements (59). These impairments were especially exhibited when the observed arm movement was contralateral to the patient's brain lesion (59). This is considered to result from disturbed motor simulation during presentation of contralateral movements (59). Gesture comprehension deficits have also been observed in patients with limb apraxia who had lesions in the left frontal regions (67). Goldenberg et al. further examined which specific deficits brain damaged patients exhibit with regard to gesture comprehension. They found that patients with right brain lesions have difficulties in tasks involving matching gestures and "visuospatial analysis", whereas patients with left brain damage have trouble in imitation tasks (68). Rapcsak et al. report of a patient who had suffered a stroke leading to a "virtually complete destruction" of the left hemisphere yet had no trouble comprehending gestures (69). The authors suggested that such findings are due to the right hemisphere's specific role in recognizing familiar actions (69).

Although language in general has been regarded to be a function of the left hemisphere, recent evidence has pointed to an involvement of both hemispheres in various aspects of language comprehension (70, 71). While the left hemisphere is considered to be critical for processing linguistic aspects of language including semantics and syntax, the right hemisphere is considered to be crucial for processing affective facets of language, including gestures and prosody (70, 72-74). As gestures modify language by hand movement, prosody modifies language by vocal aspects such as "melody, pauses, timing, stress, and accent, as well as intonation" (73).

Gesture comprehension impairments have also been observed in individuals suffering from Autism Spectrum Disorder (ASD) (1). In fact, impaired gesture comprehension has been included in the criteria of childhood autism in the International Statistical Classification of Diseases and Related Health Problems (ICD) (75). This criterion is part of a set of symptoms concerning abnormal or impaired development of social interaction, frequently observed through lack of facial expression, gesture, and eye gaze (75). Gesture comprehension deficits and other symptoms of ASD, such as deficits in communication and understanding of others are hypothesized to originate from a "broken mirror" neuron system (76, 77). It has been proposed that ASD patients have "a deficit in the chained organization of motor acts and, as a consequence, […] are unable to activate it during action observation" (76). Support for this premise stems from findings in ASD patients, in which mu rhythm suppression was observed during action performance but not during action observation (77, 78). Researchers opposing the "broken mirror theory" with respect to ASD are of the opinion that it is not clear "which cognitive components of imitation are supported by [the] MNS" and that there is not a single cause that is responsible for the deficits seen in ASD (79).

Clinical symptoms regarding impaired gesture comprehension are also evident in patients suffering from schizophrenia. These patients show difficulties in social communication, i.e. production of non-verbal communication such as gestures and understanding facial expressions, intonation and speech-accompanying gestures (80-83). Bucci et al. studied the effects of presenting different gesture videos to a group of patients with psychotic symptoms (80). The patients were required to decide whether a sentence presented subsequently to a gesture video expressed the actual meaning of the gesture, the meaning of a different gesture, or an insult (80). The study demonstrated that patients with schizophrenia tend to interpret incidental movements as gestures and misinterpret intended gestures as insults (80). A further study by Cohen-Maximov et al. analyzed the accuracy and response times of schizophrenic patients on interpreting gestures and succeeding phrases as either congruent or incongruent in meaning (81). They found that schizophrenic patients performed less accurately and responded slower than a healthy control group (81).

In order to develop adequate treatments for patients exhibiting deficits in gesture comprehension, it is necessary to ascertain whether activation of the involved cerebral areas can contribute to enhancement of gesture comprehension (1-4). Additionally, it is important to determine which of the cerebral hemispheres makes a greater contribution to gesture understanding. A recently conducted study by Cohen-Maximov et al. aimed at examining this question (81). This study explored the effect anodal tDCS over the right IFG has on a semantic gesture integration task. Subjects were required to decide whether the presented gesture and a subsequently presented phrase were congruent or incongruent in meaning (81). The implemented gestures were either of symbolic or instrumental nature or landscape videos. The study demonstrated that under anodal tDCS over the right IFG and cathodal tDCS over the left IFG, subjects' response was quicker, especially to symbolic gestures (81). Additionally, semantic priming, which is an essential tool in exploring the "link between linguistic and non-linguistic systems", was considered to be effective in this task (6, 7, 81, 84, 85). Gulan and Valerjev define priming as "an increased sensitivity to certain stimuli due to prior experience" (86). Semantic priming is tested by presentation of a word or non-verbal stimulus that is either semantically related or unrelated to a succeeding word (87). The subjects' task is to decide whether a semantic connection exists between the two (87). Semantic priming occurs when a visual presentation of a word leads to activation of the mental representation of the identical word (86). As activation of related cerebral areas takes place, facilitation of processing of analogous targets occurs, which leads to quicker reaction times and higher accuracies (cf. 7, 81, 86).

1.5 Transcranial Direct Current Stimulation (tDCS)

The afore-mentioned study by Cohen-Maximov et al. was able to induce facilitation of response times and accuracies by applying tDCS. TDCS is a promising tool in neurological research and therapies (88, 89). Over the last 20 years, a great amount of research has been conducted concerning the influence of tDCS on short and long-term plasticity (90). Application of tDCS has been studied in both healthy and clinical populations. For example, a positive effect of tDCS on language learning was demonstrated through stimulation over the left peri-Sylvian area (91). TDCS entails the noninvasive application of direct currents in two modalities – an anodal and a cathodal polarization (92-94). The anodal polarization leads to an increase of excitability through a positively charged electrode, whereas the cathodal polarization leads to a decrease of excitability through a negatively charged electrode (92-95). TDCS modulates cortical networks in contrast to other non-invasive brain stimulation methods such as TMS, which induces neuronal action potentials (95). The excitability changes induced by tDCS have been shown to be focal, long-lasting, and reversible (92, 96).

Short lasting tDCS is considered to modulate resting membrane potentials with anodal stimulation leading to depolarization and cathodal to hyperpolarization (97). It has been suggested that the underlying mechanisms of tDCS-induced plasticity are changes in membrane potentials and in N-methyl-D-aspartate (NMDA) receptor activation, which lead to long-term potentiation (LTP) or long-term depression (LTD) of neuronal transmission (88, 89). How effectively tDCS functions is dependent upon factors including the size of the electrode, current strength, and current density (current density is the quotient of current strength and electrode size) (95).

A large amount of studies employing tDCS have focused on its effects over the M1 (98). Anodal tDCS over the M1 has been shown to have an effect on tasks that involve motor learning and motor function and lead to improvement of connectivity to other cerebral areas (99-101). A study conducted by Nitsche et al. demonstrated that application of anodal tDCS over the left M1 leads to an increase in motor learning (102). This was exhibited when subjects were required to press a button as quickly as possible when observing an asterisk on-screen (102). Lapenta et al. illustrated that anodal tDCS over the left M1 leads to mu rhythm synchronization whereas cathodal tDCS results in mu rhythm desynchronization (103).

Different application modalities of tDCS have been implemented in past studies. These are anodal, cathodal and dual stimulation (95). Dual tDCS has been shown to have a positive effect on different tasks. A study by Karok and Witney demonstrated that dual tDCS with the anode placed over the right M1 and the cathode placed over the left M1 had a larger effect on a motor learning task than did anodal tDCS with the anode placed over the right M1 (104). The specific motor task in their study consisted of subjects memorizing a numerical pattern and repeating the pattern on a keyboard as quickly as possible (104). In a study on stroke patients, improvement of a motor task was achieved when dual tDCS was conducted with the anode placed over the M1 of the lesioned hemisphere and the cathode placed over the contralateral M1 (105). The motor task of this particular study consisted of a flexion and extension exercise (105).

2. Objective of the Study

A vast amount of studies have established the deep-seated link between gesture and language. Gestures are meaningful motions that convey information and may accompany speech or occur alone (5-8). The cerebral areas activated by gesture perception include the M1, the posterior STS and STG, the MTG, the IPL, the PMC, and Broca’s region (2, 4, 9, 17, 54, 55, 60, 61). Gesture comprehension impairments can be observed in, among others, ASD, limb apraxia, schizophrenia, and hemiplegia (1, 59, 67, 68, 76). Investigation of possible improvements in gesture comprehension and gesture-language integration are relevant, as results from such studies could be applied in the treatment of patients suffering from gesture comprehension impairments.

The goal of this study was to further investigate the involvement of the M1, particularly of the right hemisphere in gesture comprehension. The objective of our study was to assess whether increasing excitability of the right M1 through tDCS, accompanied by decreasing excitability of the left M1, could influence gesture comprehension and semantic integration. Our study specifically examined whether a combination of these approaches (“dual” tDCS) over the primary motor cortices could enhance gesture processing in a semantic integration task. The semantic task of this study was based on the strong link between gestures and language, as subjects were required to evaluate whether lexical stimuli were congruent or incongruent in meaning with a preceding video sequence depicting a variety of gestures. These gestures were either instrumental or symbolic in nature; that is, they either conveyed an action, an idea, or an emotion, respectively. Landscape videos such as a volcano eruption or a waterfall were chosen as a control, being that they present motion. However, contrary to movement in landscapes, gestures are comprised of human movement. In line with the afore-mentioned study by Cohen-Maximov et al., which examined the effects of anodal tDCS over the right IFG and cathodal tDCS over the left IFG (81), the following study questions were raised:

- Does dual tDCS with anodal stimulation over the right M1 and cathodal stimulation over the left M1 have an effect on gesture comprehension and semantic integration?
- Do accuracy and response times differ in congruent and incongruent trials?

With these study questions in mind, the following hypotheses were made:

(i) Application of dual tDCS with anodal stimulation over the right M1 and cathodal stimulation over the left M1 leads to higher accuracies and faster response times in a semantic integration task.

This hypothesis is based on the strong motor component embodied in symbolic and instrumental gestures. These gestures functioned as primes in our study. Additionally, the right hemisphere has been shown to be active when observing meaningful gestures and when semantic decision-making is required – it is considered to be essential in social cognition and processing affective aspects of speech while the left hemisphere is considered to be more important for language comprehension (cf. 54, 55, 70, 72-74, 81). Thus, anodal stimulation of the right hemisphere, specifically of the right M1, was hypothesized to facilitate performance on our task.

(ii) Accuracies are higher and response times faster in congruent conditions.

This hypothesis is based on the semantic priming paradigm, according to which processing of related targets is facilitated (7, 81, 86).

3. Methods

The study was approved by the Ethics Commission of the Charité – Universitätsmedizin and conducted according to the Helsinki Declaration (106). All standards of Good Scientific Practice were followed (107). All subjects received an explanation as to the procedure of the study as well as possible side effects and gave their informed signed consent. All subjects received a monetary compensation for participating in the study. Subject data was anonymized and pseudonymized.

