

Original Research

Imagined and Actual Movements with and without Suggestions for anesthesia in Subjects with Different Hypnotizability

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Academic Editor: Giuseppe De Benedittis**Special Issue:** [Hypnosis: from Neural Mechanisms to Clinical Practice](#)

OBM Integrative and Complementary Medicine
2019, volume 4, issue 4
doi:10.21926/obm.icm.1904066

Received: September 10, 2019**Accepted:** December 13, 2019**Published:** December 18, 2019

Abstract

Background: Hypnotizability is a psychophysiological trait associated with several differences including the level of functional equivalence (FE) between imagery and perception, i.e., the similarity of the cortical activations and network configurations associated with each of them. FE is stronger in high hypnotizability individuals (*highs*) than low hypnotizable participants (*lows*). In this framework, this study investigates the correlation between electroencephalogram (EEG) of imagined arm/hand movements (MI) and of actual movements performed in the absence of suggestions (M) and in the presence of suggestions of arm/hand anesthesia (MA) in *highs* and *lows*.

Methods: The EEG alpha (8–12 Hz) and beta (13–25 Hz) absolute power, classically associated with movement preparation and execution, were studied in 18 *highs* and 17 *lows* classified according to the Stanford Hypnotic Susceptibility Scale, form A. EEG was recorded during M, MI, and MA. The subjective reports of imagery and the duration of movements were also studied.

Results: The duration of movements did not differ between *highs* and *lows*. *Highs* reported better imagery during MI, greater perceived influence of the suggestion of anesthesia during MA, and lower cognitive efforts than *lows* for both tasks. In line with earlier studies, the



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spectral analysis did not reveal significant restructuring of the cortical activity during tasks in *highs*, whereas *lows* showed cortical changes during MI and MA indicating that they were able to mentally simulate movements and to accept suggestions for anesthesia during voluntary movement, despite their low hypnotizability scores.

Conclusions: The present study indicates that unusual psychophysiological characteristics can differ in the response of individuals to suggestions.

Keywords

Imagery; hypnotizability; motor control; suggestions; functional equivalence; anesthesia

1. Introduction

Hypnotizability is a psychophysiological trait that is measured by scales predicting the proneness to modify perception, memory, and behavior according to specific instructions named “suggestions” [1]. Several cognitive, emotional, and physiological differences have been described between the subjects with high (*highs*) and low hypnotizability (*lows*) out of hypnosis and in the absence of specific suggestions [2].

1.1 Hypnotizability as a Psychophysiological Trait

The EEG studies based on spectral analysis conducted in resting conditions out of hypnosis and in the absence of specific suggestions failed to separate the effects of hypnotizability from those of relaxation [3]. The study also did not recognize any variable which could discriminate *highs* from *lows* and medium hypnotizable participants (*mediums*). Recurrence quantification analysis of the EEG plot [4] revealed that the plot determinism discriminates *highs* from *lows* at midline parietal sites [5, 6]. Additionally, the topological analysis of EEG signals has shown a qualitatively different cortical activity during both sensorimotor and cognitive tasks. *Highs* exhibit a widely distributed mode of information processing whereas *lows* show localized changes [7]. In *highs*, earlier reports showed greater left activation than right anterior activation and hemispheric differences in information processing for electrodermal responses, brightness, haptic discrimination, tones evoked cortical potentials [8], temporal judgment of visual stimuli [9], and line bisection [10].

