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ORIGINAL ARTICLE

Exploring the positive involvement of primary motor cortex in observing motor sequences with music: a pilot study with tDCS

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Abstract

Introduction The present study aims at exploring the effects of the depolarization of the primary motor cortex (M1), which is supposed to be associated to the mirror neuron system (MNS), via transcranial direct current stimulation (tDCS), and of synchronous music on individuals' responses to observed actions/non actions in a sample of individuals with low sports expertise.

The two main theories behind this study are linked to the role of the MNS in the human brain and the embodied cognition theory, which suggests an interdependent relationship between action, perception and cognition.

Method Nineteen college students attending to BA in motor science watched five videos (one presenting a target motor action performed by a basketball player and the other four presenting human vs. non-human performed actions as a control), with or without background music and with or without anodal tDCS of the primary motor cortex.

Results and Conclusions Data highlighted that observation promoted the activation of MNS, which led to a more deep and probably adequate processing of the stimulus. Music enhanced this effect, even when the MNS is affected by anodal stimulation, and should hence be considered as a valid support when both physical and psychological complications occur in rehabilitation.

Keywords Motor stimuli · Skin temperature · Anodal tDCS · Primary motor cortex · Music

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Introduction

From to the perspective of the mirror neurons system (MNS), several motor areas are activated not only when a person performs an action, but also when he/she observes the same action carried out by others. This specific "resonance" of the motor areas allows one to implement the same cognitive and physiological mechanisms that would had been activated performing the action in the first-person [1]. In humans it has been showed that the MNS involves several motor areas: the ventral and dorsal premotor cortex, the inferior parietal lobe and the primary motor cortex [2–5]. A key feature of the MNS is that its activation occurs in response to the observation of meaningful action performed by human actors [6]. Activations of the MNS has not be found as a response to the observation of action performed by robots [7, 8]. Yet, the selective activation of the MNS by human actions has been questioned. In some studies the activation of the MNS was reported also in response to the observation of actions performed by robots, if these actions had an immediate purpose [9, 10].

The experimental evidence of a motor response in the body that can be elicited without the actual performance supports the idea that those mental activities are embodied [11]. According to embodied cognition theories (ECT) the mind emerges from the action of the body in its real context and this experience is made possible by perceptual and motor skills, which are inseparable, interrelated and interacting [12]. ECT are supported by behavioral and neuroscientific evidence of the direct involvement of specific activity of sensory and motor systems during cognitive tasks [13, 14].

Considering MNS and ECT together, we also know that brain areas involved in the sensory and the motor information processing are activated by movement observation. On such a basis observational rehabilitation (which is based on the assumption that observing movements can foster learning even when patients are not, still, able to actually perform the movement) is possible and possibly extremely efficient, since a sensory-motor training without performing action could be implemented. A first general aim of this study is to provide further evidence to support the validity of such an approach using brain stimulation.

In this study we used transcranial direct current stimulation (tDCS), a non-invasive technique which modifies temporarily neuronal excitability of specific brain areas [15, 16], resulting in real-time neuropsychological effects [17]. We choose tDCS for two main reasons. First of all, it is an extremely reliable and useful tool to explore in a non-invasive way the effects of cortical modulation on neural networks. It efficacy has been widely proved and tDCS has been effectively used to explore (among other cognitive and emotive processes) language [18], sensory perception [19], decision making [20], and memory [21]. The positive results of these studies, often confirmed by fMRI evidence, support the use of tDCS to explore directly the effects due to changes on specific neural networks, allowing to read results as area-function causal connections and not only correlations, as is the case with the normal visualization methods use in neuropsychological studies. Secondly, tDCS has also been used as a rehabilitation tool: so using tDCS can also provide information about possible active use of the tool within a rehabilitation program. Several studies showed that the application of tDCS on primary motor area (M1) produces a change in cortico-spinal excitability: anodal stimulation acts on brain plasticity [22] and causes an improvement in motor functioning [23–25]. Because of these effects, the use of tDCS has been introduced in rehabilitation [26, 27], even if it is with a different perspective than the one adopted in the present study. Anodal tDCS application over the stroke patients' motor cortex stimulated a motor functioning improvement [23–25]. Moreover, anodal tDCS increased synaptic efficiency in the cortico-spinal tract examined [25, 28]. Finally, recent studies, using the paradigm of reaction-time task, showed that tDCS can also increase the implicit learning of motor sequences [29].