3.1 Participants

41 healthy, young, right-handed subjects, of which one female subject had to be excluded due to misunderstanding instructions, were recruited to participate in our study (mean age = 24.7 years; SD = 3.8; range = 20-35; 20 females, 20 males). Subjects were recruited by email and bulletin notices at the Charité – Universitätsmedizin, the Freie Universität, the Technische Universität and the Humboldt-Universität, all located in Berlin, Germany. Inclusion criteria were: ages 20 to 40 years, right-handedness and German mother tongue. Right-handedness was determined by the "Edinburgh Handedness Inventory" (108) (see Appendix A). Exclusion criteria were: severe internal or psychiatric diseases, pregnancy and breast-feeding. Subjects were requested to answer a general questionnaire and a tDCS questionnaire in order to ensure that they did not present any exclusion criteria (see Appendix B and Appendix C). Subjects were asked to refrain from the intake of drugs and excessive amounts of alcohol the day prior to their participation in the study. Furthermore, subjects were requested to wash their hair without applying hair gel, oil or similar ointments the day before the testing took place. These measures were taken in order to prevent external factors from influencing tDCS.

3.2 Procedure

The study took place in a separate room, with only the subject and the examiner present. Tasks were conducted on a Samsung NP-R522H laptop (screen diagonal 40 cm, Intel Core TM2 Duo Processor), with the subject's head at a distance of approximately 60 cm on eye level with the screen. Subjects sat in a comfortable chair with back and arm rests. The participants were randomly split into two groups; one group received dual tDCS (mean age = 24.7 years; SD = 3.9; range = 20-35; 10 females, 10 males) while the other received placebo-controlled (sham) tDCS (mean age = 24.8 years; SD = 3.8; range = 20-35; 10 females, 10 males). The group receiving dual tDCS will be referred to as “real”, the placebo group as “sham”. The study was single-blinded. It consisted of various sections that were carried out in a fixed order (see Figure 2). Subjects were asked to fill out a standardized mood questionnaire (Positive Affect Negative Affect Scale, PANAS, (109)) prior to stimulation and testing. Subsequently, electrodes were positioned and tDCS began. During the first four minutes of tDCS instructions were given and a test phase was conducted. Four minutes after stimulation onset subjects began the semantic task, which was immediately followed by a working memory task (Digit Span) (see Appendix E) (110). At the end of tDCS and the semantic task, subjects filled out the mood questionnaire (PANAS) again as well as an additional questionnaire concerning side effects of tDCS (see Appendix F) (111).

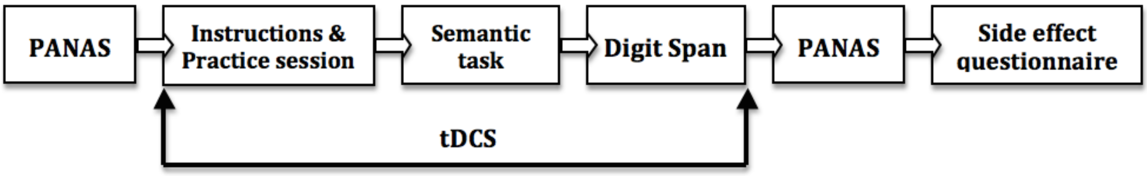

Figure 2. Procedure of the study.

3.2.1 Transcranial Direct Current Stimulation – Method

TDCS was applied using the battery-driven NeuroConn DC-Stimulator Plus (NeuroConn, Ilmenau, Germany[1]). The anodal electrode was placed over the right M1 and the cathodal electrode over the left M1 using position C4 and C3 according to the 10-20 EEG system, respectively (see Figure 3) (112).

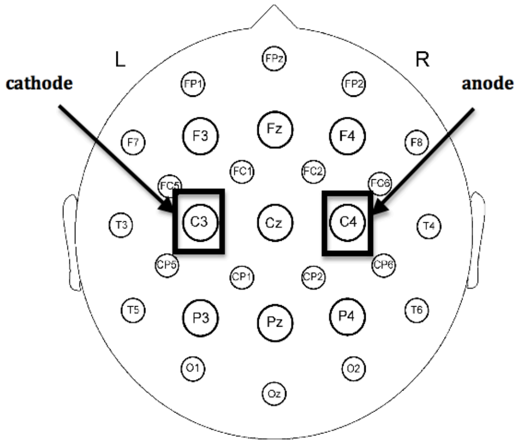

Figure 3. Placement of the anode and cathode on the scalp (adapted from Blackford et al. (113)).

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[1] neuroConn GmbH, Grenzhammer 10, 98693 Ilmenau, Germany.

Prior to tDCS application, the specific scalp area was disinfected using Softasept® N skin desinfectant[2] according to guidelines (95). Subsequently, two saline-soaked sponge electrodes (50 mm x 70 mm) were used for tDCS. The electrodes were held in place by two rubber straps, which were placed around the subject's forehead and around the chin (see Figure 4).

Dual tDCS consisted of a 20 minute single mode stimulation period with a fade in and fade out of 10 seconds. TDCS current was 1.5 mA with a maximum impedance of 10 kΩ. During sham tDCS, the stimulator was switched off automatically after 30 seconds.

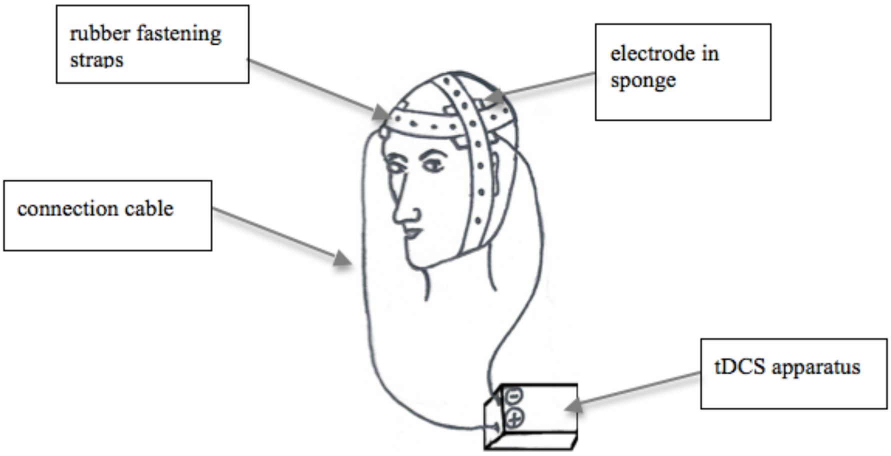

Figure 4. Sketch of the tDCS set-up of the study (adapted from Jefferson et al. (114)).

3.2.2 Semantic Task

The semantic task consisted of watching a set of video sequences, which were filmed at the Department of Psychology at the Bar Ilan University, Ramat Gan, Tel Aviv, Israel (81). Stimuli were validated at the Charité – Universitätsmedizin Berlin by studying accuracy and response times of 10 native German speakers. The gestures were chosen to be implemented in the final study if they were responded to correctly in at least 50% of the cases and if the response times were no longer than two standard deviations from the mean. The videos were in "AVI file type, 30.0 Mbps bit rate, 25 frames per second" (81). The videos were shown on a laptop using the presentation program "Presentation 14.8". In each video, an actor pantomimed commonly known gestures. For the purpose of excluding distraction caused by facial expressions, print or color, the actor wore a white mask, a long-sleeved dark shirt and sat at a table with a grey wall behind him (81). Gestures were grouped into instrumental and symbolic categories: instrumental gestures are those that imitate commonly known actions such as brushing teeth or changing a

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[2] Softasept® N, B. Braun Melsungen AG, 34209 Melsungen, Germany.

light bulb; symbolic gestures are those that carry figurative meaning such as “good luck” or “goodbye” (8). A third type of video consisted of landscape scenes such as an erupting volcano and trees blowing in the wind (81). All videos were followed by a short written German phrase containing a maximum of three words, which was either congruent or incongruent in meaning with the preceding video (see Figure 5). The implemented phrases were translated from a set of Hebrew phrases (81). These translations were approved by four native German speakers, in order to ensure that they were understandable. A total of 108 videos, grouped into two sessions with a 90 second break in-between, were shown (see Appendix D). Of the 108 videos, 22 were instrumental congruent, 22 instrumental incongruent, 16 symbolic congruent, 16 symbolic incongruent, 16 landscapes congruent, and 16 landscapes incongruent. The task was completed on an average of 12 minutes.

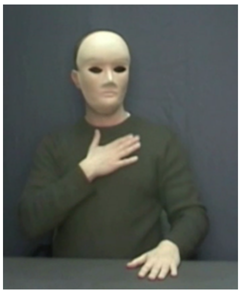
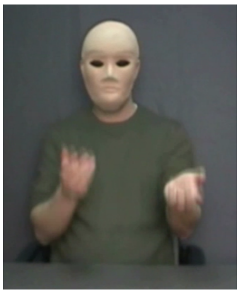
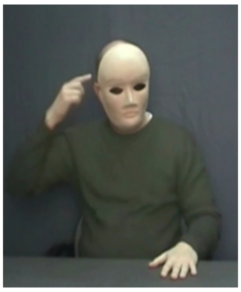
instrumental congruent	**symbolic congruent**
 changing a light bulb (German: “Lampe wechseln”)	 I swear (German: “Ich schwöre”)
instrumental incongruent	**symbolic incongruent**
 jumping (German: “hochspringen”)	 shy (German: “schüchtern”)

Figure 5. A selection of implemented videos showing the different gesture categories used, as well as the phrases following each video (modified after Cohen-Maximov T et al. (81)).

During the first four minutes of tDCS, instructions were given to allow subjects to get accustomed to the semantic task. The test phase consisted of 8 congruent and 8 incongruent trials. After each trial, the subjects received feedback as to whether their responses were correct or incorrect. During the actual task, each video was preceded by a central fixation point (+) that was presented on the center of the screen for 500 ms. The presentation of the fixation point (+) was followed by a video clip which appeared for 1520 ms. Following the video clip, the central fixation point (+) appeared again for 500 ms. Subsequently a short German phrase was presented for 150 ms (see Figure 6). Subjects were asked to decide as quickly and as correctly as possible whether or not the phrase coincided with the video preceding it (81).

Figure 6. Task set-up (modified after Cohen-Maximov T et al. (81)).

The subjects were asked to respond by using their right index finger to click the keyboard key “V” for “match” and “N” for “mismatch”. In order to prevent influencing response time, subjects were asked to rest their index finger on the key “B” in between responses. The keys “V” and “N” were labeled with a green and a red sticker, respectively (see Figure 7).

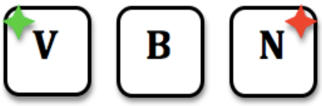


Figure 7. Labels on keyboard response keys.

3.2.3 Digit Span

Following the semantic task, subjects were asked to perform a Digit Span to evaluate working memory (110) (see Appendix E). This test lasted until the end of tDCS. The test consisted of two parts. In both parts, sets of numbers were read monotonously in a rhythm of one word per second. In the first part, subjects repeated each set of numbers in the order that they were read to them. The size of the sets of numbers increased during the task from initially 3 numbers up to 9 numbers. In the second part, subjects repeated each set ranging from 2 to 8 numbers in reversed numerical order. In each session the instructions were identical. If the subject repeated one set of numbers incorrectly, the task was repeated with a second set, which consisted of the same amount of numbers. If the subject repeated this set incorrectly as well, the testing was ended. The sum of correct answers was calculated for each round and added up to a total sum.