The earliest neuroimaging study of hypnotizability-related morphological characteristics revealed larger anterior *corpus callosum* [11] in *highs*, which may account for the better interhemispheric transfer of information. Successively, smaller grey matter volume in the entire brain [12] or in regions belonging to the salience and executive circuits has been described [13]. From a functional point of view, *highs* exhibit a stronger connection between the cingulate cortex and the dorsolateral prefrontal and parietal cortices possibly leading to increased likelihood to modulate the information selection and processing [13]. In addition, *highs* show reduced grey matter volume of the cerebellar left IV-VI lobules [14], suggesting a role of the cerebellum in the observed hypnotizability-related differences in sensorimotor integration, cerebellar control of pain and a few cognitive-emotional traits. In the absence of suggestions and out of hypnosis, *highs* show less strict postural control and less accurate visuomotor performance. The *highs* do not

exhibit learning effects due to task repetition in both postural and visuomotor tasks [2]. In contrast to the general population, reports showed increased pain perception associated with increased amplitude of cortically evoked nociceptive potentials during transcranial anodal cerebellar stimulation in *highs* [15]. The structural variations in the salience network, particularly in the insula, may be responsible for higher emotional intensity during imagery [16], recall of emotional events [17], and perception of the inner world and sensitivity/empathy in *highs* than that in *lows* [18]. The same structural brain irregularities could influence heart rate, which is parasympathetically controlled in *highs* during long-lasting relaxation in the awake state [19]. The nociceptive stimulation in *highs* releases nitric oxide (NO) from the endothelial cells of the brachial artery. This condition is not influenced by mental stress and is less profound in *lows* [20, 21]. The high concentration of NO at the cerebral level may have a role in the *highs'* brain morphofunctional peculiarities. This is because excessive or uncontrolled diffusion of endothelial NO to the cerebral tissue may be responsible for neurotoxicity [2].

1.2 Suggestions and Imagery

Suggestions are requested to imagine a sensorimotor, cognitive or emotional condition different from the actual one that is effective in both the awake and hypnotic state [22]. Many studies have analyzed hypnotizability-related differences by standard imagery questionnaires which, however, have often provided negative results concerning the vividness of imagery [23]. In contrast, semistructured interviews related to the mental images experienced during specific experimental conditions have shown greater vividness and lower effort in *highs* than that in *lows* [24], which may be due to the kinaesthetic modality of imagery [25–29].

More importantly, hypnotizability-related differences have been found in the functional equivalence (FE) between imagery and perception/action [29, 30]. FE is generally described in terms of similar activations observable during actual and imagined perception [31–33] or action [34–37]. FE is found stronger in *highs*, which means that they experience the suggested mental images at both subjective and physiological levels more than that in *lows* [24, 28–30, 38].

Greater cerebral cortical excitability (Spina, personal communication) could be responsible for stronger FE possibly due to greater cortical activation by ascending systems [39, 40] or lower cerebellar inhibition of cortical sensorimotor areas [14]. Among activating systems, the dopaminergic pathway plays the best role [41–45]. The cholinergic contribution may be roughly excluded on the basis of tests of visual and verbal memory [46], which did not detect any difference between *highs*, *mediums*, and *lows* [47]. The noradrenergic contribution from the *Locus Coeruleus* (LC) is also excluded from the primary findings because of the similar pupil diameter [48, 49] as observed in *highs*, *mediums*, and *lows*.

1.3 Hypnotizability and Motor Imagery

Actual and imagined actions have been compared in *highs* and *lows* through neuroimaging and EEG studies. The former revealed the activation of a parietal-cerebellar circuit during ideomotor movements induced by suggestions. This is experienced by *highs* as an involuntary action. According to the feed-forward model of motor control, it was proposed that the inhibition of the peripheral reafference may be responsible for the perception of involuntariness [50]. As observed

in postural imagery, the latter showed different activation modes in *highs*, in contrast to *lows* who do not exhibit local cortical changes with respect to baseline [7, 28, 29, 30].

The main physiological difference between actual and imagined action consists of the presence or absence of the peripheral reafference. In the general population, fMRI studies have shown activation of a distributed frontoparietal occipital network during motor planning, imagery, and execution [35, 36, 51]. EEG source analysis has shown that physical suppression of the kinaesthetic reafference reduces the source activity at pre and postcentral sites and that the same occurs during imagined movements in which the sensory reafference is absent [52]. In *highs*, the lack of sensory information could be replaced by its mental image owing to their stronger functional equivalence between imagery and action [27, 29]. This may lead to the suppression of the difference between actual and imagined action. On the other hand, during actual movement, the *highs'* stronger FE should induce greater effects of suggestions of anesthesia than that in *lows*.

