Somatic and movement inductions phantom limb in non-amputees

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Abstract. The illusion of the mirror box is a tool for phantom limb pain treatment; this article proposes the induction of phantom limb syndrome on non-amputees upper limb, with a neurological trick of the mirror box. With two study situations: a) Somatic Induction is a test of the literature reports qualitatively, and novel proposal b) Motor Induction, which is an objective report by recording surface EEG. There are 3 cases proposed for Motor illusion, for which grasped movement is used: 1) Control: movement is made, 2) illusion: the mirror box is used, and 3) Imagination: no movement is executed; the subject only imagines its execution. Three different tasks are registered for each one of them (left hand, right hand, and both of them). In 64% of the subjects for somatic experience, a clear response to the illusion was observed. In the experience of motor illusion, cortical activation is detected in both hemispheres of the primary motor cortex during the illusion, where the hidden hand remains motionless. These preliminary findings in phantom limb on non-amputees can be a tool for neuro-rehabilitation and neuro-prosthesis control training.

1. Introduction
The amputations of the upper limb in most of the cases occur from congenital malformation in the case of children and trauma in the case of adults, only in the United States there are about 40,000 people with upper limb amputation[1]. It is known that about 90% of patients with some amputation reports having experiences of phantom limb such as pain, stinging, itching, tingling, voluntary and involuntary movements, these are typical of Phantom Limb (PL)[2][3].

There are two different concepts in these experiences: Somatic sensation and proprioception (corporeal awareness). Somatic sensations are those in which stimuli are applied to the body and produce feel pressure, heat, joint pain cold and others. Proprioception is related to the conscious awareness of the schema of body parts such as shape, size and position. There is another classification among the movement phantom limb sensations: voluntary, quasi involuntary (e.g. answering the telephone) and totally involuntary (e.g. new positions or spasms by tighten the fingers on the loss limb [4].

Treatments of Phantom Limb Pain (PLP) include the use of drug, which is directed to pain management with drugs such as anticonvulsants, muscle relaxants and antidepressants. However, since some years ago, one of the most common therapies for PLP has been the mirror box, in which body symmetry and proprioception are taken as an advantage, performing a neurological illusion
where the subject sees the uninjured limb reflected as the limb loss, reducing pain and improving motor sensations, thus giving the patient a visual feedback of the movement[2].

Something similar occur in augmented reality system based on a brain computer interface (BCI) that provides feedback to the patient in the treatment of PLP syndrome [5]. These treatments are an illusion, which occur in afferent way in the Central Neural System CNS, while imaginary movement occur efferent way[6].

These neurologic illusions/tricks in recent research have been applied to induce phantom limb on non-amputated people. These techniques use the mirror box and tactile stimulation while looking at the mirrored limb, recording evoked potentials from illusion on somatosensory cortical activity of the reflected limb [7]. A second technique uses the rubber hand illusion, with tactile stimulation synchronously in the control limb and the rubber hand, evoking the withdrawal reflex while threatening the rubber hand, to observe the cortical activation with functional Magnetic Resonance Imaging (fMRI) and skin conductance response) [8][9][10][8][9][10]. Therefore, literature shows that the techniques employed only study somatosensory cortical activation and that the study of motor cortex activity by phantom limb are only studied with fMRI[11].

Moreover, the neuroprosthesis are still under development and current control methods for them require a great deal of mental concentration by the patient. Consequently, it requires the patient to do the control by imagination, of non-invasively with surface EEG or invasive, in which the array of microelectrodes are implanted on the cortex. For example, a quadriplegic patient with invasive BCI moves a robotic arm in a few weeks of training, with slow movements though [12]. Another invasive application, is method in which an array of microelectrode implantation in peripheral nerve provide a feedback of pressure and feel to the brain[13][14]. Relationship of motor imagery and movement of a hand orthosis, is performed in a study from BCI based on proprioceptive feedback control, with a 128 channels of sEEG [15].