3.2.4 PANAS

In order to assess the subjects' mood, subjects were asked to fill out a digital PANAS questionnaire (109) before and after tDCS. The PANAS questionnaire comprises a set of a total of 20 items of which 10 refer to positive and 10 to negative moods (109). In the computer version of PANAS, adjectives describing mood appeared on a laptop screen consecutively. The subjects were required to rate to what extent the adjectives applied to their current mood on a scale from 1 to 5 with 1 meaning "does not apply at all" (original German phrase: "trifft gar nicht zu") and 5 meaning "fully applies" (original German phrase: "trifft äußerst zu").

3.2.5 Side Effect Questionnaire

In the last part of the study, subjects were asked to fill out a questionnaire concerning side effects of tDCS. Based on a systematic meta-analysis, Brunoni et al. proposed this self-rated questionnaire (111). The recommended questioning of adverse effects is based upon a variety of studies taking into consideration different side effects. The questionnaire includes side effects such as itching (original German word: "jucken"), fatigue (original German word: "Müdigkeit"), neck pain (original German word: "Nackenschmerz"), and lapse of concentration (original German word: "Konzentrationsschwäche") (111) (see Appendix F). In addition to responding as to whether a side effect occurred, subjects were asked to assess to what extent the side effect occurred on a scale from one to four and whether they thought it was related to tDCS. Subjects were asked to assess whether they received real or sham tDCS in order to verify effective blinding.

3.3 Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics Version 21[3]. Prior to data analysis, the Kolmogorov-Smirnov test was implemented to test for normality, set to $p < .05$.

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[3] IBM SPSS Statistics Version 21, IBM Deutschland GmBH, 71137 Ehningen.

Repeated measures analysis of variance (ANOVA) was used to analyze the influence of the stimulation condition (real tDCS, sham tDCS) on the semantic integration task (measured by accuracies and response times). Independent t-tests were used to examine group differences in the Digit Span and PANAS. Post Hoc analyses were conducted using independent and paired samples t-tests corrected for multiple comparisons. Mann-Whitney Tests were implemented for analyzing side effects and subjects' responses regarding tDCS, as these values were not normally distributed. Data was considered significant at a level of $p < .05$. All data is expressed as mean ± Standard Deviation unless mentioned otherwise.

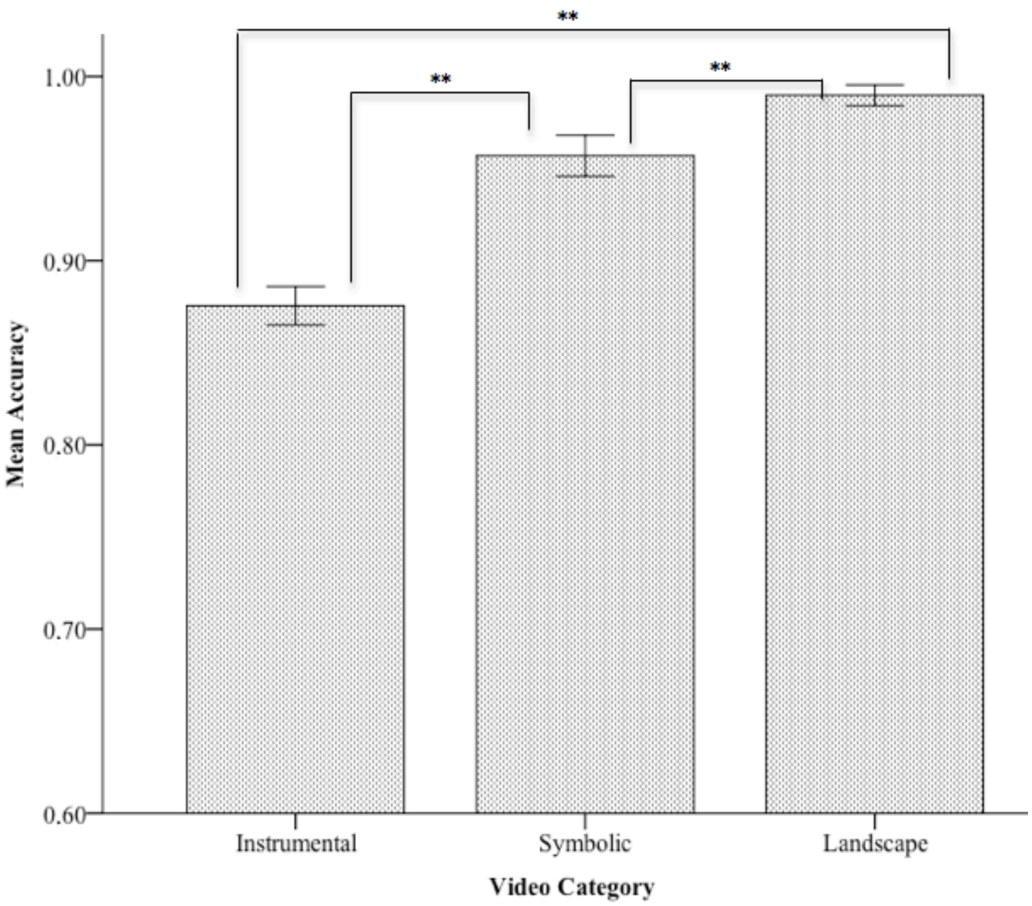
4. Results

The results of the performed tDCS study are presented in the following section. Subjects performed a semantic task while receiving either real or sham dual tDCS. Data was comprised of accuracies, response times, PANAS results, Digit Span results, and answers to the side effect questionnaires.

Data was filtered by excluding response times which were greater or less than 2.5 SD from the mean reaction times of all subjects. Out of 41 subjects, one female subject had to be excluded from statistical analysis due to her misunderstanding of the instructions. 40 subjects were included in the statistical analysis (mean age = 24.7 years; SD = 3.8; range = 20-35; 20 females, 20 males). The presented figures were generated using IBM SPSS Statistics Version 21[3].

4.1 Results on Accuracy

Repeated measures ANOVA of correct responses with video category (instrumental, symbolic, landscape) and congruency (congruent, incongruent) as within-subject factors and tDCS type (real, sham) as between-subjects factor was performed. A significant main effect of congruency was found ($F(1, 38) = 152$, $p < .001$) showing higher accuracy in incongruent trials ($M = .98$, $SD = .023$) than in congruent ones ($M = .90$, $SD = .033$). There was also a significant main effect of tDCS ($F(1, 38) = 5.84$, $p = .021$); subjects performed slightly better in the sham tDCS group ($M = .95$, $SD = .019$) than in the real tDCS group ($M = .93$, $SD = .015$). Furthermore, there was a main effect of category ($F(2, 76) = 178$, $p < .001$), with the highest accuracy in response to landscape videos ($M = .99$, $SD = .018$). The second highest accuracy was in response to symbolic videos ($M = .96$, $SD = .035$) and the lowest to instrumental videos ($M = .88$, $SD = .033$). Post hoc paired t-tests revealed that accuracy for trials with landscape videos was significantly higher than accuracy for trials with symbolic gestures ($t(39) = 5.27$, $p < .001$) and instrumental gestures ($t(39) = 19$, $p < .001$). Furthermore, accuracy on trials with instrumental gestures was significantly lower than on trials with symbolic gestures ($t(39) = -11.7$, $p < .001$). Figure 8 shows the mean accuracy of responses as a function of video category (see Figure 8).



Error Bars: +/- SEM

Figure 8. Mean accuracy of responses as a function of video category. (Note: the scale starts at an accuracy of 0.6. Each pair of asterisks indicates a significant difference of p < .001. The error bars represent the Standard Error of the Mean).

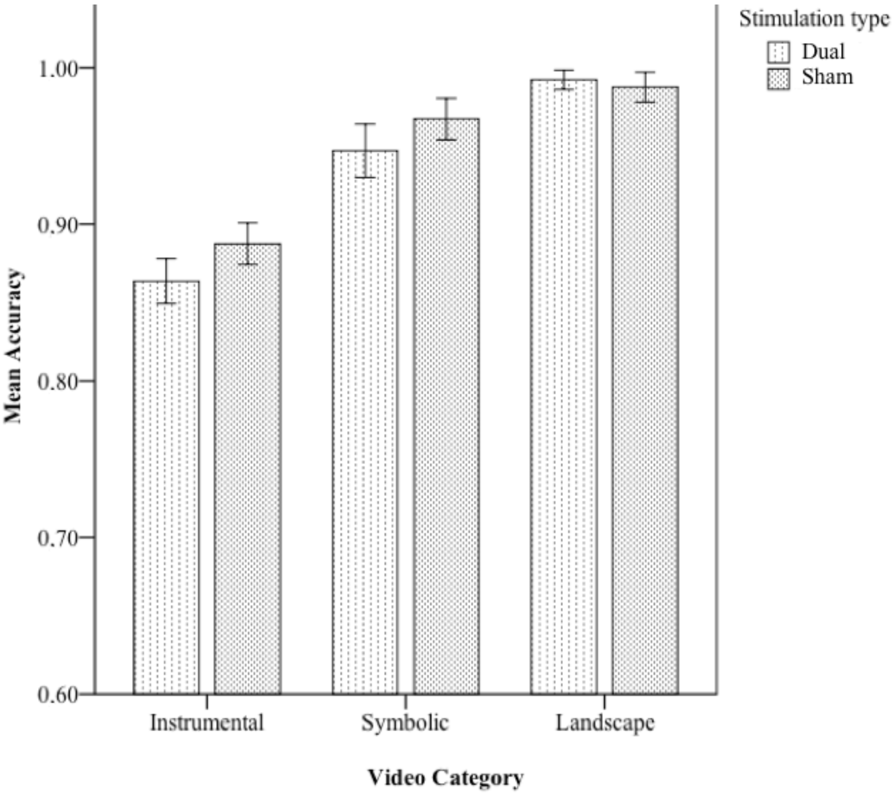
There was a significant interaction between video category and congruency of subsequent phrases (F(2, 76) = 83.9, p < .001). Congruency effect was calculated separately for each category by subtracting incongruent from congruent trials. The congruency effect of instrumental videos was the largest (M = -.19, SD = .078), followed by that of symbolic videos (M = -.042, SD = .079) and landscape videos (M = -.011, SD = .04). Table 1 shows the congruency effect as well as accuracy values on congruent and incongruent tasks as a function of video category (see Table 1). Post Hoc paired t-tests were used to test whether the congruency effect differed between categories. There was a significant difference between the congruency effect of instrumental and symbolic videos (t(39) = -9.38, p < .001), as well as between instrumental and landscape videos (t(39) = -12.7, p < .001). The congruency effect between symbolic and landscape videos did not differ significantly (t(39) = -2.21, p = .033).

Table 1. Mean accuracy values for congruent and incongruent phrases as well as congruency effect as a function of video category.

