Innate Muscle Patterns Reproduction During Afferent Somatosensory Input With Vojta Therapy in Healthy Adults. A Randomized Controlled Trial

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***Abstract*— Objective: Vojta therapy describes stereotypic widespread motor responses as a pattern of tonic muscle contractions during a peripherical pressure stimulation. The present work proposes to characterize the responses at muscles level to a specific tactile input based on Vojta therapy, assessed by sEMG, compared to a sham stimulation in healthy subjects. Methods: Surface electromyography (sEMG) signal was acquired with dipolar electrodes placed at wrist extensors of both forearms, right tibialis anterior, and top part of rectus abdominus, ground channel placed over the right olecranon. It was amplified and digitized by a 4-channel hub Biosignalsplux device (Plux Wireless Biosignals S.A., Lisboa, Portugal), sampled at 1000 Hz with 16-bit per channel. A continuous 10-minute record of the sEMG signal from the four electrodes were registered. Resting EEG during the first minute before the stimulation period was recorded by 64 active electrodes. Results: Statistically significant differences were showed between sham and experimental group. Experimental group participants were subjected to cluster analysis based on their muscle activation patterns, generating three different models of activation. Differences in the previous resting cortical activity in left superior frontal area were found between clusters that activated limb muscles and the cluster that did not. Conclusions: Vojta specific stimulation area activates innate muscle responses assessed by sEMG in healthy subjects, compared to a sham stimulation. Significance: This characterization might be helpful to the prescription and application of Vojta therapy in an individual-basis for non-neurophysiologically damaged adult subjects.**

***Index Terms*— Afferent input, electromyography, muscle patterns, muscle activity, resting EEG, reflex locomotion, tactile stimulation, Vojta therapy.**

I. Introduction

DIFFERENT top-down approaches have been defined, consisting on defining the rehabilitation therapies based on the state of the brain after brain its injury, and based on some elements such as learning skills and error-drive-learning. However, not all patients are candidates to be treated under this paradigm or at least at the beginning of the rehabilitation process due to their capacity of active participation. Bottom-up approaches have been shown to be effective in causing changes at central level through peripheral sensory stimuli, which in turn influence on muscle activity, postural control and locomotion systems [1], [2]. Under this paradigm Vojta therapy is a bottom-up approach, also known as reflex locomotion, and It was defined and deeply developed by the neurologist Václav Vojta at the latest 50's. A stereotypic widespread motor response was observed by Vojta during a maintained peripherical pressure stimulation, as a pattern of tonic muscle contractions in both sides of the neck, trunk, and limbs resulting of a spatial summation leading to postural control improvement.

Vojta therapy basic principle is posture regulation [3]. Postural control is accomplished through a required plans and programs, also defined as "innate patterns" which gather task related movements' automatic adjustment and posture related with task [4]. Innate movement patterns activation befalls without patient's conscious intention. Reflex creeping and reflex rolling, both Vojta's coordination complexes contain all the "building blocks" employed at any human posture and movement up until free walking [5].

An initial patient's specific position is required to activate these coordination complexes, defined by exact extremities angulation, which are related to each other. Reflex rolling develops initially in a supine position goes through to lateral position and ends in crawling [5]. Reflex rolling activates

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whole musculature activation on a global and specific way: an abdominal muscle contraction, spine's longitudinal axis alignment, and pelvic retroversion, 90 ° of hip and knee flexion and dorsal flexion on ankle. At the upper limb level on head rotation side, a shoulder's external rotation with 45° arm flexion on sagittal plane and 30° arm flexion on frontal plane, elbow semi-flexion, wrist's dorsal flexion with radial deviation, metacarpals' opening, thumb abduction with extension and fingers separation is befallen. On non-head-rotation side upper limb, a shoulder 90° abduction with external rotation, 90° elbow flexion, wrist's dorsal flexion, metacarpal's abduction and fingers extension is conducted [6].

Originally, Vojta therapy rehabilitation was focus on infants and children with risk on cerebral palsy. Later on, it was successfully applied to motor and neurological adults' problems [6], [7]. Regardless patient's age, an isometric muscle contraction is triggered as to walk on all fours or roll because of the peripherical pressure stimulation [8]. This technique is used clinically and, although there are studies which aim to demonstrate its effectiveness in children and adults with neurological disorders, currently the basis able to objectify the patters of muscular contractions described at the theoretical postulate has hitherto not been developed: Gajewska *et al.* [9] recorded bilateral deltoids and rectus femoral contraction using a surface polyelectromyography (sEMG) in healthy subjects during Vojta therapy. Notwithstanding their exhaustive study, they assessed both sides in two different positions but there was not a control group of healthy subjects to compare information with a sham stimulation. Furthermore, activation time window was limited to 1-4 minutes. Perales and Fernández [10] recorded, using sEMG, extensor digitorum muscle bilaterally activity in healthy adults during reflex rolling's Vojta manual stimulation versus a mechanical mechanism which tried to reproduce the same stimulation. However, muscle reactions to this afferent stimulation were not deeply analyzed neither compared to a sham stimulation group.

Vojta therapy analysis over multiple sclerosis subjects has been deeply investigated by Laufens *et al.* [11]–[13]. EMG measures were performed bilaterally in upper and lower extremities muscle groups (biceps femoris, rectus femoris, triceps brachii, and biceps brachii) although neither muscle reaction to Vojta therapy was analyzed nor a control group was defined. Furthermore, combination of therapies plus Vojta therapy [14], different patients' positions [11], [12] or different stimulation points without a comparison with a healthy control group [13] were conducted by this research group.

After Vojta therapy it has been observed different muscle activity patterns (or even no activity), either anatomical or temporal, on the application of tactile afferent stimulation in healthy adults and people with neurological disorders [4], [9]. However, few studies have assessed and characterized muscle activity after Vojta therapy and all researches in this line presented methodological limitations described above. Therefore, the aim of this study is to characterize the responses at muscle level to a specific tactile input, assessed by sEMG, compared to a sham stimulation in healthy adult subjects. Since it has already been proved that the Vojta's afferent stimulation induces changes in the cortical activity regardless of the muscle activity triggered [6], [8], we hypothesize that the muscle response might be conditioned by the cortical activity before the stimulation. Consequently, the present study also attempts to find a cortical activity-based conditioning factor, assessed by electroencephalography (EEG), for the subsequent muscle activity pattern. To our best knowledge, this is the first study that has used sEMG to assess, characterize and explain the muscle activity triggered during tactile stimuli following Vojta therapy on healthy subjects during reflex rolling position and bilateral sEMG locations recording, compared to a sham stimulation during a wide time window of recording.