The present study aims at providing evidence, using anodal tDCS, to support the role of M1 in observational learning of action based on motor sequences linked to sport (basketball), providing also a theoretical and empirical base for a future new use of tDCS in rehabilitation, so to enhance the efficacy of the existing techniques.

Another new and promising tool used in rehabilitation is music. The use of synchronized music during physical training execution appears to empower rehabilitation. Several studies highlighted the natural predisposition of humans to respond to the rhythmic quality of music [30, 31]. Indeed, when music and a concurring motor sequence are synchronized, the rhythmic aspects of music provide a sound stimulus which temporally regulates the movement, and this facilitates its execution and its memorisation [32, 33]. In addition, the crucial role of cortical motor area in relation to music perception was stressed by showing that this area is involved in the perception and elaboration of both musical rhythm and motor stimuli [33].

Given these premises, it would be important not only to prove the efficacy of these techniques per se, but also to identify one or more key variables linked to both of them, which can help explain their efficacy and support future developments of these procedures. A key factor linked to physical, cognitive and emotive response to a stimulus is the change of specific physiological indexes. The link between their variations and individuals' cognitive and emotive responses have been widely proved [34–40]. Changes in one or more indexes in different stimulation condition will hence allow us to deduce the role that music plays either cognitively or emotively in processing a stimulus or providing an adequate answer.

Starting from this assumption, we decided to focus on skin temperature variation, which depends on the cerebral vasoconstriction (decrease) and vasodilation (increase) caused by hormonal mechanisms [41, 42]. Therefore, skin temperature variation can be conceived as an individual psychophysiological response to an external stimulus (emotive or cognitive). Even in primates decreases in peripheral skin temperature are indicative of negative sympathetic arousal [43]. In humans, this index is closely influenced by emotional response to a music stimulus [44], decreasing in response to sad music and increasing as a response to happy music. It also mirrors unaware preparation, both cognitive and physiological, in view of an action to be carried out [45, 46], increasing just before performing an action. Moreover, fluctuations in skin temperature are associated with fluctuations in the latency of the P300, an event-related potential (ERP) component elicited by the evaluation of a stimulus [47]. We can figure out that this index can be a useful indication of preparation to action, also providing information on concomitant emotional appraisal of the stimuli.

So, declining more precisely the aims of the present study, it explores how the manipulation of the primary motor cortex, where mirror neurons are located, and the presence of a synchronous music, influence individuals' responses (measured by changes in peripheral skin temperature) to observed actions/non actions, focusing on the performance of a specific sport based (basketball) motor action.

A first goal is to collect more data on the involvement of M1 during observation, using brain stimulation, in order to predict the efficacy of its involvement in the observational learning of a specific sport-based motor action. Increasing the activation of M1 we should expect different activation patterns, dysfunctional if compared to the sham condition. Differences should be mirrored by different activation patterns in skin temperature—where higher temperature in response to the observation of a human actor performing a motor task should reflect more adequate and emotionally positive responses. Focusing on the role of music, we expect the effect of observation to be enhanced by the presence of background synchronized music, but only when the functionality of M1 is not altered. After the anodal stimulation we expect that the effect of music will be absent or reduced because of the lacking of proper response from the MNS.

Methods

Sample

The sample consists of 19 college students (birth year: $M = 1{,}988.89$; $SD = 2.23$) attending to a BA in motor science, with no professional expertise of basketball. They were neither paid nor received any course credit for participating to the experiment. Before starting the experiment, each participant read and signed and informed consent form.

Participants were randomly divided according to stimulation condition: 10 were assigned to the tDCS anodal condition and 9 to the sham condition.

Instruments

Biofeedback

Participants' skin temperature was recorded and measured using a biofeedback (Biofeedback 2000^{x-pert} by Schufried). This equipment allows to monitor and record the variation of skin temperature by a sensor connected to the subjects' index finger (electrodermograph) which, through Bluetooth technology, sends waves coming directly to the computer.