Video Category	Congruent	Incongruent	Congruency effect
Instrumental	.781 (± .063)	.971 (± .036)	-.190 (± .078)
Symbolic	.936 (± .066)	.978 (± .036)	-.042 (± .079)
Landscape	.984 (± .031)	.995 (± .022)	-.011 (± .040)

Note: The Standard Deviation is presented in parentheses.

The interaction between video category and tDCS type was marginally significant (F(2, 76) = 3.11, p = .05). Post hoc independent t-tests revealed that accuracy on instrumental videos was higher under sham tDCS (M = .89, SD = .03) than under real tDCS (M = .86, SD = .032), (t(38) = -2.43, p = .02). Figure 9 shows the mean accuracy of responses to individual video categories as a function of tDCS type (see Figure 9).



Error Bars: +/- SEM

Figure 9. Mean accuracy of responses to individual video categories as a function of tDCS type. (Note: the scale starts at an accuracy of 0.06. The error bars represent the Standard Error of the Mean).

In summary, accuracies were found to be highest on landscape videos, followed by symbolic gestures and by instrumental gestures. Additionally, accuracies on congruent gestures were significantly lower than on incongruent ones. Furthermore, the congruency effect was largest in the instrumental gesture condition. A significant effect of tDCS on accuracy was observed. Subjects' performance was better in the sham tDCS group than in the real tDCS group. In addition, accuracy was marginally significantly higher on instrumental gestures in the sham stimulation than in the real tDCS.

4.2 Results on Response Times

Repeated measures ANOVA of response times with video category (instrumental, symbolic, landscape) and congruency (congruent, incongruent) as within-subject factors and tDCS type (real, sham) as between-subjects factor was performed. In the following results, milliseconds (ms) are rounded to the nearest whole. The analysis revealed a significant main effect for video category (F(2, 76) = 21.0, p < .001). Response times to landscape videos were fastest (M = 764 ms, SD = 107 ms), followed by response times to symbolic videos (M = 835 ms, SD = 111 ms) and to instrumental videos (M = 854 ms, SD = 108 ms). Post hoc paired t-tests showed that response times differed significantly between instrumental and landscape videos (t(39) = 12.1, p < .001). Furthermore, there was a significant difference between response times to instrumental and symbolic videos (t(39) = 3.47, p = .001), as well as between landscape and symbolic videos (t(39) = -10.4, p < .001). Table 2 shows the mean response times as a function of the different video categories (see Table 2).

Table 2. Mean response time as a function of video category.

Video category	Mean response time
Landscape	764 ms (± 107 ms)
Symbolic	835 ms (± 111 ms)
Instrumental	854 ms (± 108 ms)

Note: The Standard Deviation is noted in parantheses.

No significant main effect of congruency was found in the study (F(1, 38) = .562, p > .05). Reaction times on congruent trials were only slightly shorter (M = 811 ms, SD = 105 ms) than reaction times on incongruent ones

(M = 824 ms, SD = 112 ms). Furthermore, the analysis revealed no significant interaction between video category and tDCS type (F(2, 76) < 1). No significant interaction between tDCS type and congruency of subsequent phrases was evident (F(1, 38) < 1). In addition, no significant main effect of tDCS type could be observed (F(1, 38) < 1).

In summary, response times to landscape videos were fastest, followed by those to symbolic and instrumental gestures. In regard to congruency, no significant enhancement of response times was found in response to congruent gestures. In addition, no significant interaction between video category and tDCS type or tDCS type and congruency was found. Lastly, no main effect of tDCS was observed.

4.3 Results on PANAS

The scores on PANAS collected before and after tDCS were computed into a new variable (before tDCS – after tDCS), which was then analyzed using an independent samples t-test. There was no significant difference between real tDCS (M = -.1, SD = 1.82) and sham tDCS (M = -.1, SD = 1.65), (t(798) = .00, p > .05).

4.4 Results on Digit Span

The sum of Digit Span results was analyzed using an independent samples t-test. There was no significant difference between the sums in Digit Span testing for the group receiving real tDCS (M = 15.9, SD = 3.49) and the group receiving sham tDCS (M = 16.0, SD = 2.85), (t(38) = -.099, p > .05).

4.5 Side Effects of tDCS

Conduction of a Mann-Whitney Test revealed no significant difference of side effects between the sham and real tDCS groups (headache, z = -.065, p > .05; neck pain, z = -.026, p > .05; scalp itching, z = -.705, p > .05; tickling, z = -.995, p > .05; itching, z = -1.223, p > .05; burning, z = -.136, p > .05; red scalp, z = -1, p > .05; fatigue, z = -1.846, p > .05; lack of concentration, z = -.932, p > .05; mood changes, z = -1, p > .05). Analysis of subjects' answers as to whether a side effect occured due to tDCS revealed a significant difference of subjects' responses in regard to fatigue, z = -2.564, p = .024. In the real tDCS group tiredness was related to tDCS less frequently (M = .25, SD = .444) than in the sham tDCS group (M = .75, SD = .716).

Aside from this, the other responses of subjects did not differ significantly between the tDCS groups (headache caused by tDCS, z = -.330, p > .05; neck pain caused by tDCS, z = -1, p > .05; scalp itching caused by tDCS, z = -.294, p > .05; tickling caused by tDCS, z = -.392, p > .05; itching caused by tDCS, z = -.447, p > .05; burning caused by tDCS, z = -.661, p > .05; red scalp caused by tDCS, z = -1, p > .05; lack of concentration caused by tDCS, z = -1.155, p > .05; mood change caused by tDCS, z = -1, p = > .05). Furthermore, there was no significant difference between the responses of the two groups as to which type of stimulation they thought they had received, z = -2.257, p > .05.

5. Discussion

5.1 Main results

The goal of this study was to assess whether dual tDCS with anodal tDCS over the right M1 and cathodal tDCS over the left M1 improves accuracy and response times on a semantic task involving gesture recognition and semantic judgment. Although overall accuracy was very high, accuracy on congruent trials was lower than on incongruent trials. Furthermore, congruency effects were negative in all video categories with the largest effect in the instrumental condition. In addition, accuracy was significantly lower in the real tDCS group compared with the group receiving sham tDCS. Lastly, the real tDCS group was shown to perform slightly less accurately in response to instrumental gestures than the group receiving sham tDCS.

Response times in all categories differed significantly. Response times to landscape videos were quickest, followed by those to symbolic gestures and lastly those to instrumental gestures. Response times on congruent trials were only marginally shorter than those on incongruent trials. Furthermore, no main effect of stimulation was observed.

With regard to PANAS scales and Digit Span results, no significant differences between the two study groups were found. In the side effect questionnaire, the question as to whether fatigue was thought to have occurred due to tDCS was the only question in which answers differed significantly between the two study groups. The sham tDCS group attributed their fatigue to tDCS more frequently.

5.2 Methods Discussion

Contrary to our hypothesis, dual tDCS over the M1 did not lead to a significant improvement of response times on the semantic task. Other than hypothesized, a significant decrease in accuracy was shown in the real tDCS group. In the following, different aspects of our study's methods that may have led to the fact that our hypothesis could not be verified will be discussed:

- Dual tDCS and cathode placement
- Anode placement
- Limitations of tDCS

Dual tDCS and Cathode Placement

An aspect that must be taken into consideration is that dual tDCS may not simply lead to an upregulation of the anodally stimulated area and downregulation of the cathodally stimulated area. As Lindenberg et al. pointed out, "the impact of bihemispheric [dual] tDCS cannot be explained by mere add-on effect of anodal and concurrent cathodal stimulation, but rather by complex network modulations" (112). Implementation of functional magnetic resonance imaging (fMRI) could help clarify to what extent our dual set-up led to a network modulation.

In addition, the placement of the cathode over the left M1 may have caused changes in the interaction between the two motor cortices. In tDCS, both the anode and cathode are physiologically active (95, 98, 112, 115). Cathodal tDCS over the hemisphere contralateral to that receiving anodal stimulation has been shown to possibly interfere with activity in the anodally stimulated hemisphere (98). Thus, the right hemisphere's function in processing gestures and prosodic aspects of speech may have been disturbed (70, 72). It must be noted, however, that some authors presume that dual tDCS could have a positive effect on interhemispheric interaction (112). For example, an fMRI study by Lindenberg et al. which implemented a choice reaction time task, showed that dual tDCS led to the strongest bilateral activity in the M1 compared to anodal and sham stimulation (112). The question as to what extent activation of the right M1 was inhibited in our study could be clarified by comparing response times and accuracies in a group receiving dual stimulation with those in a group receiving anodal stimulation.

Anode Placement

Placement of the anode over the right M1 may have stimulated left hand reaction, while response execution was limited to the use of the right hand. It is thus possible that responses were inhibited, correspondingly leading to longer response times and lower accuracies. Pellicciari et al. studied the effect of anodal tDCS over the left M1 on corticospinal activity and response times. They were able to demonstrate faster response times under anodal stimulation in a task in which subjects had to respond to a presented fixation point as quickly as possible (94). Notably, the response times were only enhanced under anodal tDCS over the left M1 when using the stimulated right hand to carry out responses (94). In our study, stimulation of the M1 of one hemisphere may have led to inhibition of the muscles activated by the contralateral hemisphere (116). In view of these findings, it would be of interest to investigate whether improvement of accuracies and response times would occur if one were to compare our dual set-up with one in which responses were allowed to be carried out by the left hand.

Limitations of tDCS

Limitations of tDCS must also be taken into consideration with respect to our study's results. Due to the gyrated structure of the cerebral cortex, tDCS does not necessarily stimulate all neurons equally (90). Whereas neurons on one side of a gyrus may be hyperpolarized, neurons situated on the opposite side of a gyrus may be depolarized, thus leading to inhomogeneous stimulation (90). Furthermore, the thickness of a subjects' hair and sweat under the site of stimulation could affect the amount of current that reaches the area investigated and to what extent stimulation is effective (90). Additionally, an "interference effect" cannot be ruled out (117). The "interference effect" refers to the observation that thinking of movement or performing a cognitive task while undergoing tDCS, can lead to an elimination of a tDCS effect (117). A further aspect that must be noted is that accuracy and response times depend greatly on how engaged a subject is and how well he/she is rested (118). TDCS has further been shown to be dependent on the time of day, gender, age, attention and genetic polymorphisms (119). Based on these findings it cannot be excluded that such factors influenced the results of our study.

Strengths of the Study

The strengths of this study lie in the structured procedure, as well as in blinding. Blinding effectiveness was ensured by implementing a side effect questionnaire, which included questions as to whether side effects were thought to be tDCS-induced. Additionally, PANAS and Digit Span were implemented in order to ascertain whether tDCS over the M1 had an effect on other cognitive components such as mood and working memory. Our method proved to be effective as we were able to rule out an influence of tDCS on the afore-mentioned components. Furthermore, studying two separate groups – one group receiving real tDCS and one group receiving sham tDCS – ensured that no learning effect occurred due to prior exposure to the stimuli.