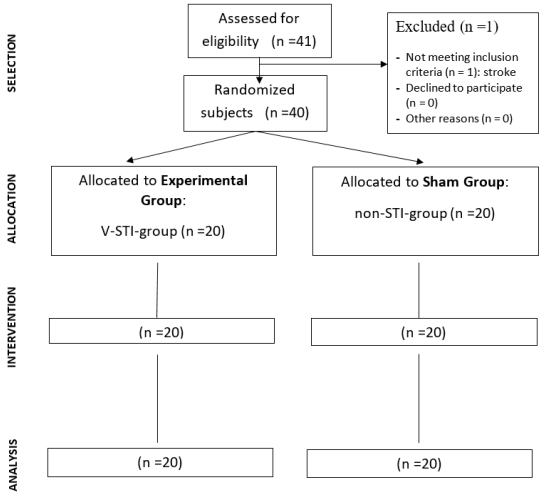

Fig. 1. CONSORT flow diagram.

II. Material and Methods

A. Design

A randomized-controlled trial (RCT) was conducted (Fig. 1) prior to SARS-CoV-2 pandemic era, so no specific or additional biosafety procedures were necessary to those described in this research. Participants were randomly distributed into two groups using the EPIDAT 3.1 sofware: a non-specific tactile input-group (non-STI-group) and a Vojta specific tactile input-group (V-STI-group). None of the participants previously knew the groups or the area of the stimulus where it was going to be applied (participants blinded). A physiotherapist was the only one who knew the place of stimulation for subjects and all assessments were recorded with an assessor blinded.

Approval was obtained from Ethics Committee, conforming to Helsinki Declaration. This trial was retrospectively registered in ClinicalTrials with the register number NCT04317950 (February 5, 2021).

All participants received a document informing them of the study aims and signed an informed consent. Directives of Consolidated Standards of Reporting Trials (CONSORT) declaration [15] for non-pharmacological RTCs were followed.

B. Participants

40 healthy subjects between 18 to 50 years old were initially recruited to take part in this study. Participants' recruitment were made by e-mail, telephone calls and through an informative meeting in Polibea Foundation at Tres Cantos (Madrid, Spain) and European University of Madrid (Madrid, Spain). Each participant received a single session.

Inclusion criteria were healthy subjects without previous neurologic disease or any other pathology which may interfere in the intervention, age between 18 to 50 years old, non-alcoholic or drugs addition at the intervention moment, be unaware of Vojta therapy's foundations or its stimuli's response after applying the therapy, non-pharmacological treatment which may affect nervous system functioning and may interfere in intervention's results.

Exclusion criteria were subjects who not fit inclusion criteria, presence of any musculoskeletal alteration in the last 6 months, presence of any sensorial alteration, presence of neurological disease or condition that may interfere at the intervention as pain, radiculopathy, presence of inflammatory illness or fever and pregnancy.

C. Procedure

During the intervention, participants remain in a comfortable position, in a supine position with his head oriented towards the side where the stimulus will be performed. They were asked to remain relaxed and still during the whole process.

After a first minute of resting, V-STI-group received a continuous stimulus according to Vojta therapy, during the next 8 minutes. On the contrary, non-STI-group received a continuous sham stimulus on the thigh during the next 8 minutes. Both groups ended the intervention with an additional final resting minute with no stimulus. Therefore, interventions lasted 10 minutes during which sEMG signal was continuously recorded. Both stimuli were applied by a physiotherapist expert on Vojta therapy.

Despite the absolute blinding of either assessor and participants, It is not possible in hands-on interventions. We performed bias control following some of the recommendations collected in Mehling *et al.* [16]: i) the informed consent signed by all the participants were the same, and did not contained details that could allow to distinguish the effects of the two types of interventions. Moreover, all participants were randomized before consent signing; ii) we did not collect the participants' expectations about the interventions but both groups were instructed in the same way (remain relaxed regardless any possible sensation) before the procedure. In addition, the placebo ("sham") intervention mimicked the study intervention closely; iii) the assessment was made with objective outcome measures (EMG and EEG) so that the therapist was not totally aware of the effects of his actions.

Finally, in order to monitor possible side-effects and despite all participants fulfilled the inclusion criteria previously described, a physical therapist carried out a constant observation of adverse effects and reactions during the treatment session, as well as by telephone contact during 72 hours after the therapy to register possible side-effects.

D. Reflex Locomotion and Sham Stimulation

Stimulation's skin place was the main difference between both stimuli (V-STI-group and non-STI-group). V-STI-group was stimulated in a specific area (intercostal space, at the mammillary line between the 7th and 8th ribs) according to reflex locomotion described in Vojta therapy [17], [18], while non-STI-group was stimulated in a distal third of thigh (in quadriceps distal area, 8cm cranial from superior angle of the patellar bone). This sham area was selected because it has no relation to any other known point within Vojta therapy [19] and following a previous study with a sham stimulation group conducted by our research team [6].