In this study we were interested in monitoring the variation of temperature compared to the initial value (i.e. individual baseline) recorded in the experimental session, since skin temperature is a reliable indicator of the sympathetic nervous system activation level, as explained in the introduction.

Transcranical direct current stimulation (tDCS)

The tDCS is a simple technique for brain stimulation, silent and painless, which, through electrical current of constant intensity, modulates spontaneous neuronal changes [48] producing a temporary hypo/hyperactivity in a specific cortical area. The positive pole (anodal stimulation) increases the excitability of neural tissues, whereas the negative (cathodal stimulation) decreases it [15]. The tDCS equipment used in the study (HDC Series by Newronika S.r.l, Milano) is composed by two sponge-based electrodes (25 cm^2), one (in our case the anodal one) positioned on the subject's scalp and the other one (the cathodal one) on the subject's arm. Participants' motor area (M1), identified through the10–20 EEG international system, was stimulated at constant current of 1.5 mA for 20 min.

Videos

Five short videos were presented (balanced for human vs. non-human action and type of movement presented): a robot performing a cognitive action, a robot performing a non cognitive action, a man performing a cognitive action, a man performing a non cognitive action, a man performing a motor sportive action (see Table 1). Half of the sample watched the videos in a version with a background music synchronized to the rhythm and speed of the movements observed. The other participants watched the videos without any background music. Participants were instructed to watch the videos, without trying to memorize them.

Mental rotation questionnaire

Participants were also asked to fill in a paper–pencil mental rotation questionnaire [49]. The task proposed by the tool is to compare two 3D objects and state if they are the same image or if they are mirror images. The test comprises pairs

Table 1 Description of the videos used in the experiment

Video	Description
Robot performing cognitive action	The video shows a robotic arm drawing a recognizable portrait of a man
Robot performing non cognitive action	The video shows a robotic arm drawing random lines
Man performing cognitive action	The video shows a human arm playing checkers
Man performing non cognitive action	The video shows a human arm drawing random lines
Man performing motor action	The video shows a man playing basketball (pulling the ball to the basket)

of images each rotated a specific amount of degree. Some pairs will be the same image rotated, and others will be mirrored. The subject is shown a set number of the pairs, and the accuracy and rapidity in distinguishing between the mirrored and non-mirrored pairs are evaluated. We added this variable since our videos have quite a strong visual component, and individual differences in using imagery to process visual information could influence individuals' responses. We hence used the scores the derived from this questionnaire as covariate in our statistical models.

Procedure

Out of a sample of 19 young adults, 10 participants had a 20 min session of anodal tDCS stimulation of M1, whereas the other 9 had a 20 min session of sham stimulation (in this condition the stimulation starts for 3 s—so that the participant can feel it—and then shuts down). To be sure that the stimulation did not affect the actual motor performance, we asked participants to perform a simple fine motor task (coping, using a pencil, small detailed symbols) before and after the stimulation. We compared the timing requested to perform the task and the accuracy of the performance (assessed by two independent judges). No significant difference emerged between the two motor performances.

After the stimulation, participants watched five short videos. While watching the videos, their skin temperature was recorded using the biofeedback equipment. Baseline values of skin temperature were recorded for 2 min for each participant before starting the experiment. These values were used to derive, from a linear regression, the standardized residuals which we used to perform the actual analysis on data and were not biased by individual differences in skin temperature.

To check that participants had an adequate comprehension of the videos' content, a self-report questionnaire was proposed at the end of the experiment. No differences between participants or videos emerged in the answers to the questionnaire, highlighting that all participants had a similar and adequate comprehension of the videos' content.

Data were analyzed using SPSS (Statistical Package for Social Science). We performed GLMs (General Linear Models) on data, deriving two models, presented below.

Results

Effect of anodal tDCS on skin temperature

The first model was aimed at assessing the direct influence of stimulation condition on participants' physiological activation.