1.4 Aim of the Study

The aim of the present study was to investigate the correlation of EEG between actual and imagined arm/hand movement and of an actual movement performed during the administration of suggestions of arm/hand anesthesia in *highs* and *lows*. We expect that a) *highs* report better vividness of imagery and greater movement difficulty for the actual movement performed during suggestions of analgesia and that b) in contrast to subjective experience, the EEG changes associated with tasks are more pronounced in *lows* than in *highs* [28, 29, 30]

The EEG midline alpha power (8-12 Hz), indicating cognitive engagement, and hemispheric alpha and beta (13-25 Hz) absolute power, classically associated with movement preparation and execution [53], were studied.

2. Methods

The research was approved by the Bioethical Committee of the University of Pisa (n.4/2018, January 25, 2019) and conducted ethically according to the Declaration of Helsinki.

2.1 Subjects

Thirty-five students of the University of Pisa participated in the study who were drug free, healthy (according to neurological, psychiatric, and medical anamnesis), and right-handed (Edinburgh Handedness Inventory score ≥ 16). Their hypnotic susceptibility was assessed through the Italian version of the Stanford Hypnotic Susceptibility Scale, form A [54]. Seventeen low hypnotizable (*lows*, 9 females; (mean, SD): age 22 ± 1.21 ; SHSS score 1.19 ± 1.38) and 18 high hypnotizable individuals (*highs*, 7 females; (mean, SD): age 21 ± 0.92 ; SHSS score 10.06 ± 1.39) were sorted from a database which included *highs* and *lows*. No medium hypnotizable individuals (*mediums*) accepted to join the experimental session.

2.2 Experimental Procedure

Experimental sessions were conducted between 11 a.m. and 2 p.m. Upon arrival, the participants read and signed the informed consent. Throughout the experimental session, participants were comfortably seated in a semi-reclined arm-chair in a sound and light-attenuated

room. The experimental procedure consisted of three eyes-closed trials which were divided into basal and task conditions (actual movement, M; motor imagery of it, MI; actual movement during suggestions for anesthesia, MA). In the basal condition preceding each task (b_M , b_{MI} , and b_{MA}), the participants were asked to relax. M consisted of the execution of a complex flexor-extensor movement of the right arm, i.e., opening and closing of hand repeated five times consecutively. MI consisted of the motor imagery of M, and MA consisted of M associated with suggestions for anesthesia. Tasks were presented to all subjects in the described sequence. The instructions for M (“...please perform a flexor-extensor movement of your right arm, close your hand into a fist and then re-open it, repeat it five times and then put your arm and hand in their initial position...”), MI (“...please, now try to imagine the described movement looking at it from your own eyes..from inside your body...”) and MA (“...please, now imagine you do not perceive any sensation from your arm and hand...”). Instructions and suggestions were given immediately before the respective task which was triggered by verbal commands. For M and MA, the delay between the verbal command (“please, now move”) and the movement of onset, as well as the movement duration (that is the time interval between the verbal command and the observed end of the movement), were measured. MI duration was calculated by measuring the time interval from the verbal command (*please now listen to me and imagine.....*) to the “STOP” command. The participants were invited to say at the end of their imaginative experience. After MI, the subjects scored the vividness and easiness of their imagery and the ability to maintain their mental image through the requested modality of imagery (range: 0–10). After MA, the subjects were asked to score the influence of the suggestion on movement easiness on a scale of 0–10.

Arm/hand movement monitoring during M and MA was performed through the marker-less infrared sensors Xbox 360 Kinect Sensor System that tracks body joints in real-time without requiring markers attached to the body [55].