There are systems to treat phantom limb pain with signals process EEG to move a virtual hand model[5]. Similarly, in another study of phantom limb pain with a the control of a virtual avatar based on EMG’s signal from stump, thereafter this control is integrated into a prosthesis[16]. However, there were not found studies in literature linking the prosthetic control to neurological changes associated with the presence of PLP. Nevertheless, it is known that subjects preserve their intentions or natural movements even after amputees.

The present paper starts checking the techniques of Inducing-Somatic Phantom Limb (ISPL) in non-amputees. It is also proposed to study Induce-Movement Phantom Limb (IMPL) in non-amputees using the register of the activity of the primary motor (MI) cortex using electroencephalography (EEG). We propose the hypothesis that these results of the induction PLM in non-amputees could be used to generate knowledge bases that help neuroprostheses's control training. This training provides the use of a noninvasive method, with few electrodes from signals that occur naturally or intuitively in amputation patients or diseases peripheral nerve.

2. Methodology

2.1. Experimental setup
In this study, participants were seated in a comfortable chair and a table in front of the subject in which they rested both arms. In situations when mirror box is used (see section study situations), it was placed on the table in front of the participant in which the subject introduced one arm (hidden limb), while the outside limb is reflected in mirror box[2]. The box rested on the shoulder joint to ensure the reflected limb proprioception. This is because the location of the limb has a strong relationship with the visual information that the subject has of the body[10]. The figure 1 shows experimental setup.
2.2. Study Conditions
The study has two different tests for induction of PL in non-amputees; the first is a checking of the
techniques used for ISPL, while the second investigates IMPL. Each test is described below:

2.2.1. Test 1. Inducing-Somatic Phantom Limb (ISPL)
The subject was asked to stare the limb in the mirror, to rest his elbows on the table, to flex
the wrist and keep his hands in the air. While the experimenter sitting opposite the subject, stimulates
the fingers of the reflected and hidden limbs during 2 minutes, inside and outside the mirror box,
applying synchronously brushstrokes with identical brushes. Then, the subject is asked to close his
eyes for 10 sec and when opening the eyes receives an attack with a false knife in the limb outside
of the mirror box. This is done to test is inducing withdrawal reflex in both limbs.

2.2.2. Test 2. Inducing-Movement Phantom Limb (IMPL)
We have three conditions in which the three auditory stimuli are applied, described in section EEG
acquisition. These conditions arose in order to make a comparative analysis of each case, as
described below:

- **Control Case 1**: Movement made without a mirror box. The subject placed both forearms
  on the table, he was asked to open and close their hands according to stimulus indicated.
  (See Table 1).
- **Illusion Case 2**: neurological trick (illusion) is performed by positioning the mirror box as
described in the section above hiding his left hand. The subject was asked move his hands
  same as case 1, watching his hand in the mirror. (See Table 1).
- **Imaginary Case 3**: Imaginary move. In this case the subject does not execute any
  movement, only imagine move hand according to stimulus indicated. (See Table 1).

| Case                      | Stimulus                  | 1 Left                        | 2 Right                       | 3 Both                        |
|---------------------------|----------------------------|-------------------------------|-------------------------------|-------------------------------|
| Control (Without mirror   | Movement of the            | Movement of the               | Movement of the               |
| box)                      | Left hand grip             | Right hand grip              | Both hands grip              |
| Illusion (With mirror box)| Movement of the            | Movement of the               | Movement of the               |
|                           | Left hand grip hidden      | Right hand grip. Looking     | Both hands grip.            |
| Imaginary (Without mirror | Imagine movement of the    | Imagine movement of the      | Imagine movement of both     |
| box)                      | Left hand grip             | Right hand grip.             | hands grip.                  |

Table 1. Stimulus and cases
2.3. Subjects
The tests were applied to 19 subjects, healthy adult volunteers (7 females and 12 males) mean age 31.55, 2 left-handed, 16 right-handed and 1 ambidextrous. The group includes 16 subjects without prior knowledge (naïve) of ISPL. In particular we select 6 subjects (2 female and 4 males), in which the withdrawal reflex was observed stronger in the ISPL experience. This group was applied the second method IMPL recorded with EEG. Within this group all subjects are right handed and the mean age is 23 years. All subjects given a written consent form for recording EEG signals and performing the experimental protocol.