This first model considered skin temperature as dependent variable, the stimulation condition as fixed factor and individual levels of special ability (as assessed by mental rotation questionnaire) as moderating variable (see Table 2). The influence of the moderating variable on the model (B values) has been computed using a *t* test on the data computed with the GLM model (see Table 2).

The anodal stimulation affected participants' temperature while watching the videos. The general model (implying an effect of all the considered variables)—whose general significance is reflected by the F values, while the level of fit of the model is showed by R^2_{adj} and the effects size value is η^2—was significant for video presenting the robot performing a non cognitive action. In the sham condition temperature was lower than in the anodal condition and individual differences in visual spatial ability influenced negatively (see the B values) the temperature while watching the video.

The model was also significant for the video showing a man performing a cognitive action. In the sham condition temperature was lower than in the anodal condition. Individual differences in visual spatial ability played the same role in influencing this result, being negatively related to the skin temperature changes.

The general model was also found to be significant for our target video showing a man performing a motor action (playing basketball). In this case, quite interestingly, the trend was the opposite and in the sham condition temperature was higher than in the anodal condition. Individual differences in visual spatial ability influenced negatively the temperature while watching the video.

Considering just differences between stimulation conditions, using pairwise comparison, it is interesting to highlight how this difference was reported as significant for the target video featuring the basketball action (see Table 3).

Effect of anodal tDCS and music on skin temperature

The second model was computed adding the presence vs. absence of music as a second fixed factor to explore the influence of this other independent variable.

The general model was found to be significant when considering temperature levels. Results are reported in Table 4 (general significance is reflected by the F values, while the level of fit of the model is reflected by R^2_{adj} and the effects size value is η^2).

Music appears to have a major role in enhancing participants' temperature in the sham condition. Music effect was not present in the anodal condition: apparently the stimulation inhibited any effect of music.

In the motor action video it is interesting to notice that the sham condition with no music produced similar scores to the

Table 2 GLM presenting differences between mean scores of skin temperature of sham and anodal conditions and influence of the individual levels of spatial ability

	GLM						Influence of moderating variable		
Condition	Mean	SD	$F_{(4:1)}$	p*	η^2	R^2_{adj}	$B_{(spatial\ ability)}$	t	p**
Robot performing a cognitive action									
Sham	0.09	1.22	2.11	0.14	0.39	0.21	−0.15	−1.72	0.11
Anodal	−0.08	0.79							
Robot performing a non cognitive action									
Sham	−0.21	0.52	6.40	<0.01	0.66	0.56	−0.29	−4.48	<0.001
Anodal	0.21	1.27							
Man performing a sportive motor action									
Sham	0.13	0.91	5.64	<0.01	0.70	0.63	−0.29	−4.04	<0.001
Anodal	−0.11	1.12							
Man performing a cognitive action									
Sham	−0.01	0.81	6.31	<0.01	0.72	0.66	−0.28	−4.32	<0.001
Anodal	0.05	1.20							
Man performing a non cognitive action									
Sham	0.21	1.16	2.55	0.10	0.44	0.27	−0.15	−2.15	0.06
Anodal	−0.21	0.82							

* Probability level of the *F* values (GLM model)

** Probability level of the *t* test linked to the *B* score, assessing the probability of the influence of the considered moderating variable

Table 3 Pairwise comparisons between stimulation and sham conditions for each video

Video	Mean difference	Standard error	p*
Robot performing a cognitive action	0.73	0.46	0.14
Robot performing a non cognitive action	0.21	0.34	0.54
Man performing a sportive motor action	0.94	0.36	<0.05
Man performing a cognitive action	0.62	0.35	0.09
Man performing a non cognitive action	0.96	0.45	0.06

* Adjustment for multiple comparisons: Sidak

anodal condition with music. We can hypothesize that, even when M1 functioning is altered by stimulation, using music can allow observational learning to be potentially effective.

Considering just differences between the two stimulation conditions, using pairwise comparison within this second model, a significant difference emerged again only for the "Man performing motor action" video (see Table 5).

Discussion and conclusions

The first question that his paper addressed was related to the actual involvement of M1 during observation of motor actions performed by others. We were also interested in highlighting key variables of this possible involvement.