Electroencephalogram (EEG) was recorded by means of a 32-channels DC-coupled monopolar amplifier (Scan LT, Neuroscan). Scalp EEG signals were filtered with a notch filter centered at 50 Hz and a bandpass one (0.5–45 Hz) and acquired with a 1000 Hz sampling rate by means of electrodes with contact impedance below 10 k Ω . It was referenced to FCz. Off-line signals were re-referred to A1/A2 and FCz was restored. Eye (right medial/lateral; left medial/lateral) and ECG electrodes (standard DI lead) were also used. No participant had more than 1 bad channel per condition and this was calculated using the spherical interpolation method (EEGLAB pop_interp function). The signal components were obtained by running independent component analysis decomposition (infomax ICA algorithm, EEG LAB function runica) and were visually inspected to remove artifacts. The signal was divided into 20 s epochs (20.000 samples). According to the exclusion criteria (amplitudes ≥ 100 μ V or median amplitude $> 6SD$ of the remaining channels), a maximum of 1 epoch per condition was deleted per subject.

Variables and statistical analysis

SPSS15 was used for all statistical analysis. Self-reports were analyzed by means of non-parametric tests (Mann-Whitney or Wilcoxon). *Highs'* and *lows'* delay in movement initiation in MA was analyzed through univariate ANOVA. The movement durations in M and MA were analyzed through repeated measures ANOVA (2 Hypnotizability \times 2 Task). The kinematics of the arm/hand movement could not be analyzed because most signals were too noisy and a part of them was lost.

Repeated measures ANOVA was applied to EEG log-transformed absolute beta power (F3-F4, C3-C4, P3-P4) according to a 2 Hypnotizability (*highs, lows*) × 2 Hemisphere × 3 Trial (b_M -M, b_{MI} -MI, b_{MA} -MA) × 2 Condition (basal, task). The analysis of midline fronto-central alpha power (μ rhythm, Fz, and Cz) was performed through 2 Hypnotizability (*highs, lows*) × 3 Trial × 2 Condition design.

In addition, the changes occurring during tasks with respect to basal conditions (Task Related Power (TRP) changes: Δ_M , Δ_{MI} , Δ_{MA}) were computed in order to compare Δ_M with Δ_{MI} and Δ_{MA} (2 Hypnotizability × 3 Tasks design). The possible basal differences may have prevented the detection of significant interactions between trials and conditions by the former analysis. Negative TRP values indicate desynchronization, while positive TRP values indicate synchronization. The Greenhouse-Geisser ϵ correction for non-sphericity was used when necessary. Post-hoc comparisons between conditions (Δ_M vs. Δ_{MI} ; Δ_M vs. Δ_{MA}) were carried on through contrast analysis. The level of significance was set at $p = 0.05$. The number of participants included in the various comparisons was not the same owing to the exclusion of a different number of outliers from each condition.

3. Results

3.1 Self-Reports and Movement Duration

During MI, *highs* reported higher vividness ($Z = -2.41$, $p < .017$) and longer maintenance of the kinaesthetic modality of imagery than *lows* ($Z = -2.01$, $p < .010$), whereas no significant difference between *highs* and *lows* was observed for the easiness of MI (FIG 1A).

Highs exhibited a greater influence of the anesthesia suggesting their movement during MA with respect to *lows* ($Z = -2.07$, $p < .007$). A few *highs* reported the experience of “weak arm” or “absence of joint localization”. One of the subjects was not able to move his arm at all. However, the mean delay in the movement initiation during MA with respect to M was not significantly different between *highs* and *lows* (Fig. 1B).