5.3 Discussion of Accuracies

Accuracy was very high in all conditions of the semantic judgment task. Contrary to the results observed in other studies with regard to the semantic priming paradigm, accuracy on congruent trials was lower than accuracy on incongruent trials. In contrast to our study, Kelly et al.'s study achieved semantic priming, reflected in higher accuracies on congruent conditions

(120). Kelly et al.'s specific task required that subjects decide whether actions they were presented with were congruent with speech and gestures presented subsequently (120). Whereas Kelly et al.'s study implemented gestures followed by speech, our study presented pantomimes followed by written words. Speech has been shown to lead to a clearer understanding of the meaning of gestures (8, 27). The absence of speech in our study may have caused certain gestures to be understood ambiguously, thus making semantic processing less efficient. Therefore it would be of great interest to study whether implementation of speech following gesture presentation, as opposed to written words, would lead to enhancement of accuracies.

A further aspect that must be taken into consideration when interpreting our study's results, are cultural differences. The videos implemented in this study were filmed in Israel and chosen with respect to their use in Israeli culture (81). There is a vast amount of evidence that suggests that cultural differences regarding the use and meaning as well as the complexity of implemented gestures exist (121). Although the gestures in this study were validated by 10 German native speakers, one cannot rule out that cultural differences influenced gesture interpretation.

Accuracy on landscape videos was highest. The landscape videos acted as control stimuli. Responses to this task were expected to be most accurate, as landscape comprehension is not considered to be culture related (81).

Overall accuracy in the real tDCS group was significantly lower than in the group receiving sham tDCS. As cathodal stimulation has been demonstrated to reduce cortical activity, the activation of the left M1 may have been impaired by cathodal stimulation (29, 92-94). Thus the interaction of the two hemispheres in comprehending gestures could have been disturbed (116). Alterations in cathode placement are necessary in order to verify whether our particular set-up had an inhibitory effect on gesture comprehension. A marginally significant difference of accuracy on instrumental gestures was found between the two groups, with lower accuracies in the real tDCS group. This can be attributed to the fact that the set-up of tDCS over the M1 was assumed to have the greatest influence on the instrumental gesture condition, as these gestures contain a larger motor component compared to symbolic gestures.

Cohen-Maximov et al. found improvement of accuracies when anodal tDCS was applied over the right IFG (81). This can be due to the fact that the right IFG has been shown to play an essential role in semantic retrieval as well as in selection of semantic knowledge (122, 123). Additionally, the IFG of the right hemisphere is regarded to be essential in inhibiting inappropriate responses (124). Hence it is possible that tDCS of the primary motor cortices did not lead to the hypothesized enhanced accuracies, as the primary motor cortices may play a more crucial role in understanding individual actions and gestures than in semantic judgment (cf. 36, 62). In our task, however, semantic judgment was a main component. Moreover, our study's task involved various cognitive components including motor comprehension, language comprehension and semantic judgment. Perhaps implementing a task that focuses on the motor component of the M1 could clarify whether our tDCS set-up would have a positive effect when other cognitive components are omitted. The role of the M1 in comprehending action language, including gestures, is reflected in the theory of "Embodied Cognition". This theory maintains that action comprehension involves similar cortical systems as those required for action planning (125). The role of the M1 in the "Embodied Cognition" theory is supported by an MRI study by Hauk et al. in which M1 and PMC activation was observed while subjects read action words (126).

Based on the afore-mentioned studies, application of tDCS over additional cerebral areas essential for semantic judgment could have a positive effect on our specific task. Areas that would be of interest include the inferior temporal gyrus, the left inferior prefrontal cortex, and the PMC (cf. 81, 127). Specifically, tDCS over the PMC may have a positive effect on our study's task, as the PMC is thought to be an intermediate between the language and the motor systems (18, 128). Indeed, studies reported that the PMC is activated both when subjects observe movements and perceive speech, and is part of the MNS (18, 30, 128). Thus, our task, which requires both action observation and language comprehension, could be positively influenced by stimulation of this specific area.

5.4 Discussion of Response Times

Previous studies by Cohen-Maximov et al. and Vainiger et al. found response times to congruent symbolic gestures and instrumental gestures to be enhanced significantly in semantic judgment tasks (7, 81). In our study slightly quicker, yet non-significant, response times on congruent trials were found. In the afore-mentioned studies a larger amount of gestures was presented than in our study (in Vainiger et al.'s study 84 symbolic gestures were presented, in Cohen-Maximov et al.'s study 69 symbolic gestures and 94 action gestures were presented, whereas in our study a total of 32 symbolic and 44 instrumental gestures was presented) (7, 81). In our study fewer trials were presented, due to only including stimuli that were responded to correctly by more than 50% of a German test group and where response times were no longer than two standard deviations from the mean. Presentation of a greater amount of videos for each category in our study may have led to significant results with respect to semantic priming in congruent tasks, being that priming is influenced by practice on trials and how well one is acquainted with a task (129). One must note that we implemented a specific number of videos, in order to ensure that the semantic task would have a duration of approximately 12 minutes, as a study by Nitsche et al. demonstrated long-lasting tDCS effects to occur when applying anodal tDCS over the left M1 for 9 to 12 minutes (95).

Response times to landscape videos were found to be quickest. These findings can be attributed to the fact that landscapes are independent of culture and their understanding does not rely on speech. Additionally, phrases following gestures may have been more complicated, as they included a greater number of words than the phrases following landscape videos. Furthermore, isolated gestures such as instrumental ones can be understood ambiguously, as they are not standardized movements and are dependent upon culture (cf. 8, 27, 121). In order to exclude such a possibility, gestures containing one clearly defined meaning must be employed in future studies.

Contrary to what we hypothesized, response times to gestures were not enhanced by dual tDCS over the primary motor cortices. Cohen-Maximov et al.'s study, in contrast, demonstrated shorter response times to presented gestures when applying anodal tDCS over the right IFG and cathodal tDCS over the left IFG (81). Whereas the IFG is considered to be important in retrieving semantic information, the M1 is essential in performing and understanding actions of others (4, 5, 30, 36, 62, 123). Although the basis of our study was to examine the involvement of motor processing in the integration of gestures into language, it is possible that language related areas are more engaged in this type of task. It is therefore necessary to select the area of stimulation with respect to task requirements. For example, Weiss et al. demonstrated facilitation of gesture matching when applying anodal tDCS over the IPL (96). Their task required subjects to decide whether two gestures presented from different angles were the same or different (96). Here, the IPL was found to be involved in gesture processing for matching (96). In light of this it would be of interest to study whether stimulation of the IPL with implementation of our study's semantic task would have a positive effect on accuracies and response times.

5.5 Discussion of Additional Questionnaires

For the purpose of excluding mood changes in both the real and sham tDCS groups, the PANAS questionnaire was conducted before and after tDCS (109). Mood changes had to be excluded, in order to ensure that mood did not have a positive or negative effect on accuracy or response times. As expected, no differences in PANAS were found between the real and sham tDCS groups. This result is supported by a study by Plazier et al., which did not find changes in PANAS when investigating mood changes occurring during bifrontal tDCS (130).

In addition to PANAS, the Digit Span task was conducted after tDCS in order to assess whether sham or real tDCS had an effect on working memory (131). There were no differences between the groups on performance in the Digit Span task.

Side-effect questionnaires were implemented in order to control for safety and blindedness. No significant differences in reported side effects were found between the real and sham tDCS groups, thus ensuring that side effects did not affect performance on the study's task. Gandiga et al. found similar results with respect to side effects and blinding. In their study, subjects received sham or real tDCS, with the anode placed over the M1 and the cathode placed over the contralateral orbit (132). They showed that the study groups exhibited no significant differences in side effects and that blinding was effective (132). Subjects in our study were furthermore asked to decide whether they thought that the reported side effects were caused by tDCS. Interestingly, a significant, yet very small difference between the sham and the real tDCS group was found in regard to fatigue, demonstrating that the sham group suspected their fatigue to be caused by tDCS more frequently. This finding could be attributed to effective blinding. Furthermore, some subjects in the sham tDCS group responded to the question "which stimulation type do you think you received" with "real tDCS", while some subjects in the real tDCS group responded with "sham stimulation". There was no significant difference between the two study groups with regard to this question. PANAS, Digit Span, and the side effect questionnaire were able to demonstrate that tDCS is a safe method that allows for efficient blinding.

5.6 Conclusion

The cerebral motor system as well as the right hemisphere have been ascribed a role in gesture comprehension. As gestures are essential in social communication, insight into the mechanisms underlying understanding of gestures is needed, in order to aid subjects with gesture comprehension impairments. The effects of dual tDCS over the primary motor cortices have been presented in this study. The results show that contrary to our hypothesis, accuracy and response times were not improved by tDCS in our specific set-up. Accuracy was found to be lower in the real tDCS group. Additionally, this group showed lower accuracies on instrumental gestures. Response times on congruent gestures were not significantly enhanced in either stimulation group. These effects perhaps resulted from cathodal stimulation of the left M1. The placement of the cathode over the left M1 may have hindered right hand responses and may have led to disturbance of the interaction between the two hemispheres (29, 92-94, 116). A further aspect that must be taken into consideration is that the results of our study may be due to the M1 playing a larger role in distinct action and gesture recognition than in semantic judgment. Additionally, in contrast to the semantic priming paradigm, accuracies were found to be lower on congruent than on incongruent tasks and response times only slightly faster on congruent tasks. This could be due to the fact that the presented gestures were followed by written words and not by speech (8, 27). Therefore, the gestures could have been understood ambiguously. Additionally, the comparably small number of presented gestures may have led to the lack of semantic priming (129).

5.7 Outlook

Gesture comprehension is essential in social interaction. It remains to be examined how the function of the primary motor cortex and of the right hemisphere can be influenced in order to positively modulate the understanding of gestures. Specific adjustments of the set-up of our study may allow us to eliminate some of the possible shortcomings that have been discussed. In light of Lindenberg et al.'s study, additional research using fMRI should be conducted on the question whether dual tDCS leads to an upregulation of activity in the right hemispheric M1 and a downregulation in the left hemispheric M1, or if a more complex network modulation is achieved by this set-up (112). Additionally, research is needed with respect to whether the cathode placement over the left M1 has an inhibitory influence on the right M1. This could be achieved by comparing the dual set-up of the present study with a set-up implementing anodal stimulation only. In line with Pelliciari et al.'s study, examining response to the task with the left hand would help determine whether right hand response is hindered by cathodal stimulation, which may have been the case in our study (94).

In the presented study semantic priming was not exhibited. Implementation of a task that focuses on action recognition could verify whether semantic priming would occur during our dual tDCS set-up over the M1 (84). It would also be of interest to ascertain whether implementation of a greater number of gestures would lead to effective semantic priming (129). Additionally, tDCS over other cerebral areas would be of interest, as the primary motor cortices may play a more important role in comprehending individual actions. Two additional areas that should be studied in order to achieve more clarity as to whether tDCS could have a positive effect on our study's task, are the PMC, which is considered to be an intermediate between the language and motor system (18, 30, 128), and the IPL, which is involved in gesture processing and matching (cf. 96). Lastly it remains to be examined whether tDCS over the specific cerebral regions examined in this study has a beneficial effect on clinical conditions associated with gesture comprehension deficits such as Autism Spectrum Disorder and schizophrenia (1, 80).