Data highlighted a different vegetative activation of participants as a response to our target video (human performing a sport motor action). This activation showed the exactly opposite trend than the one recorded in response to all other videos. To be more precise, anodal stimulation elicited lower skin temperature level—which suggests negative emotional appraisal [44] and less effective cognitive evaluation of the stimulus [47]. It also suggests that participants do not get ready to perform the action [45, 46], as in the sham condition. It can be argued that, by increasing the activation of M1 when the MNS is supposed to be active, we recreated a condition similar to the hyperactivation of the pars opercularis (belonging to the MNS) during observation of human motion in autistic subjects [50]. We did not find a similar trend while participants were looking at other videos. Hence we can deduce that the difference was due to the actual activation of the MNS. Moreover the specific fluctuation in skin temperature levels stresses that both emotive responses (linked to the appraisal of the stimulus) and cognitive evaluation are linked to the observation, suggesting a deep and complex elaboration of the stimulus, as hypothesized by the ECT. These changes are also coherent with recent findings that highlight how the activation of specific populations of neurons is involved in thermogenic changes [51], which can influence

Table 4 GLM presenting differences between differences mean scores of skin temperature in sham and anodal condition—while watching videos with and without music

Condition		GLM						Influence of moderating variable		
		Mean	SD	$F_{(6:1)}$	p*	η^2	R^2_{adj}	$B_{(spatial\ ability)}$	t	p**
Robot performing a cognitive action										
Sham	Music	1.27	0.66	2.94	<0.05	0.62	0.41	−0.20	−2.25	<0.05
	No music	−0.48	0.98							
Anodal	Music	−0.05	0.66							
	No music	−0.09	0.90							
Robot performing a non cognitive action										
Sham	Music	1.65	0.21	4.08	<0.05	0.69	0.52	−0.30	−4.38	<0.01
	No music	−0.40	0.54							
Anodal	Music	0.02	0.78							
	No music	0.30	1.52							
Man performing a motor action										
Sham	Music	0.83	1.00	4.27	<0.01	0.70	0.54	−0.32	−4.63	<0.001
	No music	−0.22	0.67							
Anodal	Music	−0.33	0.64							
	No music	−0.01	1.34							
Man performing a cognitive action										
Sham	Music	0.48	0.55	4.75	<0.01	0.72	0.57	−0.31	−4.21	<0.001
	No music	−0.26	0.84							
Anodal	Music	0.03	1.19							
	No music	0.06	1.32							
Man performing a non cognitive action										
Sham	Music	0.84	1.43	1.57	0.24	0.46	0.17	−0.19	−2.03	0.07
	No music	−0.10	0.99							
Anodal	Music	−0.39	0.55							
	No music	−0.12	0.96							

* Probability level of the F values (GLM model)

** Probability level of the t test linked to the B score, assessing the probability of the influence of the considered moderating variable

Table 5 Pairwise comparisons between stimulation and sham conditions for each video

Video	Mean difference	Standard error	p*
Robot performing a cognitive action	0.79	0.40	0.08
Robot performing a non cognitive action	0.20	0.35	0.57
Man performing a sportive motor action	0.96	0.36	<0.05
Man performing a cognitive action	0.60	0.34	0.11
Man performing a non cognitive action	0.98	0.48	0.07

* Adjustment for multiple comparisons: Sidak

sympathetic activities that are closely related to the management of energy: an increase in parasympathetic activity can induce a enhancement of energy consumption [52].

Findings can be effectively used to build enhanced action observational rehabilitation programs. In motor rehabilitation it is important to identify new techniques to prompt effective and rapid recovery. Observational rehabilitation, which is based on observational learning, appears to be particularly promising. It is a basic assumption that people can learn an action by observation and that it is possible to react to simple observation with physiological regulation mechanisms, without actually performing any action. Consequently, the simple movement observation can be useful in rehabilitation [53, 54], where often patients cannot move, or have limited motor abilities. The second question addressed by this paper was linked to the positive role of music in enhancing the effect of the observational learning, declined in this study as response of the MNS. Data supported this hypothesis. Considering our target video, whereas the general trend discussed above was still present, in the sham condition with background synchronized music we had the more active and positive response to the stimulus (as displayed by higher skin temperature). We found no clear effect of music in the anodal condition. Yet, it is interesting to report how the sham condition with no music yielded similar scores to anodal condition with background music. So, apparently, the music slightly improved the response even of MNS, even after the stimulation that, as seen before, clearly altered its functioning.