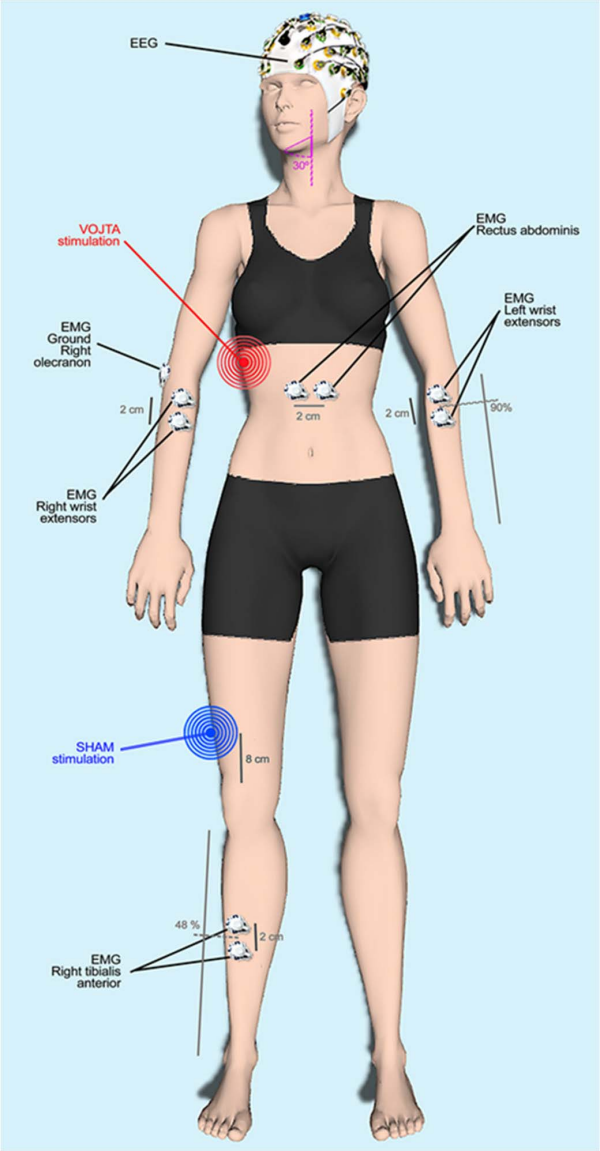

Fig. 2. Disposition and instrumentation of the participants for the experimental protocol.

All participants were placed with a 30° head rotation on the same side of stimulation zone, in supine decubitus with a relaxed anatomical position (Figure 2). Nevertheless, all of them were stimulated by an ipsilateral input. V-STI-group was stimulated over the skin on the intercostal space, at the mammillary line between the 7th and 8th ribs. This stimulus was applied by a physical tehrapist with his right thumb. A slight pressure with dorsal, cranial, and medial directional stimuli, toward contralateral shoulder, for 8 minutes, according to Vojta theory was applied [17], [18]. On the other hand, non-STI-group was stimulated in the non-specific area described above. Furthermore, the same direction and duration were performed in both groups on the right side.

E. EMG Signal Acquisition and Processing

EMG signal was acquired with dipolar electrodes, with a separation of 20 mm [20], placed along muscle fibers at wrist extensors of both forearms, at 90% of their length [20], at right tibialis anterior, at 48% of its length [21] and at top part of rectus abdominus, ground channel placed over the right olecranon (Fig. 2). It was amplified and digitized by a 4-channel hub Biosignalsplux device (Plux Wireless Biosignals S.A., Lisboa, Portugal), sampled at 1000 Hz with 16-bit per channel, and wirelessly transmitted to a PC computer (Intel core i3, 4GB RAM, 256GB SATA HDD, Windows 7 32-bit operating system). Transmitted signal was monitored and locally stored in the computer by the Opensignals software (Plux Wireless Biosignals S.A., Lisboa, Portugal). A continuous 10-minute record of the EMG signal from the four mentioned electrodes was stored in one single file for each participant.

EMG signal was preprocessed with Matlab v2017b (The Mathworks Inc., USA) by a standard procedure [22]: signal from each electrode was detrended (Matlab's function 'detrend(x)'), filtered by a 5th-order Butterworth bandpass, zero-phase digital filter between 10Hz and 495Hz (Matlab's functions 'butter' and 'filtfilt'), and rectified (taking the absolute value of the samples). Each participant and electrode's signal were split into one minute's consecutive fragments, and average root-mean-square envelope (RMS) of each fragment was obtained (Matlab's function 'rms(x)'). This one-minute fragment duration was selected to get a relatively stable average EMG activation based on triggered motor behaviors' duration observed according to experienced therapists who participated in this study. Finally, for each 1-minute stimulation period's fragment and last post-stimulation resting minute, ratio between the corresponding RMS and the RMS in the first pre-stimulation resting minute was calculated to quantify changes during stimulation with respect to previous resting state. This process was done for each participant and muscle group independently.

F. EMG-Based Cluster Analysis

Due to muscle activation heterogeneity observed, participants in the V-STI-group were subjected to cluster analysis based on their muscle activation patterns. For that purpose, each participant was represented as a vector containing the relative RMS (to pre-stimulation resting interval) of each muscle group of every stimulation period's minute and post-stimulation minute, resulting in a total of 36 dimensions ((8 stimulation minutes + 1 post-stimulation resting minute) x 4 muscle groups). Analysis was performed with RapidMiner Studio v9.8 Community Edition software (RapidMiner Inc., Boston MA, USA). X-Means algorithm [23] was used to obtain clusters with the minimum number of clusters of 2 and maximum number of clusters of 10, maximum runs of 100 and maximum optimization steps of 1000, and the rest of parameters as default in the software. Algorithm was run 13 times, one with each of the different numerical measures of distance between clusters available in the software. Clusters produced in the run with the minimum average within cluster centroids were selected and further analyzed statistically.

G. EEG Acquisition and Processing

Electroencephalography (EEG) signal was amplified and digitized at 512 Hz by an actiCHamp amplifier (Brain Vision LLC, NC, USA). EEG data were stored in a PC running Windows 7 (Microsoft Corporation, Washington, USA). EEG activity was acquired from 32 active Ag/AgCl scalp electrodes (actiCAP electrodes, Brain Vision LLC, NC, USA) following the 10-20 system: F5, F3, F1, Fz, F2, F4, F6, FC5, FC3, FC1, FCz, FC2, FC4, FC6, C5, C3, C1, Cz, C2, C4, C6, CP5, CP3, CP1, CPz, CP2, CP4, CP6, P3, P1, Pz, P2), placing the ground and reference electrodes on the Fz and FCz positions, respectively.

Signal was preprocessed by MATLAB (The Math- works Inc., Natick MA, USA), concretely using the EEGLab toolbox [24]. Next preprocessing pipeline was applied to the continuous EEG signal for each channel: 1) artifact correction by the Artifact Subspace Reconstruction (ASR) algorithm [24], disabling all parameters except the high-pass 'filttran' band width (0.25-0.75) and the burst repairing (kurtosis $>$ 20); 2) band-pass filtering between 3Hz and 31Hz with a Finite Impulse Response (FIR) filter (order 846); 3) channel rejection and spherical interpolation of the channels with a kurtosis higher than 5 standard deviations of the average channel kurtosis. 4) artifact removal by the elimination of the independent components obtained from Independent Component Analysis (ICA) according to Multiple Artifact Rejection Algorithm (MARA) [26] (probability $>$ 0.9).