6. Résumé

Background

This study is, to our knowledge, the first to assess the effect of dual transcranial direct current stimulation (tDCS) over the primary motor cortices on a gesture-language integration task. The hypothesis of our study was based on the fact that the primary motor cortex (M1) has been found to be activated both when executing actions and when observing actions of others (4, 30, 36, 61, 62). As gestures are a subtype of actions, the M1 is expected to be activated by them, most notably when perceiving action-related gestures such as instrumental ones. Furthermore, gestures are considered to have been essential in the evolution of language and have been shown to enhance language understanding (20, 21, 27). Therefore, dual tDCS over the primary motor cortices was expected to have a positive effect on gesture comprehension. In our study specifically, an upregulation of activity in the right M1 through anodal stimulation and a downregulation of activity in the left M1 through cathodal stimulation was aimed at, in order to maximize the influence of the right M1 on the semantic integration task. The basis of this set-up lies in the findings that the right hemisphere has been demonstrated to play a role in understanding gestural aspects of communication (17, 55, 69). Therefore, stimulation of these specific areas was expected to lead to an enhancement of gesture-language integration exhibited by higher performance on a semantic task.

The study examined the following hypotheses:

(i) Application of dual tDCS with anodal stimulation over the right M1 and cathodal stimulation over the left M1 leads to higher accuracies and faster response times in a semantic integration task.

(ii) Accuracies are higher and response times faster in congruent conditions.

Methods

In order to verify our hypotheses, tDCS was applied with the anodal electrode over the right M1 and the cathodal electrode over the left M1. 41 healthy subjects, split into two groups, were examined. Of the 41 subjects, 40 subjects were included in statistical analysis, as one subject misunderstood instructions. One group received real tDCS (mean age = 24.7 years; SD = 3.9; range = 20-35; 10 females, 10 males) while the other received sham tDCS (mean age = 24.8 years; SD = 3.8; range = 20-32; 10 females, 10 males). The semantic task consisted of watching different videos showing either a symbolic or instrumental gesture or a landscape. Subsequently, the subjects were required to reply to a phrase which appeared on-screen. The phrase was either congruent or incongruent in meaning with the preceding video. Subjects were required to reply as accurately and as quickly as possible.

Results

Accuracy was very high in all tasks of this study. However, overall accuracy on congruent gestures was lower than accuracy on incongruent gestures ($p < .001$), which was also reflected in the congruency effect of each category. The congruency effect was calculated as a difference between replies to congruous and incongruous conditions. This effect was found to be largest in the instrumental condition. Furthermore, overall accuracy in the real tDCS group was significantly lower than in the group receiving sham tDCS ($p = .021$). A marginally significant difference of accuracy on instrumental gestures was found between the two groups ($p = .05$), the real tDCS group performing slightly less accurately. In regard to response times, slightly faster response times on congruent trials were exhibited, which, however, were not significant ($p > .05$). Response times to specific categories differed significantly ($p < .001$), those to landscape videos being quickest. Lastly, contrary to what was hypothesized, response times to gestures were not enhanced by real tDCS over the primary motor cortices.

Conclusion

There are several possible reasons why our hypotheses could not be confirmed. This paper discusses alterations of the presented study's set-up which could lead to enhancement of gesture comprehension. The finding that semantic priming was not observed when dual stimulation was applied may be due to the fact that presented gestures were followed by written words and not by speech. This in turn possibly led to ambiguous interpretations of specific gestures. In addition, other than presumed, response times to instrumental gestures were not shown to be enhanced to the greatest extent by tDCS. The fact that this presumption could not be verified may have been due to the placement of the cathode over the left M1. This most likely led to interference of semantic processing of the right hemisphere and inhibition of right hand response. Furthermore, the M1 may be more important for sole action recognition than for semantic judgment. Perhaps the dual tDCS set-up over cerebral areas more involved in semantic judgement, including the IPL and PMC could lead to enhanced performance on the study's semantic task.

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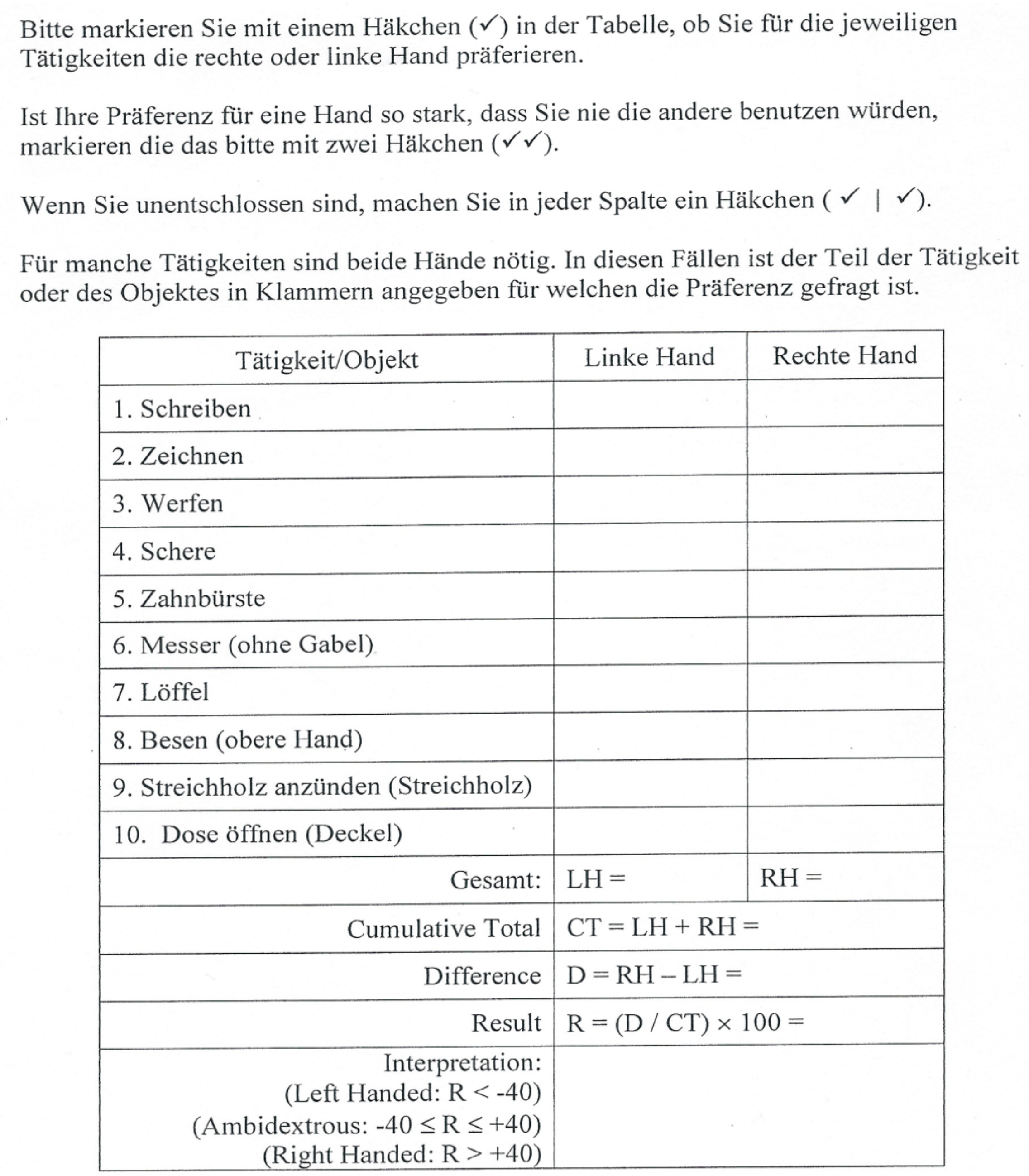
Appendix A – Edinburgh Handedness Inventory[4]



Bitte markieren Sie mit einem Häkchen (✓) in der Tabelle, ob Sie für die jeweiligen Tätigkeiten die rechte oder linke Hand präferieren.

Ist Ihre Präferenz für eine Hand so stark, dass Sie nie die andere benutzen würden, markieren die das bitte mit zwei Häkchen (✓✓).

Wenn Sie unentschlossen sind, machen Sie in jeder Spalte ein Häkchen (✓ | ✓).

Für manche Tätigkeiten sind beide Hände nötig. In diesen Fällen ist der Teil der Tätigkeit oder des Objektes in Klammern angegeben für welchen die Präferenz gefragt ist.

Tätigkeit/Objekt	Linke Hand	Rechte Hand
1. Schreiben		
2. Zeichnen		
3. Werfen		
4. Schere		
5. Zahnbürste		
6. Messer (ohne Gabel)		
7. Löffel		
8. Besen (obere Hand)		
9. Streichholz anzünden (Streichholz)		
10. Dose öffnen (Deckel)		
Gesamt:	$LH =$	$RH =$
Cumulative Total	$CT = LH + RH =$	
Difference	$D = RH - LH =$	
Result	$R = (D / CT) \times 100 =$	
Interpretation: (Left Handed: $R < -40$) (Ambidextrous: $-40 \leq R \leq +40$) (Right Handed: $R > +40$)		

---

[4] Oldfield, R.C. The assessment and analysis of handedness: The Edinburgh inventory. Neuropsychologia. 1971;9(1):97-113

Edinburgh Handedness Inventory – English translation:

Please checkmark, whether you prefer using your right or left hand for the specific activity / object.

If you clearly prefer one hand and would never use your other hand, please checkmark the activity with two checkmarks.

If you are uncertain, put a checkmark in each column.

For some activities both hands are needed. In this case, the part of the activity in question is noted in parentheses.