Considering the two main findings together, we can conclude that observation appears to be effective because it promotes an activation of MNS that leads to a deeper and probably adequate processing of the stimulus. Music enhances this effect, even when the MNS is not working adequately, and should hence be considered as a valid support even for cases where rehabilitation has both physical and psychological complications.

Even if results provided by this study are encouraging, it is important to stress some limits that will be addressed in future studies. First of all it would be important to replicate the findings adding a cathodal stimulation condition and enlarging the sample. Also the role of participants' expertise in relation to the performed action could be relevant and could be addressed by considering an enlarged sample, divided between experts and non-experts. This would allow collecting data useful to build AOR programs diversified according to expertise level.

Conflict of interest None.

References

1. Rizzolatti G, Craighero L (2004) The mirror-neuron system. Ann Rev Neurosci 27:169–192
2. Fadiga L, Fogassi L, Pavesi G, Rizzolatti G (1995) Motor facilitation during action observation: A magnetic stimulation study. J Neurophysiol 73:2608–2611
3. Hari R, Forss N, Avikainen S, Kirveskari E, Salenius S, Rizzolatti G (1998) Activation of human primary motor cortex during action observation: A neuromagnetic study. Proc Nat Acad Sci USA 95:15061–15065
4. Iacoboni M, Woods RP, Brass M, Bekkering J, Mazziotta C, Gallese V (1999) Cortical mechanisms of human imitation. Science 286:2526–2528
5. Rizzolatti G, Fogassi L, Gallese V (2001) Neurophysiological mechanisms underlying the understanding and imitation of action. Nat Rev Neurosci 2:661–670
6. Buccino G, Lui F, Canessa N, Patteri I, Lagravinese G, Benuzzi F, Porro CA, Rizzolatti G (2004) Neural circuits involved in the recognition of actions performed by nonconspecifics: An fMRI study. J Cognitive Neurosci 16:114–126
7. Kilner JM, Paulignan Y, Blakemore SJ (2003) An interference effect of observed biological movement on action. Curr Biol 13:522–525
8. Tai YF, Scherfler C, Brooks DJ, Sawamoto N, Castiello U (2004) The human premotor cortex is 'mirror' only for biological actions. Current Biology 14:117–120
9. Gazzola V, Rizzolatti G, Wicker B, Keysers C (2007) The anthropomorphic brain: The mirror neuron system responds to human and robotic actions. NeuroImage 35:1674–1684
10. Oberman LM, McCleery JP, Ramachandran VS, Pineda JA (2007) EEG evidence for mirror neuron activity during the observation of human and robot actions: Toward an analysis of the human qualities of interactive robots. Neurocomputing 70:2194–2203
11. Brandi L (2009) Dall'atto psico-fisiologico ai neuroni specchio. Quaderni del Dipartimento di Linguistica Università di Firenze 19:77–100