After prepocessing pipeline, LORETA-KEY software package (KEY Institute for Brain-Mind Research, Zurich, Switzwerland) was used to apply sLORETA algorithm [27] for source localization. sLORETA algorithm provided the source current density for each of the 6239 voxels in which the algorithm divides the cortex model, for six frequency bands: theta (4Hz-7Hz), low alpha (7Hz-10Hz), high alpha (10Hz-13Hz), low beta (13Hz-18Hz), mid beta (18Hz-25Hz) and high beta (25-Hz-30Hz). The current density of each voxel was standardized by the average current density in each participant.

H. Statistical Analysis

Relative RMS of each minute of stimulation and post-stimulation resting minute for each muscle group between each cluster and control group were compared. MANOVA test was discarded due to the small sample size (some of the compared groups was smaller than the number of groups itself). Therefore, we performed univariate analyses, one for each of the independent variables compared. In addition, the populations in most groups and independent variables were not normal nor homoscedastic according to Shapiro-Wilk's and Levene's tests, respectively. Consequently, a non-parametric Kruskal-Wallis test were applied to each independent variable, using post-hoc Mann-Whitney tests with Bonferroni-adjusted alpha level correction to account for the pairwise comparisons between groups.

EEG source current density's comparison of the pre-stimulation resting minute for each voxel between the Vojta-stimulated clusters was performed on the log of F-ratio assuming equal variances, by statistical nonparametric

TABLE I
SAMPLE FEATURES

Groups (n)	Age (years) Mean ± SD	Male	Female
All sample	30.3 ± 7,3	16 40%	24 60%
non-STI-group (20)	30.5 ± 5,67	9 45%	11 55%
V-STI-group (20)	30.1 ± 8,67	7 35%	13 65%

SD = standard deviation.

mapping methodology (snPM) [28] with 5000 randomizations, correcting for multiple comparisons, included in LORETA-KEY software used for source localization. Differences with p <.05 were considered statistically significant.

I. Sample Size Calculation

Given that the we want to compare the relative RMS of two equally-sized groups, where one of them, the non-STI-group with sham stimulation, was expected to take a value of one with a standard deviation close to 0 (no muscle activity during sham stimulation), we foresaw differences with an effect size of Cohen's d = 1 (one standard deviation of the RMS of V-STI-group). Since we also looked for significance values of p<.05 and statistical power 1-B>0.8 derived from a t-test, the minimum estimated sample size for each group using the software G∗Power v3.1(Heinrich-Heine-Universität Düsseldorf, Germany) was 17.

III. RESULTS

A. Sociodemographic Data

Total sample consisted of 40 patients, 16 male and 24 female of the 41 selected at the study onset (Figure 1). One subject was excluded due not to meet inclusion criteria (stroke). Whole sample's mean age was 30.3 ± 7,3. Non-STI-group's mean age was 30.5 ± 5,67. V-STI-group mean age was 30.1 ± 8,67. Sample features are summarized in Table I. No side-effects were observed for both groups during the treatment and no adverse effects were identified 72 hours after the procedure.

B. EMG-Based Clusters of Vojta-Stimulated Participants

From cluster analysis, run with minimum average distance to cluster centroids was the one using Manhattan distance, obtaining three clusters with an average within centroid distance of 3.141. Three clusters have 8, 3 and 9 Vojta-stimulated participants, respectively. Figure 3 presents muscle activity (RMS relative to the first resting minute) profile of each of the clusters for each of the muscle groups during stimulation period and post-stimulation resting minute.

Figure 3 shows how cluster 0 groups participants who only activated rectus abdominis during stimulation period from the beginning in a constant way. By contrast, cluster 1 assembles participants who barely activated any muscle group until stimulation's seventh minute, when only limbs became activated, keeping an increasing activation during post-stimulation resting minute. Finally, cluster 2 gathers participants who increasingly activated all muscle groups from the beginning

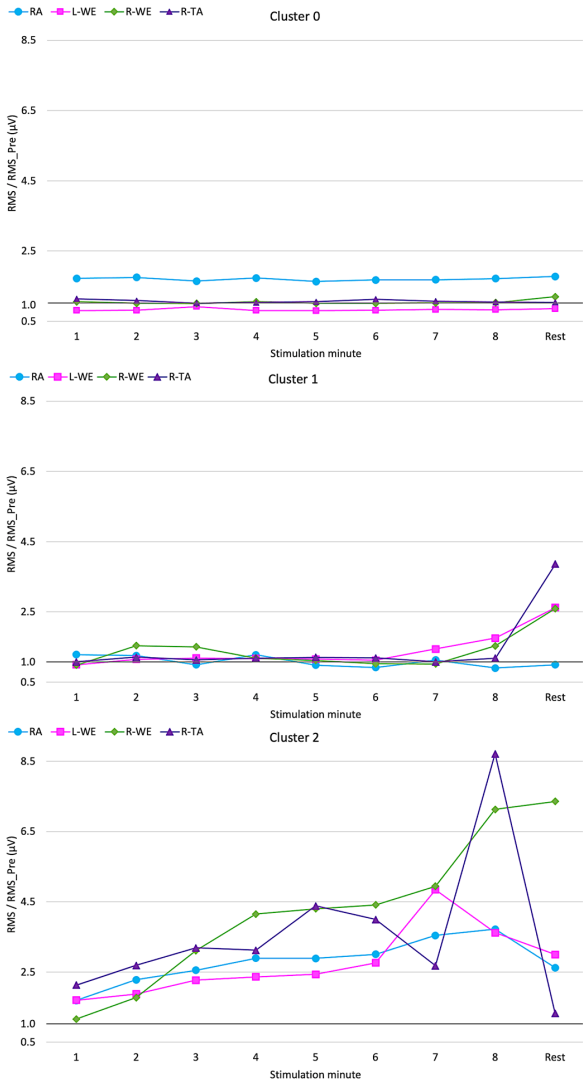

Fig. 3. RMS relative to RMS in the first resting minute pre-stimulation for each muscle group during the stimulation and post-stimulation periods for the three clusters of Vojta-stimulated participants obtained.

over the stimulation period, suffering from an activation's decrease during post-stimulation resting minute. Notice that Figure 3 shows EMG RMS values relative to the EMG RMS of the pre-stimulation resting minute, a value higher than 1 meaning higher activation than during pre-stimulation period and a value lower than 1 meaning lower activation with respect to pre-stimulation minute.