Activity / Object	Left hand	Right hand
1. Writing		
2. Sketching		
3. Throwing		
4. Scissor		
5. Toothbrush		
6. Knife (without fork)		
7. Spoon		
8. Broomstick (upper hand)		
9. Lighting a match		
10. Opening a can (lid)		

Appendix B – Personal Data

Persönliche Daten des Probanden: tDCSM1G - _____

Alter des Probanden: _______

Geschlecht: ______________

Raucher: ja o nein o
Wenn ja: _____Zigaretten/Tag, seit________

Koffein: ja o nein o
Wenn ja:_______Tassen o. Gläser/Tag, seit___________

Medikamente: ja o nein o
Wenn ja, welche:_______________________

Drogen: ja o nein o
Wenn ja, welche:_____________________, wann zuletzt:_________

Alkohol: ja o nein o
Wenn ja, wann zuletzt:__________, wie viel___________, was________
wie viel pro Woche:__________________________

Linkshändigkeit in der Familie: ja o nein o
Wenn ja, bei wem______________

Sprachentwicklungsstörungen: ja o nein o
Wenn ja, welche____________________________

Anzahl flüssig gesprochener Fremdsprachen: ________________
Welche:_____________ erlernt seit_______________

Höchster erreichter Schulabschluss: _________________________

Dauer der Schulzeit: _____________________________________

Beruf:____

Bei Studium: bisherige Semesteranzahl________________________

Sicht: Brille / Kontaktlinsen / Korrigiert ________________________
Frühere Erfahrung mit tDCS ________________________________
Frühere Erfahrung mit TMS _________________________________
MRT vor Studie ____

Personal Data – English translation:

Age: ______

Sex: ______

Smoker: yes o no o
If yes __ cigarettes/day, since____

Caffeine: yes o no o
If yes: ___ cups /day, since____

Medication: yes o no o
If yes, which medication:____

Drugs: yes o no o
If yes: when were drugs consumed for the last time:___, which ones:________

Alcohol: yes o no o
If yes, when was it last consumed: ___, how much___ , which:_____________
How much per week:____

Does left-handedness exist in the family: yes o no o
If yes, who ___

Language development disorders: yes o no o
If yes, which ones ____

Number of languages fluently spoken:__________________________
Which languages:____, learned since__________________________

Level of education:____

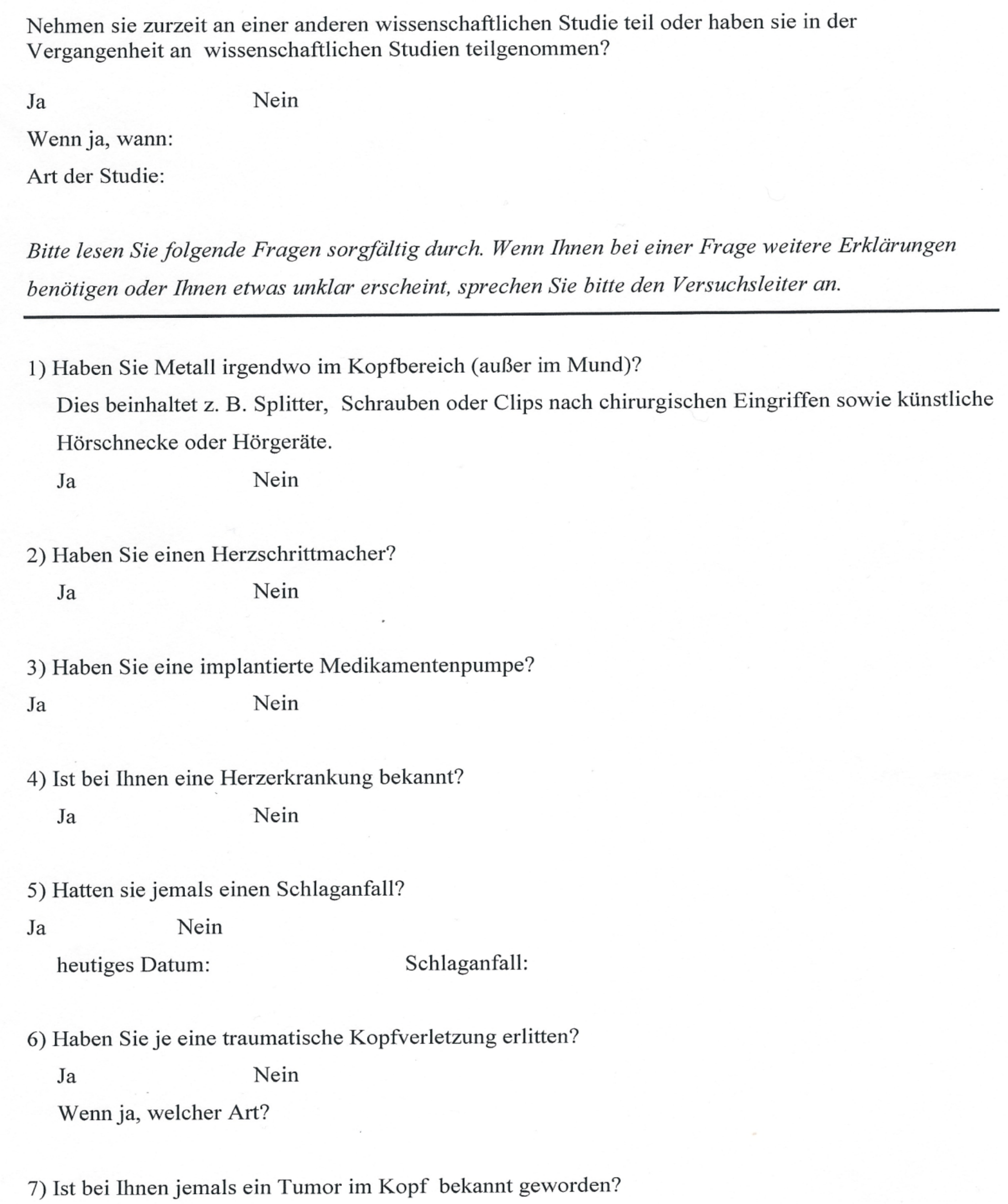
Years in school:____

Occupation: ____

Number of semesters____

Eyesight: Eyeglasses / Contact lenses / corrected _________________
Prior experience with tDCS __________________________________
Prior experience with TMS___________________________________
MRI before study____

Appendix C – TDCS Questionnaire[5]



Nehmen sie zurzeit an einer anderen wissenschaftlichen Studie teil oder haben sie in der Vergangenheit an wissenschaftlichen Studien teilgenommen?

Ja Nein

Wenn ja, wann:

Art der Studie:

Bitte lesen Sie folgende Fragen sorgfältig durch. Wenn Ihnen bei einer Frage weitere Erklärungen benötigen oder Ihnen etwas unklar erscheint, sprechen Sie bitte den Versuchsleiter an.

1) Haben Sie Metall irgendwo im Kopfbereich (außer im Mund)?

Dies beinhaltet z. B. Splitter, Schrauben oder Clips nach chirurgischen Eingriffen sowie künstliche Hörschnecke oder Hörgeräte.

Ja Nein

2) Haben Sie einen Herzschrittmacher?

Ja Nein

3) Haben Sie eine implantierte Medikamentenpumpe?

Ja Nein

4) Ist bei Ihnen eine Herzerkrankung bekannt?

Ja Nein

5) Hatten sie jemals einen Schlaganfall?

Ja Nein

heutiges Datum: Schlaganfall:

6) Haben Sie je eine traumatische Kopfverletzung erlitten?

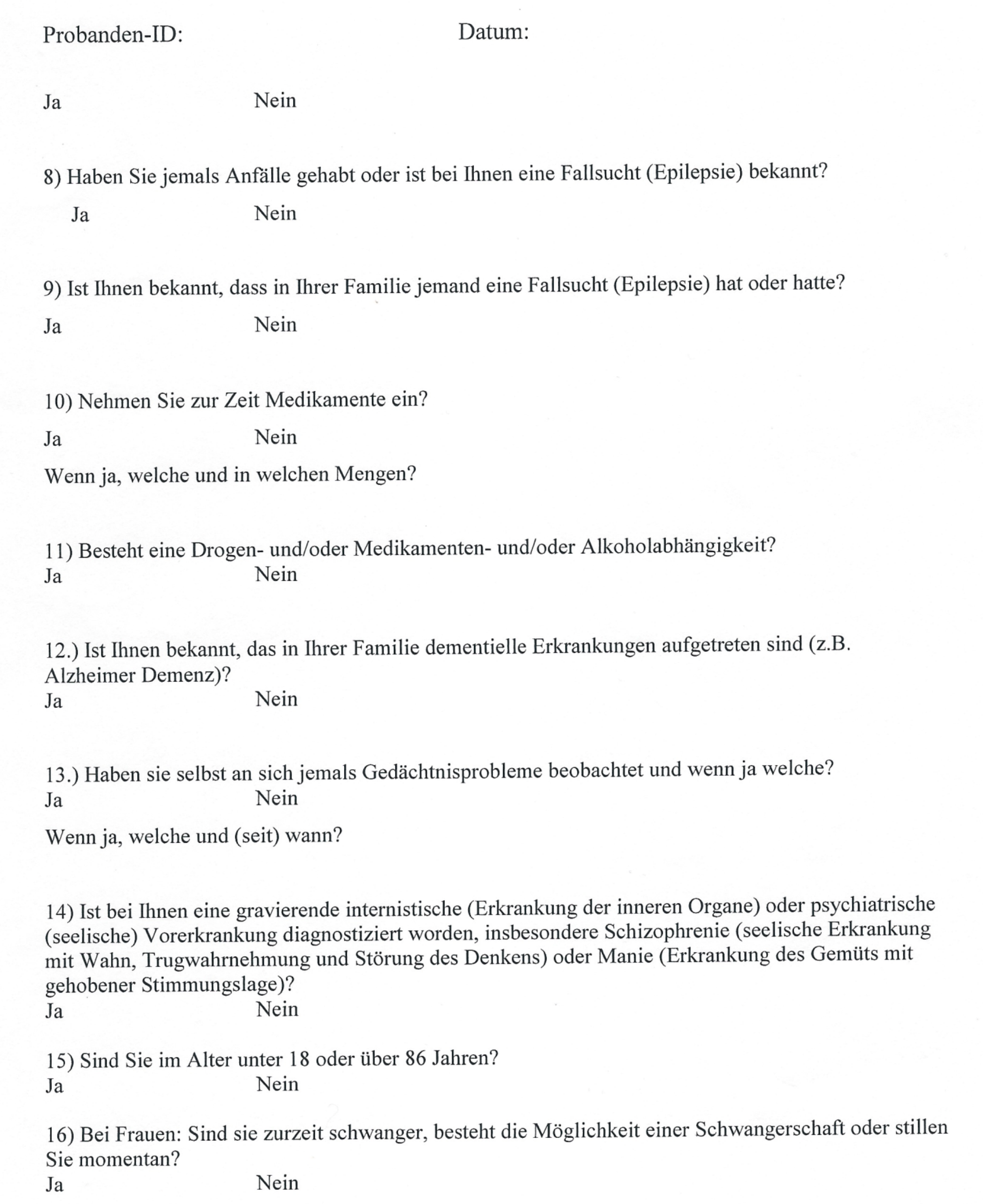
Ja Nein

Wenn ja, welcher Art?

7) Ist bei Ihnen jemals ein Tumor im Kopf bekannt geworden?

---

[5] The questionnaire was adapted from the study “Verbesserung des expliziten Sprachlernens durch non-invasive Hirnstimulation” (English translation: “Improvement of explicit language learning through non-invasive brain stimulation”) which was conducted at the Cognitive Neurology Laboratory, Charité – Universitätsmedizin Berlin.



Probanden-ID: Datum:

Ja Nein

8) Haben Sie jemals Anfälle gehabt oder ist bei Ihnen eine Fallsucht (Epilepsie) bekannt?

Ja Nein

9) Ist Ihnen bekannt, dass in Ihrer Familie jemand eine Fallsucht (Epilepsie) hat oder hatte?