12. Barsalou LW, Santos A, Simmons WK, Wilson CD (2008) Language and simulation in conceptual processing. In: De Vega M, Glenberg AM, Graesser AC (eds) Symbols, embodiment, and meaning. Oxford University Press, Oxford
13. Kiefer M, Barsalou LW (2011) Grounding the human conceptual system in perception, action, and internal states. In: Prinz W, Beisert M, Herwig A (eds) Tutorials in action science. MIT Press, Cambridge
14. Kiefer M, Pulvermüller F (2012) Conceptual representations in mind and brain: theoretical developments, current evidence and future directions. Cortex 48(7):805–825
15. Nitsche MA, Paulus W (2000) Excitability changes induced in the human motor cortex by weak transcranial direct current stimulation. J Physiol 527(3):633–639
16. Lang N, Siebner HR, Ward NS, Lee L, Nitsche MA, Paulus W, Rothwell JC, Lemon RN, Frackowiak RS (2005) How does transcranial DC stimulation of the primary motor cortex alter regional neuronal activity in the human brain? Eur J Neurosci 22(2):495–504
17. Reidler JS, Zaghi S, Fregni F (2011) Neurophysiological Effect of Transcranical Direct Current Stimulation. In: Coben R, Evans JR (eds) Neurofeedback and Neuromodulation Techniques and Application. Elsevier, New York, pp 319–350
18. Flöel A, Rösser N, Michka O, Knecht S, Breitenstein C (2008) Noninvasive brain stimulation improves language learning. J Cogn Neurosci 20(8):1415–1422
19. Boggio PS, Zaghi S, Lopes M, Fregni F (2008) Modulatory effects of anodal transcranial direct current stimulation on perception and pain thresholds in healthy volunteers. Eur J Neurol 15(10):1124–1130
20. Fecteau S, Pascual-Leone A, Zald DH, Liguori P, Theoret H, Boggio PS, Fregni F (2007) Activation of prefrontal cortex by transcranical direct current stimulation reduces appetites for risk during ambiguous decision making. J Neurosci 27(23):6212–6218
21. Fregni F, Boggio PS, Nitsche M, Bermpohl F, Antal A, Feredoes E, Marcolin MA, Rigonatti SP, Silva MT, Paulus W, Pascual-Leone A (2005) Anodal transcranial direct current stimulation of prefrontal cortex enhances working memory. Exp Brain Res 166(1):23–30
22. Stefan K, Cohen LG, Duque J, Mazzocchio R, Celnik P, Sawaki L, Ungerleider L, Classen J (2005) Formation of a motor memory by action observation. J Neurosci 25(4125):9339–9346
23. Fadiga L, Buccino G, Craighero L, Fogassi L, Gallese V, Pavesi G (1999) Corticospinal excitability is specifically modulated by motor imagery: a magnetic stimulation study. Neuropsychologia 37:147–158
24. Hummel F, Celnik P, Giraux P, Floel A, Wu WH, Gerloff C, Cohen LG (2005) Effects of non-invasive cortical stimulation on skilled motor function in chronic stroke. Brain 128(3):490–499
25. Hesse S, Werner C, Schonhardt EM, Bardeleben A, Jenrich W, Kirker SGB (2007) Combined transcranial direct current stimulation and robot-assisted arm training in subacute stroke patients: A pilot study. Restor Neurol Neurosci 25(1):9–15
26. Schlaug G, Renga V, Nair DG (2008) Transcranial direct current stimulation in stroke recovery. Arch Neurol 65(12):1571–1576