1) EMG-Based Comparison Between Vojta-Stimulated Participant Clusters and Sham Group: Table II shows EMG RMS relative to the first resting minute for each Vojta cluster found and sham group, and corresponding statistical analysis, during every stimulation period's consecutive minute and resting minute post stimulation, for each of the four muscle groups recorded. Table II shows statistically significant differences during the whole stimulation period and post-stimulation minute in rectus abdominis and left forearm muscle groups, the former presenting the highest significance. For the right forearm, significant differences appeared from 4th minute of stimulation on. This same pattern is also present for tibialis anterior group, despite the differences from 4th minute are only close to significant but not significant.

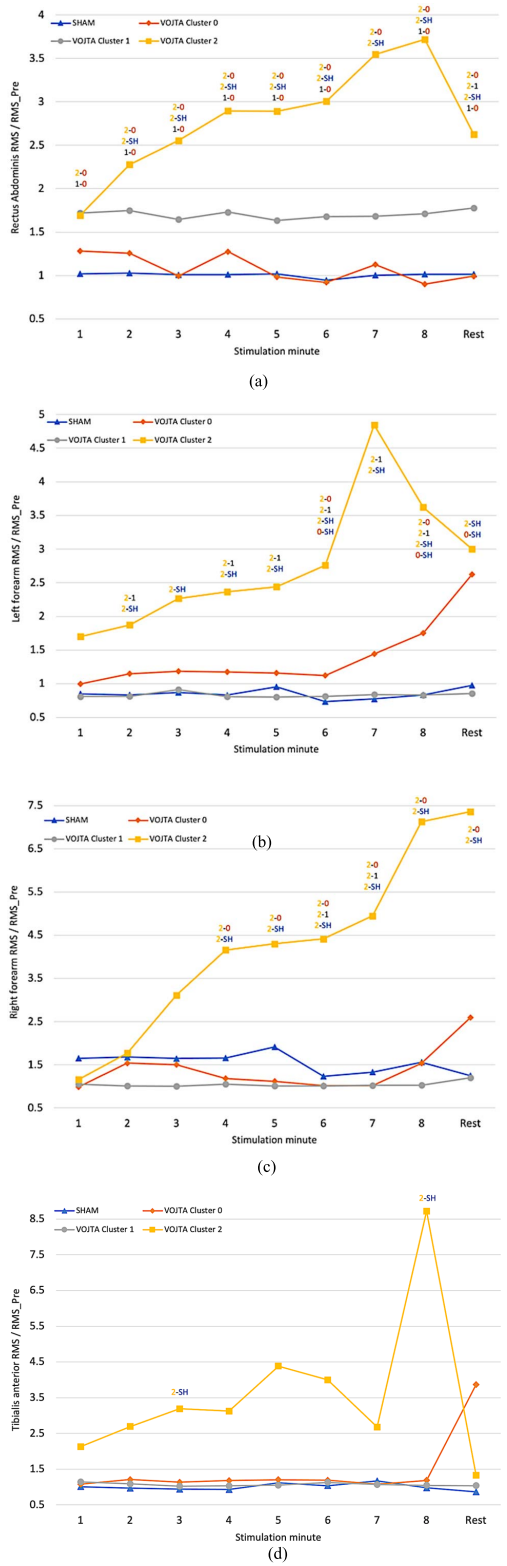

Fig. 4. Mean EMG RMS relative to the first resting minute for each of the 8 consecutive minutes of stimulation and the post-stimulation resting minute, and for each Vojta-stimulation cluster and the sham group (and the pairwise statistically significative differences) in a) rectus abdominis, b) left forearm, c) right forearm and d) tibialis anterior.

Figure 4 depicts average values in Table I for different muscle groups (in each quadrant) recorded for a better observation of the pairwise post-hoc differences. With respect to rectus abdominis, Vojta-stimulation cluster 2 participants presented

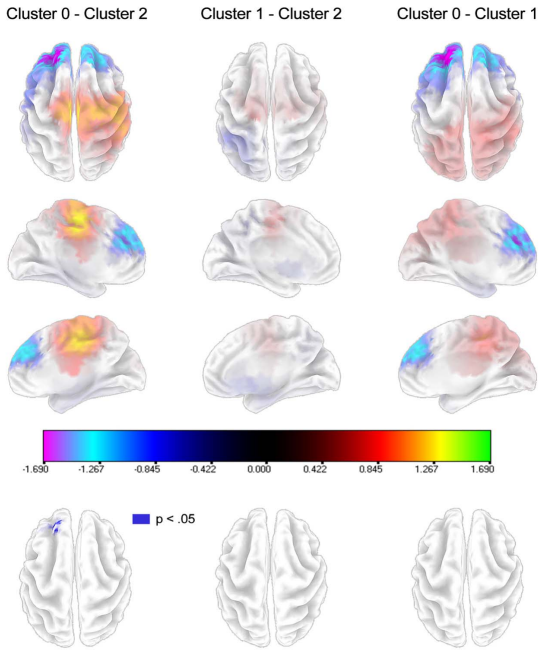

Fig. 5. Color-projected differences of sLORETA solutions (current density at cortical voxels) of EEG sources in the 4Hz-30Hz band, during the pre-stimulation resting minute, between each pair (columns) of Vojta-stimulation clusters obtained.

a significantly higher activity than cluster 0 and sham group from second minute's stimulation until even post-stimulation resting minute. Vojta-stimulation cluster 1 also presented a significantly higher activity than cluster 0 during all periods. However, cluster 0 did not showed significant differences with sham group or cluster 2. Regarding left forearm activity, cluster 2 showed a significantly higher activity than cluster 1 and sham group from second minute's stimulation during all time periods. From sixth minute's stimulation, cluster 2 activity was also significantly higher than cluster 0 activity. Cluster 0 also showed a significantly higher activity than sham group from sixth minute's stimulation. Concerning to right forearm, cluster 2 activity was significantly higher than cluster 0 activity and sham group from fourth minute's stimulation in all time intervals. Finally, right tibialis anterior's activity only showed significantly higher activity for cluster 2 with respect to sham group in minutes 3rd and 8th of the stimulation period.