2.4. EEG data acquisition
EEG was recorded from 10 Ag / AgCl, electrode positions F3, F4, T7, C3, Cz, C4, T8, Pz and two mastoid reference channels. The EEG-amplifier G.TecMobilab Plus has the following characteristics: Filters 0.5-100 Hz, sensitivity of 500μV, monopole, ADC with 16 Bits and 256 Hz sample rate and Bluetooth communication. Were programmed tasks in open source BCI2000 [17], in which auditory stimuli, indicating the subject the task, each stimulus for 1.7 s + 0.2 s, with 10 random repetitions of each stimulus were recorded and four runs each session. The auditory stimuli are "right", "left" and "both", the actions shown in Table 1. The rest condition occurs between stimulus and stimulus, the subject should not make none task, remaining in a relaxed state.

2.5. Analysis data
A questionnaire for experience ISLE analysis was performed, although it was a subjective measure, it provides an initial assessment of the existence of PL in non-amputees. After the experience, the subject answers a questionnaire consisting of 6 closed questions (yes or no) additionally the subject freely expresses his/her experience. The questionnaire is adapted from the somatic experience of White et al.[18].
Pr 1. Did you feel comfortable or weird during the experiment? (Comfortable: yes, weird: no)
Pr 2. Did you feel any unnatural sensation in your hands?
Pr 3. Did you feel at any time having another hand?
Pr 4 Was your hidden hand longer than usual?
Pr 5. Did you feel that the hidden hand’s movements were entirely normal?
Pr 6. Have you ever seen something similar to this experiment before?
Pr 7. Is there anything you want to add?

Questions 1 and 2 enable the assessment of the feeling that the subject experiences in front of the mirror box; 3 to 5 evaluate the suggestion that the subject may have as regards the hidden hand, question 6 assesses whether the prior knowledge of the experiment affects the withdrawal reflex response.

Moreover, BCI2000 Offline Analysis graphical tool was used in the analysis of Inducing-Movement Phantom Limb, which is based on characteristics. It operates in two steps, the first, turns time signal to features, such as: EEG amplitude, time after some stimulus and channel. After transformation the raw data EEG to characteristics, the data is selected and organized into two groups, rest or stimulus.

Therefore, there is a number of samples for each feature from two different conditions, the coefficient of determination (r-squared - r²) is calculated between the two conditions on the signal. r² values provide a measure of magnitude in which certain characteristic of EEG (frequency and amplitude of a particular location) is influenced by the stimulus or task performed (condition). The tool provides 3 graphics, the first relates r² values and frequencies; the second is a histogram (not shown), which relates r² values with frequencies and the channels being used, finally the last is a topographic map that displays the spatial distribution of r² values for a selected frequency.

The graph of the frequency spectrum and r² were used to manually verify frequency at which occurs event of desynchronization of each individual with the maximum value of r², because each
subject has its own frequency range in which occur non-synchronization and synchronization in their EEG signals and located between the $\mu$ and $\beta$ rhythms (8 to 30 Hz) when doing the proposed tasks. The frequency determined was used as input to generate the respective topographic map and a visual inspection of motor activity of the cerebral cortex for each subject and each condition.

3. Results

3.1. Test 1 ISPL
The expected response to the stimulus is the withdrawal reflex, evoked by attacking with a false knife. Figure 2 shows the percentage of three types of response: non response to the stimulus, undefined and a clear response in withdrawal reflex. A considerable percentage of subjects show a clear withdrawal reflex response to the attack with the false knife.