27. Merzagora AC, Foffani G, Panyavin I, Mordillo-Mateos L, Aguilar J, Onaral B, Oliviero A (2010) Prefrontal hemodynamic changes produced by anodal direct current stimulation. Neuroimage 49(3):2304–2310
28. Hummel FC, Cohen LG (2006) Non-invasive brain stimulation: a new strategy to improve neurorehabilitation after stroke? Lancet Neurol 5:708–712
29. Nitsche MA, Liebetanz D, Antal A, Lang N, Tergau F, Paulus W (2003) Modulation of cortical excitability by weak direct current stimulation–technical, safety and functional aspects. Suppl Clin Neurophysiol 56:255–276
30. Karageorghis CI, Terry PC, Lane AM (1999) Development and validation of an instrument to assess the motivational qualities of music in exercise and sport: the Brunel Music Rating Inventory. J Sports Sci 17:713–724
31. Large EW (2000) On synchronizing movements to music. Hum Movement Sci 19:527–566
32. Terry PC, Karageorghis CI (2011) Music in sport and exercise. In: Morris T, Terry PC (eds) The new sport and exercise psychology companion. WV: Fitness Information Technology, Morgantown, pp 359–380
33. Zatorre RJ, Halpern AR, Perry DW, Meyer E, Evans AC (1996) Hearing in the mind's ear: a PET investigation of musical imagery and perception. J Cognitive Neurosci 8:29–46
34. Dennis SS, Mulcahy RF (1980) Heart-rate changes during covert rehearsal and response execution. Percept Motor Skills 50(2):595–602
35. Ikuma LH, Nussbaum MA, Babski-Reeves KL (2009) Reliability of physiological and subjective responses to physical and psychosocial exposures during a simulated manufacturing task. Int J Ind Ergonom 39(5):813–820
36. Levenson RW, Ruef AM (1997) Physiological aspects of emotional knowledge and rapport. In: Ickes W (ed) Empathic accuracy. Guilford Press, New York, pp 44–72
37. Lukavský J (2010) The effects of cognitive and emotional workload on physiological reactions in word association test in healthy adults. Studia Psychologica 52(1):15–22
38. Ritz T, Alatupa S, Thöns M, Dahme B (2002) Effects of affective picture viewing and imagery on respiratory resistance in nonasthmatic individuals. Psychophysiology 39(1):86–94
39. Schachter S, Singer JE (2001) Cognitive, social, and psychological determinants of emotional state. In: Parrott W (ed) Emotions in social psychology: Essential readings. Psychology Press, New York, pp 76–93
40. Scholey AB, Moss MC, Neave N, Wesnes K (1999) Cognitive performance, hyperoxia, and heart rate following oxygen administration in healthy young adults. Physiol Behav 67(5):783–789
41. Cohen RA, Coffman JD (1981) Beta-adrenergic vasodilator mechanism in the finger. Circ Res 49:1196–1201
42. Freedman RR, Sabharwal SC, Ianni P, Desai N, Wenig P, Mayes M (1988) Nonneural beta-adrenergic vasodilating mechanism in temperature biofeedback. Psychsom Med 50(4):394–401
43. Parr LA (2001) Cognitive and physiological markers of emotional awareness in chimpanzees (Pan troglodytes). Anim Cogn 4(3–4):223–229
44. Krumhansl CL (1997) An exploratory study of musical emotions and psychophysiology. Can J Exp Psychol/Revue Canadienne De Psychologie Expérimentale 51(4):336–353
45. Kleitman N (1963) Sleep and Wakefulness. University Of Chicago Press, Chicago
46. Wright KPJ, Hull JT, Czeisler CA (2002) Relationship between alertness, performance, and body temperature in humans. Am J Physiol Regul Integr Comp Physiol 283:R1370–R1377
47. Ramautar JR, Romeijn N, Gómez-Herrero G, Piantoni G, Van Someren EW (2013) Coupling of infraslow fluctuations in autonomic and central vigilance markers: Skin temperature, EEG beta power and ERP P300 latency. Int J Psychophysiol 1. doi:10.1016/j.ijpsycho.2013.01.001
48. Priori A, Berardelli A, Rona S, Accornero N, Manfredi M (1998) Polarization of the human motor cortex through the scalp. NeuroReport 9:2257–2260
49. Shepard R, Metzler J (1971) Mental rotation of three dimensional objects. Science 171(972):701–703
50. Martineau J, Andersson F, Barthélémy C, Cottier J, Destrieux C (2010) Atypical activation of the mirror neuron system during perception of hand motion in autism. Brain Res 1320:168–175
51. Monda M, Viggiano A, De Luca V (2013) Functional decortication lowers ventromedial hypothalamic activation induced by hippocampal neostigmine injection. Cerebral Cortex [serial online] 10(12):1242–1246. Available from: Science Citation Index, Ipswich. http://www.ncbi.nlm.nih.gov/pubmed/11073873 Accessed 26 Jun 2013
52. Messina G, De Luca V, Monda M, et al (2013) Autonomic nervous system in the control of energy balance and body weight: personal contributions. Neurology Research International [serial online] 2013:639280. Available from: MEDLINE, Ipswich. http://www.ncbi.nlm.nih.gov/pubmed/23691314 Accessed 26 Jun 2013
53. Buccino G, Solodkin A, Small SL (2006) Functions of the mirror neuron system: implications for neurorehabilitation. Cogn Behav Neurol 19:55–63
54. de Vries S, Mulder T (2007) Motor imagery and stroke rehabilitation: a critical discussion. J Rehabil Med 28:163–175