Putting all these results together, we can summarize that cluster 2 is significantly more activated than other clusters and sham group in abdomen and arms from the beginning. By contrast, cluster 0 becomes significantly more activated than sham group in the left forearm just by the end of the stimulation period. Besides, cluster 1 is only more activated than cluster 0 in the abdomen, but not more than sham group. Notice, however, than cluster 1 have just 3 participants presenting a high variability in the muscle activity. Finally, although right tibialis anterior mean activation's values in cluster 2 are higher than in other clusters and sham group all over stimulation period, only significant differences were found with respect to sham group in just two intervals time, because of the high variability of this muscle's activity within this cluster (see Table I, section Tibialis anterior, fifth column).

TABLE II

AVERAGE (AND STANDARD DEVIATION) EMG RMS VALUES RELATIVE TO THE FIRST RESTING MINUTE FOR EACH VOJTA-STIMULATION CLUSTER FOUND AND THE SHAM GROUP, AND THE CORRESPONDING STATISTICAL ANALYSIS, DURING EVERY CONSECUTIVE MINUTE OF THE STIMULATION PERIOD AND THE RESTING MINUTE POST STIMULATION, FOR EACH OF THE FOUR MUSCLE GROUPS RECORDED

	Sham (N=20)	Vojta cluster 0 (N=8)	Vojta cluster 1 (N=3)	Vojta cluster 2 (N=9)	Statistics
Rectus abdominis					
1st min	1.019 (.345)$_{a,b}$	1.282 (1.950)$_{a}$	1.720 (.467)$_{b}$	1.693 (1.747)$_{b}$	H(3) = 10.825, p = .013
2nd min	1.026 (.369)$_{a,b}$	1.256 (1.870)$_{a}$	1.747 (.446)$_{b,c}$	2.278 (1.871)$_{c}$	H(3) = 14.161, p = .003
3rd min	1.009 (.351)$_{a,b}$	.993 (1.041)$_{a}$	1.644 (.453)$_{b,c}$	2.554 (1.937)$_{c}$	H(3) = 15.747, p = .001
4th min	1.010 (.353)$_{a,b}$	1.275 (1.727)$_{a}$	1.730 (.447)$_{b,c}$	2.895 (2.281)$_{c}$	H(3) = 16.701, p = .001
5th min	1.019 (.357)$_{a,b}$	.983 (.988)$_{a}$	1.633 (.441)$_{b,c}$	2.892 (1.671)$_{c}$	H(3) = 19.745, p < .0005
6th min	.948 (.391)$_{a,b}$	.919 (.824)$_{a}$	1.679 (.435)$_{b,c}$	3.006 (1.703)$_{c}$	H(3) = 17.867, p < .0005
7th min	1.004 (.366)$_{a}$	1.126 (1.274)$_{a}$	1.683 (.448)$_{a,b}$	3.545 (1.756)$_{b}$	H(3) = 18.224, p < .0005
8th min	1.015 (.378)$_{a,b}$	.901 (.752)$_{a}$	1.713 (.439)$_{b,c}$	3.721 (2.127)$_{c}$	H(3) = 18.631, p < .0005
Rest min	1.014 (.378)$_{a,b}$	.993 (1.071)$_{a}$	1.778 (.456)$_{b}$	2.625 (3.081)$_{c}$	H(3) = 13.616, p = .003
Left forearm					
1st min	.848 (.410)	.994 (.247)	.809 (.315)	1.699 (1.016)	H(3) = 5.840, p = .120
2nd min	.833 (.403)$_{a}$	1.150 (.418)$_{a,b}$	.811 (.320)$_{a}$	1.874 (1.084)$_{b}$	H(3) = 11.892, p = .008
3rd min	.869 (.517)$_{a}$	1.186 (.470)$_{a,b}$	.915 (.316)$_{a,b}$	2.267 (1.666)$_{b}$	H(3) = 12.025, p = .007
4th min	.831 (.439)$_{a}$	1.173 (.389)$_{a,b}$	.806 (.315)$_{a}$	2.365 (2.477)$_{b}$	H(3) = 12.045, p = .007
5th min	.953 (.875)$_{a}$	1.157 (.397)$_{a,b}$	.803 (.299)$_{a}$	2.437 (1.889)$_{b}$	H(3) = 12.014, p = .007
6th min	.735 (.425)$_{a}$	1.122 (.330)$_{b}$	.813 (.309)$_{a,b}$	2.760 (2.111)$_{c}$	H(3) = 18.672, p < .0005
7th min	.773 (.459)$_{a}$	1.442 (.947)$_{a,b}$	.837 (.326)$_{a}$	4.846 (6.063)$_{b}$	H(3) = 13.857, p = .003
8th min	.834 (.558)$_{a}$	1.751 (1.387)$_{b}$	.831 (.316)$_{a,b}$	3.619 (3.050)$_{c}$	H(3) = 13.422, p = .004
Rest min	.978 (.818)$_{a}$	2.625 (2.273)$_{b}$	.856 (.332)$_{a,b}$	3.000 (2.300)$_{b}$	H(3) = 9.806, p = .020
Right forearm					
1st min	1.652 (1.780)	.986 (.475)	1.054 (.054)	1.163 (.510)	H(3) = .760, p = .859
2nd min	1.679 (2.147)	1.538 (1.665)	1.009 (.047)	1.770 (1.299)	H(3) = 2.785, p = .426
3rd min	1.646 (2.292)	1.504 (1.480)	1.006 (.047)	3.112 (3.946)	H(3) = 6.868, p = .076
4th min	1.661 (2.777)$_{a}$	1.181 (.821) $_{a}$	1.053 (.067)$_{a,b}$	4.155 (4.607)$_{b}$	H(3) = 9.852, p = .020
5th min	1.910 (3.317)$_{a}$	1.116 (.598) $_{a}$	1.011 (.048)$_{a,b}$	4.300 (4.460)$_{b}$	H(3) = 13.962, p = .003
6th min	1.230 (1.643)$_{a}$	1.022 (.466) $_{a}$	1.013 (.050)$_{a}$	4.415 (4.091)$_{b}$	H(3) = 16.734, p = .001
7th min	1.330 (1.424)$_{a}$	1.019 (.472) $_{a}$	1.023 (.048)$_{a}$	4.947 (3.984)$_{b}$	H(3) = 14.191, p = .003
8th min	1.559 (2.218)$_{a}$	1.533 (1.878) $_{a}$	1.029 (.068)$_{a,b}$	7.130 (5.676)$_{b}$	H(3) = 13.085, p = .004
Rest min	1.248 (1.366)$_{a}$	2.596 (4.510) $_{a}$	1.201 (.155)$_{a,b}$	7.358 (11.940)$_{b}$	H(3) = 9.519, p = .023
Tibialis anterior					