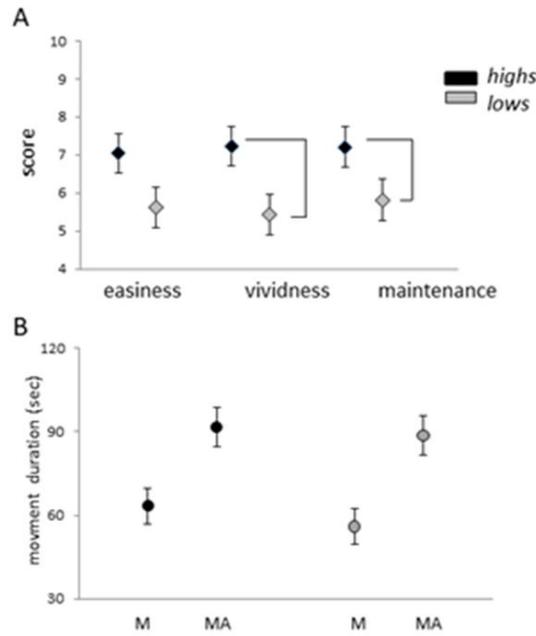


Figure 1 Motor imagery. a) Easiness and vividness of mental imagery, maintenance of the requested kinaesthetic imagery. b) movement duration in the absence (M) and in the presence (MA) of suggestions for anaesthesia in highs (black dot) and lows (grey dots). Error bars represent standard errors.

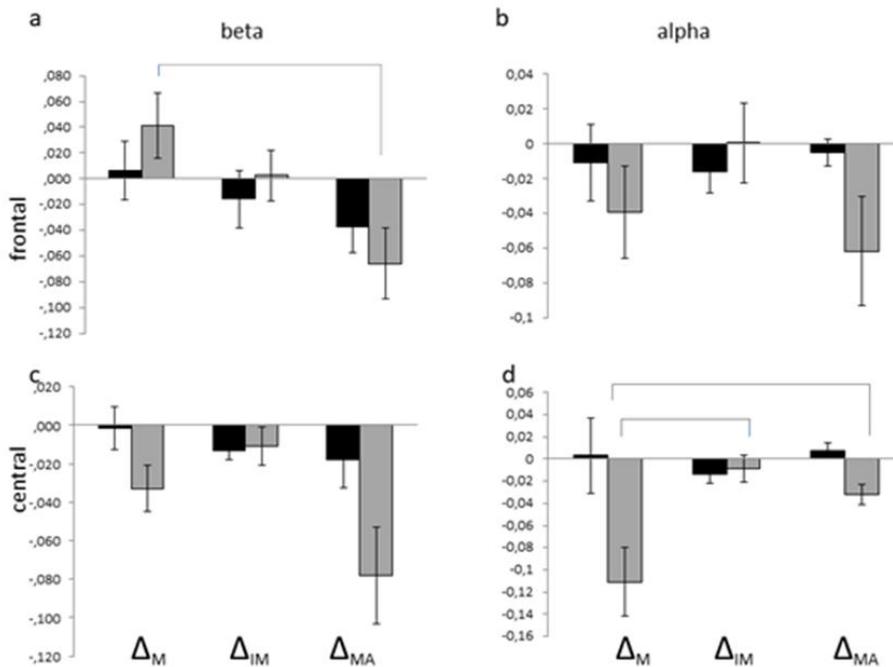


Figure 2 Task Related Power (TRP) changes. Upper panels: frontal beta and alpha; lower panels: central beta and alpha. Black columns, highs; grey columns, lows. Δ_M , actual movement; Δ_{IM} , movement imagery; Δ_{MA} , movement with suggestions for anaesthesia. Error bars represent standard errors.

3.2 EEG

The cortical correlates of the three experimental conditions showed significant hypnotizability-related differences which are reported in Table 1.

Table 1 Summary of result.