![Responses withdrawal reflex](image)

**Figure 2.** Results of responses withdrawal reflex.

The frequency of responses was obtained in the questionnaire to all subjects in the ISPL test are shown in Figure 3.

![Questionary](image)

**Figure 3.** Graphic representation of the responses to the questionnaire applied.

3.2. Test 2 IMPL
Figure 4 shows the frequency found for subjects 1 and 2 in the control case with the maximum value of $r^2$. While the frequency between individuals is different, for each subject it persists for all case studies.
Topographic distributions of the activity of the cerebral cortex are shown in Table 2. For each case study test 2 IMPL motor activation, the corresponding motor activation area is clearly observed. Activation is an important distinction in the contra lateral area at which the movement occurs. However, in the case of illusion and right hand movement in the mirror it generates a signal in the right hemisphere (which corresponds to the left hand still hidden), similar to the signal magnitude of the left hemisphere (corresponding to moving the right hand). Also, the signal in the right hemisphere (still hidden left hand) for the same case of illusion also has a comparable scale with the signal of the right hemisphere (corresponding to the left hand) when moving both hands or when moving only the hand left, in the case of control.

**Table 1** Case studies in a single subject for test 2 IMPL

| Case | Stimulation | Left | Right | Both |
|------|-------------|------|-------|------|
| Control | | | | |
| Illusion | | | | |
| Imaginary | | | | |

**Table 3** Illusion case in six different subjects

| Case | Stimulation | Left | Right | Both |
|------|-------------|------|-------|------|
| Subject 1 | | | | |
| Subject 2 | | | | |
Table 3 shows the 6 subjects who participated in the trial in case IMPL illusion, under 3 stimuli applied in each case study. It is observed that the illusion (without movement of the left hand) in subjects 1, 3, 5 and 6 generate a signal to the right hemisphere that is just weaker than the corresponding right hand moving (left hemisphere) signal. In subjects 2 and 4 illusion is even more intense for the right hemisphere than the corresponding right hand moving (left hemisphere) signal. In subjects 4 and 6, illusion shows a representation with different characteristics for the movement of both hands.

4. Discussion

4.1. Test 1 ISPL

The withdrawal reflex response to the stimulus in each person is different, in some subjects may be stronger than others. Non-response suggests that like the amputees have the PL 90% of subjects, in non-amputees could also assume that in a small percentage no PL induction is possible. This is consistent with a slightly different experiment by Ramachandran et. al[2], who found that the phantom nose is not induced in all subjects in the experiment on non-amputees. In their experiment, they found a 40% non-illusion, which is close to 36% of this work, considering 26% of non-response and 10% of indefinite answer.

In the analysis of the somatic test other researchers made questionnaires staggered for a comprehensive statistical analysis [18][10]. However, somatic experience that is recorded in this work, aims to check qualitatively whether it is possible or not to induce PL in non-amputees, as a pre-illusion assay to IMPL.

The analysis of the responses to question 1 (PR1), shows that the majority of subjects concerned have felt comfortable during the experiment. As regards question 2, it suggests that there is not abnormal sensation during the experiment (PR2). This may be interpreted that the environment is natural for the subject.

In reference to the suggestion that it can get to have the subject and felt a third hand (PR3), a high percentage of the subjects say they did not feel to have a third hand. In accordance to the literature to [18][10], when asked if a hand was longer than the other (PR4), negative response was obtained. Additionally the hidden hand movements were completely normal (pr5). The present
result suggests that there was no suggestion felt by the subject when neurological trick was done with the mirror box.

The negative answer to Question 6 (pr6 shown that having seen the experiment previously does not influence the results, because in the 3 subjects who knew the experiment the withdrawal reflex is produced all the same). This is particularly important because it shows that neurological trick can be induced even in people experienced with the mirror box.

4.2. Test 2 IMPL
The response to the stimulus 1, of the left hand (hidden hand in the case of illusion) in the three case studies it is linked to the registration of the cortical activation of primary motor area of the right hemisphere (contra lateral activation), typical for this type of movement, as seen in a conventional EEG recording [19], since the left hand is hidden does not occurs the neurological trick. In the case of imaginary the register is also common for these tasks [20].