TABLE II

(Continued.) AVERAGE (AND STANDARD DEVIATION) EMG RMS VALUES RELATIVE TO THE FIRST RESTING MINUTE FOR EACH VOJTA-STIMULATION CLUSTER FOUND AND THE SHAM GROUP, AND THE CORRESPONDING STATISTICAL ANALYSIS, DURING EVERY CONSECUTIVE MINUTE OF THE STIMULATION PERIOD AND THE RESTING MINUTE POST STIMULATION, FOR EACH OF THE FOUR MUSCLE GROUPS RECORDED

1st min	1.010 (.533)	1.077 (.309)	1.141 (.221)	2.130 (3.050)	H(3) = 1.420, p = .701
2nd min	.968 (.471)	1.208 (.594)	1.088 (.184)	2.691 (3.286)	H(3) = 4.173, p = .243
3rd min	.941 (.406)	1.133 (.515)	1.019 (.069)	3.191 (3.777)	H(3) = 7.436, p = .059
4th min	$.931\ (.379)_{a}$	$1.182\ (.572)_{a,b}$	$1.032\ (.029)_{a,b}$	$3.125\ (3.296)_{b}$	H(3) = 8.182, p = .042
5th min	1.121 (.823)	1.204 (.710)	1.054 (.105)	4.383 (4.169)	H(3) = 7.607, p = .055
6th min	1.037 (.758)	1.189 (.711)	1.130 (.067)	3.995 (3.896)	H(3) = 7.736, p = .052
7th min	1.172 (.716)	1.077 (.350)	1.072 (.053)	2.678 (2.502)	H(3) = 3.018, p = .389
8th min	.978 (.491)	1.185 (.679)	1.047 (.094)	8.717 (19.339)	H(3) = 6.934, p = .074
Rest min	$.867\ (.389)_{a}$	$3.864\ (8.212)_{a,b}$	$1.039\ (.128)_{a,b}$	$1.324\ (.424)_{b}$	H(3) = 7.969, p = .047

Values in the same row not sharing any subscript presented post-hoc statistically significant difference after Bonferroni's correction.

2) Comparison of Pre-Stimulation Resting EEG Between Vojta-Stimulation Clusters: Figure 5 shows differences in source current density during pre-stimulation resting minute between each pair of Vojta-stimulation, EMG-based clusters obtained (columns). Only statistically significant differences (bottom row) were found between clusters 0 and 2, in high alpha band, cluster 2 showing a higher activation than cluster 0 of the left superior frontal cortex, Brodmann areas (BA) 8 and 9. A lower, not significant difference, is also present in the medial and right counterparts of the mentioned areas. These same differences, also not significant, are also observable between cluster 0 and cluster 1 (right column). In addition, cluster 2 showed a lower activity than cluster 0 (left column) in the left medial motor and supplementary motor areas (M1 and SMA, BA4 and BA6, respectively), posterior cingulate areas (BA23 and BA31) and right motor and premotor areas (BA4 and BA6). Finally, differences between cluster 1 and cluster 2 (middle column) were negligible.

IV. DISCUSSION

Our findings highlight that specific stimulation area at intercostal space, on the mammillary line between 7th and 8th ribs according to Vojta therapy, activates innate muscle responses assessed by sEMG in healthy subjects, compared to a sham stimulation. In addition, participants in the V-STI-group were classified based on their muscle activation patterns (cluster 0, cluster 1 and cluster 2).

Sensory stimuli's influence on locomotor and gait activation patterns has been previously studied by some authors [1], [29]. Plantar pressure stimulation, as a supportive afference, has been seen to have an effect on increasing muscle activation. However, this activation does not have as much impact on necessary postural adjustments activation. Our results reflect an increase in abdominal muscles activation in clusters 0 and 2, which corresponds to postural regulation on which Vojta therapy is based. Other authors have evaluated muscle activity during Vojta therapy in healthy subjects. Perales and Fernández [10] studied the reflex rolling stimulating pectoral area, finding statistically significant results in common extensor of the fingers activation values measured with sEMG with respect to non-stimulation. These results are in line with results obtained in our study for cluster 1 and cluster 2 regarding wrist extensors activation. Muscular activity was also evaluated by Gajewska *et al.* [9] on healthy subjects on an attempt to explain Vojta therapy mechanism of action. A three days prior prone Vojta's posture stimulation was applied as long to achieve facilitation on EMG records day of deltoids and rectus femoral bilaterally. Their results confirmed upper and lower extremity muscles activity at about 60% of maximal contraction when Vojta stimulation was applied and showed mainly contralateral activation. Although different Vojta's posture was activated in our study, an equally contralateral activation at cluster 0 and cluster 2 on left wrist extensor was recorded.

A bilateral tibialis anterior contraction was EMG recorded along with others muscular groups during Vojta therapy on Laufens *et al.* [13] on multiple sclerosis patients, showing a changeability response depending on activation points chosen. In 1995 and 2004, Laufens [11], [14] used EMG record to assess muscular group contraction responses, among which bilateral wrist extensor and tibialis anterior were, once Vojta therapy was applied. Both researches showed a tibialis anterior positive activation record and retained on time as occurs in our study on cluster 1 and cluster 2 right tibialis anterior contraction preservation on last minute's rest.