Site	Effect	Beta			Alpha				
		F	p	η^2	F	p	η^2		
F3-F4	condition	7,898	.009	.233	b>task	6,009	.021	.177	b>task
	hypnotizability	10,270	.004	.283	highs< lows	11,503	.002	.291	highs< lows
	cond x hypn	7,354	.012	.220	highs, ns lows, b>task F(1,13)=11.374, p<.005				
C3-C4	condition					13,583	.001	.335	b>task
	hypnotizability	16,977	.0001	.369	highs< lows				
P3-P4	hemisphere	4,378	.045	.131	left < right	5.94	.021	.165	left< right
	condition	5,302	.029	.155	b>task	4,585	.040	.133	b > task
	hypnotizability					4.61	.040	.133	highs<lows

At frontal sites *highs* exhibited lower beta power than *lows* (Hypnotizability effect) and a significant Hypnotizability × Condition interaction revealed that only *lows* changed their beta power during tasks. In this group (Fig. 2) Δ_M , Δ_{MI} , and Δ_{MA} were significantly different between each other (Task effect, F (2, 32)=7.526, p<.002, μ^2 =.320) as beta power increased in M and decreased in MA with respect to basal conditions (Δ_M vs. Δ_{MA} , F (1,16)=11.035, p<.004), whereas Δ_M and Δ_{MI} did not differ between each other (Fig. 2A).

Alpha absolute power (Table 1) was always lower in *highs* than in *lows* (Hypnotizability effect) and decreased during all tasks with respect to basal conditions (Condition effect). Alpha TRP changes during M, MI, and MA did not exhibit significant differences between each other (Fig. 2).

At central sites (C3, C4), beta power was lower in *highs* than in *lows* independently from the experimental conditions (Hypnotizability effect).

Alpha changes showed a significant condition effect (basal > task) and the comparisons of alpha TRP changes (Fig. 2) revealed a significant Task effect (F (2, 26)=8.641, p<.006, μ^2 =.399) sustained by differences between Δ_M and Δ_{MI} (F (1,13)=10.063, p<.007) and between Δ_M and Δ_{MA} (F (1,13)=8.339, p<.013).

At parietal sites, alpha power was significantly lowered in *highs* than in *lows* (Table 1) (Hypnotizability effect). Both beta and alpha power were significantly lowered on left sites independently from hypnotizability, trial, and tasks (Hemisphere effect) and decreased during all tasks with respect to basal conditions (Condition effect). No significant Task effect was observed for Δ_M , Δ_{MI} , and Δ_{MA} .

Midline alpha (μ rhythm) exhibited significantly lower power in *highs* than in *lows* at both Fz (1,28)=9.950, p<.004, μ^2 = .269) and Cz (F (1,28)=6.203, p<.019, μ^2 = .181).

4. Discussion

The study confirms earlier reports of greater vividness of motor imagery and the ability to maintain the requested kinaesthetic modality of imagery in *highs* than that in *lows*. [30]. The similar easiness of mental imagery experienced by the two groups, unlike earlier studies [28, 29] can be accounted for by the experimental paradigm. In the present study, actual movement preceded its mental imagery allowing learning effects in *lows*. Also, the subjective effects of the suggestion of anesthesia were greater in *highs* than in *lows*, despite the absence of significant differences in the movement duration. This finding, however, should be considered together with nonstructured subjective reports indicating greater difficulty in initiating and/or control the movement by *highs*. The most relevant outcome of the study, however, is that, in line with studies of postural and motor imagery [28, 29, 30] *highs* did not exhibit significant EEG changes during actual and imagined tasks, in contrast to *lows*.

The μ rhythm is modulated by both sensorimotor tasks [56, 57, 58] and cognitive states and traits [59, 60, 61, 62]. In the present study, the *highs'* lower power of μ rhythm with respect to *lows* in both basal and task conditions indicates that they were more activated than *lows* in basal conditions and performed the tasks with lower effort.

In both groups, alpha power did not exhibit hemispheric differences, as often observed during various lateralized motor tasks [53]. The *lows'* smaller alpha decreases during MI and MA with respect to M observed at central sites seem to reflect their lower embodiment of the mental images of movement and anesthesia, generally worse cognitive performance with respect to *highs*. The lack of local EEG modulation in *highs* is consistent with the findings obtained during sensorimotor and cognitive tasks [7, 29, 30]. It can be accounted for a largely distributed information processing likely sustained by activating systems [39, 40] which cannot be revealed by spectral analysis but is detected by topological methods [7, 29].