Moreover, stimulus 2 corresponds to the grip of the right hand, in which the activity of the left hemisphere motor area is observed. The case control shows the corresponding activation only on the right hand; the same occurs in the case of imagination.

The most interesting case in this study occurs under stimulus 2 grip of the right hand in case 2, where the activation of the motor cortex in both hemispheres appears during registration of illusion, with the motionless hidden hand. Activation is located on the motor cortex in the same area in a common register where both hands are moved. This indicates that the position of the phantom hand on the motor cortex is established on the spot that corresponds to the motionless hand. This is similar to the activation cortical seen with fMRI on amputees with phantom limb, in which the cortical activity of the phantom hand is recorded where the missing limb was, replacing in the brain's perception of the lost limb by the perception of phantom limb [11].

Something similar also occurs in cases of patients with supernumerary phantom limb after a brain stroke, in which cortical activity is recorded using fMRI when the patient is asked to "move" his or her supernumerary phantom limb [21]. Likewise happens when induced inducing-Somatic Phantom Limb by touch in non amputated and registering EEG [7] or fMRI images that are obtained of amputees and non-amputees under ISPL [9]. This work is being extended this finding of results to movement, it is estimated that in the future control signals may be generated intuitively in amputees. These signals could command neuroprosthesis drivers with a relatively shorter learning.

The activity in the grasping movement of both hands in all cases are similar, but are somewhat different in the value of their r² being the most intense for case 1, where there is no neurological trick or imagination and smaller values for the case 3 registration imagination. This is consistent with the free and voluntary manifestation of the participants who said that the case of imagery requires more effort. Nevertheless, imagery can be recorded without prior training [19], for best results training is required, that helps to make more easily and without mental exhaustion this task [22]. Illusion can become a mechanism that facilitates learning to achieve in less time the control capabilities of neuroprosthesis.

The EEG is performed with few electrodes accordingly it is premature to say that it is not established a parallel neuroplasticity and hence it is not possible to observe a cortical activation if it occurs in a different area the brain dedicates to the attention of movement hands. In other studies where the rubber hand as a third arm is used to generate the ISPL using the tactile illusion [10][18], could also be neuroplasticity. Comparatively in a future work with more electrodes it could be established whether neuroplasticity is being generated in this condition parallel or some other type of neuroplasticity.

In the next step of this research it is planned statistical signal processing, which allows extract those characteristics of the pattern found in the illusion to generate base of intentions phantom as control strategies and training in the use of prosthetics with natural intentions of the patient.
5. Conclusion

The registers of case 2, where the setup illusion (neurological trick) was implemented, show that it is possible to induce phantom limb movement in non-amputees. Literature clearly shows that the phantom limb can be induced sensitively; however it was not entirely clear whether it could be done by movement. In this paper we verify that the induction-movement can also be registered with a non-invasive, inexpensive and easily accessible compared to fMRI study. In this context, it should be clarified that the experience of case 2 (illusion) can be understood as a sensorimotor trickery, since it explores the driving nature, hand movement reflected and vision that deceives proprioception inducing member phantom (reflected member).

For future work it is important to expand the number of subjects registered for better study window. It also remains to be established whether the proposed method can be applied to the rehabilitation of patients with brain diseases related to correct motion or the proposed solutions for quadriplegics noninvasively [12].

It also remains to consider whether this induction in people with brain injuries (e.g., Stroke), they can reach neuroplasticity in less time with the proposed method. Thus, the illusion of the mirror box is not only an aid in the treatment of phantom limb pain but can become a tool for neuro-rehabilitation and training of neuro-prostheses controlled with patient's natural signals amputation, and that could be applied with few electrodes, following these preliminary findings [8][23], instead of having a maladaptive neuroplasticity that generates the phantom limb pain.

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