Reflex rolling's theorical description from Vojta therapy profiled similar muscular activation regarding to global movement pattern on adults and newborns. Muscular activity onset is faster on newborns than adults, establishing the main difference according to Dr. Vojta. [17]. On reflex rolling pattern, extremities' distal segments (hands and feet) are prepared to support function, through forearms wrist extensors muscle activation and movement and feet dorsiflexion muscle contraction (tibialis anterior muscle) which justify EMG activation recorded on wrist extensors and tibialis anterior muscle [17]. An initial ventral movement exist on reflex rolling pattern, where an extension on pelvis is evoked due combined rectus abdominus muscle and bilaterally internal oblique abdominis

activation. Similar activation was recorded on this research on rectus abdominus muscle.

Ha and Sung [3] measured with an ultrasonic imaging system external oblique abdominal muscle's thicknesses, internal oblique abdominal muscle, transversus abdominis muscle, and rectus abdominis muscle, before and during stimulation in an experimental group using breast zone (Vojta stimulation), and in a control group using an arbitrary point. A significantly different before and during stimulation on transversus abdominis and external oblique was confirmed. However, no significant difference was found in rectus abdominis and internal oblique, either in control group for any of the muscles. In our study, rectus abdominis activation was observed for cluster 0 and cluster 2 from the beginning. However, this muscle did not experience any activation during the experiment on sham group as in Ha *et al.* [3]. These findings support that do not seem to be0 random on Vojta therapy's stimulation points.

A complex global motor movement existence seems to be derived from theoretical basis study and the present research's findings, which begins on decubitus dorsal and ends up on quadruped [5]. These theoretical patterns description was introduced on 1965, achieving a relation between stimuli and muscular activation produced from the clinical point of view [29], but in our best knowledge this is the first RCT that has used bilateral sEMG to assess muscles activity during to tactile stimuli on healthy subjects during reflex rolling position, compared to a sham stimulation during a wide time window of recording. Our results showed an EMG activation on rectus abdominus, wrist extensors and tibialis anterior, under different innate muscle patterns (cluster 0, cluster 1 and cluster 2) that might be relevant to improve rehabilitation process on neurological disorders, so future studies should corroborate our findings.

With respect to pre-stimulation resting EEG activity differences between the EMG-based clusters, only statistically significant result was found between clusters 0 and 2 in the left superior frontal gyrus (BA9). This same difference, although not significant, was also present between clusters 0 and 1. Given that cluster 0 grouped participants who did not activate any muscle until the end of the stimulation period, and that clusters 1 and 2 gathered participants who did activate some or all muscle groups from the beginning of the stimulation, this result points to the activation in the left superior BA9 as an hypothetical determining area for muscle activation by tactile reflex locomotor stimulation. This is congruent with the observation that the younger the subject the easier and higher muscle activation triggering by Vojta's tactile stimulation [19], given that the prefrontal cortex (including BA9) is not fully developed until adulthood [30]. This hypothesis is also supported by previous studies where this same area was found to be involved in response inhibition and impulsiveness [31], [32], and also in off-task thought (mind wandering) [33]. Given that participants were instructed to keep lied on their back and relaxed during pre-stimulation resting minute, mind wandering was highly likely to appear under those conditions, thus isolating participants from sensory stimuli [34], [35] and, consequently, hindering motor actions' inhibition triggered by stimulation. Therefore, our results point to a pre-intervention state rather than a physiological factor in afferent or efferent pathways for the lack of muscle activation during tactile reflex locomotor stimulation.

Notwithstanding, taking into account our findings, the results obtained open up new lines of research. Our work shows differences between the activation patterns on healthy subject, so it would be convenient to investigate what characteristics of the individual and the stimulus can influence the generation of the motor response within the automatic locomotor mechanisms of the human being. On the other hand, it would be necessary to study the relationship between sensory stimulation and activation of premotor brain areas. Further, our findings has been observed in healthy subjects, but it must be confirmed by further experimental research in subjects with neurological disorders (such as cerebral palsy, people with stroke or traumatic brain injury), and a sample-matched control group to avoid observer's bias with low capacity of active participation to corroborate our findings through our methodology used. It is important to know if Vojta therapy could be translated into functional changes due to tactile stimuli under the locomotor stimulation. The activation of innate locomotor patterns and the muscle contraction generated might present a relevant significance for patients with neurological disorders, as after sensory stimulation these muscles are more active and available for activation during function. Finally, as another clinical implication of our findings, resting cortical activity previous to stimulation in the left superior prefrontal area (BA9) distinguished participants in clusters presenting muscle activity in limbs from the ones presenting activity only in abdomen. This result could be also helpful to individual Vojta's therapy prescription, but also points to a possible neuromodulation procedure prior to the intervention to maximize the muscle response of the tactile stimulation. Future studies should corroborate this finding in subjects with neurological disorders to a better prescription of Vojta therapy.

Our research presents several limitations. First, muscle activity was delimited to four electrodes. Future studies should investigate muscle activation patterns in other localizations. In addition, we only recorded a specific time window during 8 min of stimulation and 1 minute resting period with EMG, so we cannot determine or estimate longer muscle pattern effects. Second, even though it was always the same therapist who applied the technique, the intensity should had been measured using an Algometer to maintain a consistent level of stimulation. Besides, this study was carried out with a relatively small sample of healthy subjects, especially for cross-cluster comparisons. For this reason, many differences are close to significance, specifically comparisons with cluster 1 (notice that it only included 3 participants). Furthermore, this implies that, despite consistent differences observed, our results could not be extrapolated to patients with neurological disorders or other conditions.

V. Conclusion

A specific sensorial and proprioceptive stimulation at intercostal space, on the mammillary line between 7th and 8th ribs according to Vojta therapy activates innate muscle responses assessed by sEMG in healthy subjects, compared to a sham

stimulation. Participants in the V-STI-group were classified based on their muscle activation patterns. Cluster 0 participants who only activated rectus abdominis during stimulation period from the beginning in a constant way. Cluster 1 participants who barely activated any muscle group until seventh minute of stimulation, when only limbs became activated, keeping an increasing activation during the post-stimulation resting minute. Cluster 2 participants who increasingly activated all muscle groups from the beginning over the stimulation period, suffering from a decreasing of activation during the post-stimulation resting minute. This characterization could be helpful for determinate tactile stimulation's duration to produce the desired effect in an individual basis.

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