The different beta changes observed in *lows* during the various tasks with respect to basal conditions suggest that *lows* were able to similarly represent actual and imagined motor planning ($\Delta_M = \Delta_{MI}$ at frontal sites) and execution ($\Delta_M = \Delta_{MI}$ at central sites). They were also able to prepare their movement differentially in the imagined absence and in the presence of sensory reafference (Δ_{MA} different from Δ_M).

At post-central sites low beta power was observed in the left hemisphere. At this level, *highs* and *lows* exhibited similar beta reduction with respect to basal conditions independently from the specific task, suggesting that the different experience of normal, imagined and imaginatively anesthetized arm/hand movement was sustained by central commands [63, 64, 65] rather than by the sensory reafference.

Although the basal EEG differences between *highs* and *lows* were not the objective of the present study, it was noticed that *highs* exhibited lower beta absolute power than *lows* at hemispheric levels. Lower alpha absolute power indicates different styles of resting cortical activity. This is in line with the findings of different activities of the Default Mode Network [13]. It was also observed that long-lasting relaxation is a cognitive task associated with increasing and decreasing gamma activity in *highs* and *lows*, respectively [66].

5. Limitations and Conclusion

An important limitation of the study is the absence of movement monitoring, which is due to instrumentation failure occurred in the initial phase of the study. The paradoxical increase in beta power observed at frontal sites during actual movement, although insignificant, could possibly be due to the movement, which was continuous and repetitive. The beta changes usually associated with movement preparation and execution may have been masked by the beta rebound associated with the termination of each movement within the sequence of five movements. Moreover, a better interpretation of the results could be provided by including medium hypnotizable participants (*mediums*) who were a better representative of the general population [67]. Preliminary findings however, indicate that the *mediums'* motor cortex excitability is intermediate between that of *highs* and *lows* (Spina, personal communication). From this point of view, it may be conferred that their functional equivalence may also be intermediate.

The present findings confirmed hypnotizability-related subjective differences in the ability of motor imagery [30] and in the efficacy of suggested anesthesia [27]. It replicates earlier findings of hypnotizability related sensory-cognitive information processing [7, 28, 29]. It indicated that *lows* performing motor imagery and imagery of anesthesia do exhibit EEG cortical modulation. The findings suggested that both groups were able to embody mental images, through different cortical activity [28] which were more in *highs* more than *lows* [24,28].

In the present study, it can be concluded on the basis of experimental findings that a re-approachment of the experimental hypnosis based on the classification of individual on standard scales (the Ericksonian model) – any person can be considered as hypnotizable – is quite near. In particular, it can be proposed that various “hypnotizabilities” exist [68] and individual psychophysiological characteristics may enable different subjects to respond to different suggestions.

Acknowledgments

The helpful collaboration of T. Banfi for data acquisition is gratefully acknowledged.

Author Contributions

All authors designed the study, analysed results, wrote and approved the manuscript. SR conducted the experiments and analysed EEG signals.

Competing Interests

The authors have declared that no competing interests exist

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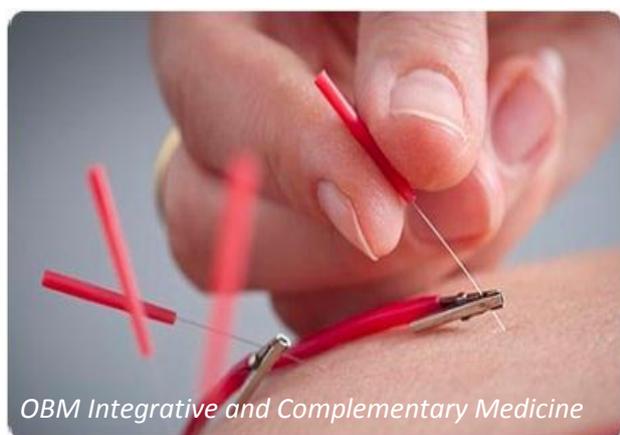
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