Ja Nein

10) Nehmen Sie zur Zeit Medikamente ein?

Ja Nein

Wenn ja, welche und in welchen Mengen?

11) Besteht eine Drogen- und/oder Medikamenten- und/oder Alkoholabhängigkeit?

Ja Nein

12.) Ist Ihnen bekannt, das in Ihrer Familie dementielle Erkrankungen aufgetreten sind (z.B. Alzheimer Demenz)?

Ja Nein

13.) Haben sie selbst an sich jemals Gedächtnisprobleme beobachtet und wenn ja welche?

Ja Nein

Wenn ja, welche und (seit) wann?

14) Ist bei Ihnen eine gravierende internistische (Erkrankung der inneren Organe) oder psychiatrische (seelische) Vorerkrankung diagnostiziert worden, insbesondere Schizophrenie (seelische Erkrankung mit Wahn, Trugwahrnehmung und Störung des Denkens) oder Manie (Erkrankung des Gemüts mit gehobener Stimmungslage)?

Ja Nein

15) Sind Sie im Alter unter 18 oder über 86 Jahren?

Ja Nein

16) Bei Frauen: Sind sie zurzeit schwanger, besteht die Möglichkeit einer Schwangerschaft oder stillen Sie momentan?

Ja Nein

TDCS Questionnaire – English translation

Are you currently participating in any other study or did you participate in any other studies?
Yes No
If yes, when:
Type of study:

Please read the following questions carefully. If you need further explanation or if something seems unclear please ask the examiner.

1) Do you have metal in your head (except in the mouth)?
This includes, i.e. splinters, screws, clips after surgery as well as cochlear implants or hearing devices.
Yes No

2) Do you have a cardiac pacemaker?
Yes No

3) Do you have an implanted drug pump?
Yes No

4) Do you suffer from a cardiac disease?
Yes No

5) Have you ever had a stroke?
Yes No
today's date: stroke:

6) Have you ever had a traumatic head injury?
Yes No
If yes, what kind?

7) Do you have a head tumor?
Yes No

8) Have you ever had an epileptic seizure or do you have epilepsy?
Yes No

9) Do you know of anyone in your family who has or had epilepsy?
Yes No

10) Do you currently take medication?
Yes No
If yes, what and how much?

11) Are you addicted to drugs, medication or alcohol?
Yes No

12) Are there cases of dementia (i.e. Alzheimer) in your family?
Yes No

13) Have you ever noticed having memory troubles?
Yes No
If yes, which ones and since when?

14) Do you suffer from a serious internal or psychiatric disease, especially schizophrenia (psychiatric disease including delusions, hallucinations and inhibition of thought) or mania (psychiatric disease with heightened mood)?
Yes No

15) Are you between the age of 18 and 86?
Yes No

16) Women: Are you currently pregnant, are you possibly pregnant or are your currently nursing?
Yes No

Appendix D – Implemented Phrases

Instrumental gestures:	**English translation**
Akkordeon spielen	playing the accordion
sägen	sawing
Ball werfen	throwing a ball
Ball fangen	catching a ball
Banane schälen	peeling a banana
Bier einschenken	pouring beer
Bier öffnen	opening beer
Hahn öffnen	opening a tap
Tafel abwischen	wiping the board
rudern	rowing
Seiten durchblättern	flipping through pages
Kasten aufheben	picking up a box
Lampe wechseln	changing a lightbulb
knöpfen	buttoning
Karten austeilen	dealing cards
Cello spielen	playing the cello
Abwischen der Stirn	wiping off the forehead
kämmen	combing
Hand davor halten	holding a hand in front
Vorhang öffnen	opening a curtain
hochspringen	jumping up
Walzer tanzen	waltzing
Tagebuch führen	keeping a diary
Zeitung lesen	reading a newspaper
Gedicht schreiben	writing a poem
Radio hören	listening to the radio
fixieren	fastening
Pflanzen gießen	watering the plants
mit Aktien handeln	dealing with stocks
Kopf bedecken	covering the head
Komplott schmieden	conspiring
Farbe wechseln	changing color
Sandalen anziehen	putting on sandals
wählen gehen	voting
Schuhe ausziehen	taking off shoes
Daten auswerten	analysing data
Schirm öffnen	opening an umbrella
Beweise zerstören	destroying proof
Gewicht zunehmen	gaining weight
Abfall wegwerfen	throwing away garbage
sich freuen	rejoicing
durchs Fernglas schauen	looking through binoculars
durchs Teleskop gucken	looking through a telescope
Gummi dehnen	stretching rubber

Symbolic gestures:	**English translation:**
jetzt	now
Ich bin stark	I am strong
Ich bettele	I beg
Ich gebe auf	I give up
Ich würge	I choke
Ich schwöre	I swear
Ich?	Me?
Du!	You!
Tschüss!	Bye!
Anführungsstriche	quotation marks
keine Zeit	no time
Trottel	fool
Ich hab's!	I got it!
Verzweiflung	desperation
schlecht	bad
Erleichterung	relief
nicht nötig	not necessary
einverstanden	agreeing with
zusammen	together
Morgen	tomorrow
sehr zufrieden	very satisfied
Ich erinnere mich	I remember
gemütlich fahren	drive comfortably
weit	far
erwägen zu verlassen	to consider leaving
sein	to be
sabbern	to drool
schüchtern	shy
ausbreiten	to spread
extrem	extreme
Besen	broom
sehr schön	very pretty

Landscape videos:	**English translation:**
Tal	valley
Pfütze	puddle
Felsen	rock
See	lake
Schmutz	dirt
Eukalyptus	eucalyptus
Koralle	coral
Getreide	grain
Blütenstaub	pollen
Schlamm	mud
Ozean	ocean
Saatgut	seeds
Mineralien	minerals
Klippe	cliff
Weinberg	vineyard
Regen	rain
Feuer	fire
Lava	lava
Wellen	waves
Wolke	cloud
Vulkan	volcano
Bäume	trees
Gletscher	glacier
Sand	sand
Tornado	tornado
Pilz	mushroom
Strand	beach
stürmisches Meer	rough ocean
Wasserfall	waterfall
Sonnenuntergang	sunset
Blüte	blossom
Pfütze	puddle

Appendix E – Digit Span

Digit Span:

ZAHLENSPANNE VORWÄRTS (*digit row forwards)*

Aufgabe	1.Versuch (*1st try)*		2. Versuch *(2nd try)*		Punkte *(points)*
1	9-5-7		2-3-7		
2	7-8-6-4		2-1-8-5		
3	1-8-2-7-4		7-4-2-6-8		
4	5-7-8-5-2-6		8-5-7-2-3-8		
5	3-5-9-1-4-6-2		8-1-5-9-4-6-3		
6	3-6-1-9-7-4-2-5		4-9-1-6-4-8-3-2		
7	7-6-2-9-3-8-4-3-5		8-7-1-5-2-9-6-4-3		
Gesamtpunktzahl-vorwärts *(total points – forward)*					

ZAHLENSPANNE RÜCKWÄRTS (*digit row backwards)*

Aufgabe	1.Versuch *(1st try)*		2. Versuch *(2nd try)*		Punkte *(pooints)*
1	3-1		2-6		
2	3-7-2		8-5-4		
3	5-9-7-4		6-1-4-7		
4	1-4-3-2-9		7-2-6-7-8		
5	3-8-4-3-2-9		3-9-2-5-6-3		
6	2-9-3-8-4-7-9		2-8-3-5-1-2-6		
7	8-7-3-1-2-7-4-6		5-1-6-9-1-4-2-5		
Gesamtpunktzahl-rückwärts *(total points – bakwards)*					
Gesamtpunktzahl *(total points)*					

Appendix F – tDCS Side Effect Questionnaire[6]

tDCS Nebenwirkungen Proband: Datum:
Session:

	Haben Sie die folgenden Nebenwirkungen oder Symptome gespürt?	Wenn ja: Wurden sie durch das tDCS verursacht?	Notizen
	(1 - gar nicht; 2 - wenig; 3 - mäßig; 4 - stark)	(1 - nein; 2 - gering; 3 - vielleicht; 4 - wahrscheinlich; 5 - sicher)	
Kopfschmerzen			
Nackenschmerzen			
Schmerzen auf der Kopfhaut			
Kitzeln			
Jucken			
Brennen			
Hautrötung			
Müdigkeit			
Konzentrationsschwäche			
Akute Stimmungsschwankung			
Andere			

English translation:

	Did you feel any of the following side effects? (1-not at all; 2- sightly; 3- moderately; 4- strongly)	If yes, would you say that they were caused by tDCS? (1 – no; 2 – slightly; 3 – maybe; 4 – probably; 5 – definitely)	Notes
Headache			
Neck pain			
Pain on the scalp			
Tickling			
Itching			
Burning			
Reddening of the skin			
Fatigue			
Lack of concentration			
Mood changes			
Others			

---

[6] Adapted from 111. Brunoni AR, Nitsche MA, Bolognini N, Bikson M, Wagner T, Merabet L, et al. Clinical research with transcranial direct current stimulation (tDCS): challenges and future directions. Brain stimulation. 2012;5(3):175-95.

Affidavit[7]

I, Laura Amelia Kampf certify under penalty of perjury by my own signature that I have submitted the thesis on the topic “The Influence of Non-Invasive Brain Stimulation over the Primary Motor Cortex on the Interaction Between Gestures and Language”. I wrote this thesis independently and without assistance from third parties, I used no other aids than the listed sources and resources.

All points based literally or in spirit on publications or presentations of other authors are, as such, in proper citations (see "uniform requirements for manuscripts (URM)" the ICMJE www.icmje.org) indicated. The sections on methodology (in particular practical work, laboratory requirements, statistical processing) and results (in particular images, graphics and tables) correspond to the URM (s.o) and are answered by me. My interest in any publications to this dissertation correspond to those that are specified in the following joint declaration with the responsible person and supervisor. All publications resulting from this thesis and which I am author correspond to the URM (see above) and I am solely responsible.

The importance of this affidavit and the criminal consequences of a false affidavit (section 156,161 of the Criminal Code) are known to me and I understand the rights and responsibilities stated therein.

Date Signature

---

[7] The text of the affidavit is taken from the office for graduate and postgraduate studies (“Promotionsbüro”, Charité – Universitätsmedizin Berlin, Campus Virchow-Klinikum, Augustenburger Platz 1, 13353 Berlin). (Accessed at: http://promotion.charite.de/promotion/promovend/dr_med_dr_med_dent/eroeffnung_nach_neuer_promotionsordnung/).

“My curriculum vitae does not appear in the electronic version of my paper for reasons of data protection.”[8]

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[8] This statement is taken from the website of the medical library of the Charité – Universitätzmedizin Berlin (“Bibliothek”, Charité – Universitätsmedizin Berlin, Augustenburger Platz 1, 13353 Berlin.)
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http://bibliothek.charite.de/en/service/abgabe_von_hochschulschriften/dissertationen/was_und_wo_muss_abgegeben_werden/).

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