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NEUROMUSCULAR TAPING (NMT) AND NEUROPLASTICITY: NMT Reduces Pain, Edema and Influences Proprioceptive Cognitive Strategies During Total Knee Arthroplasty Rehabilitation.

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Abstract

The objective of this study is to propose new integrative strategies to enhance fast-track recovery after TKA surgery. Twenty patients underwent total knee replacement arthroplasty surgery (TKA) were randomly grouped into an experimental rehabilitation group using physical therapy and application of a standardized decompression NeuroMuscular Taping (NMT) protocol on the operated knee (n° patients: 11) and a control group using physical therapy and an application of a standardized compression sham taping application on the operated knee (n° patients: 9). Each patient was asked to perform active mobilization on the operated knee in a sitting position of (3 sets of 5 repetitions) while wearing a BCI MindWave device (NeuroSky®). The aim of the study was to assess whether the NMT application induces changes in frontal cortex neuronal activity, where cognitive and attentional processes are elaborated. In addition to assess the efficacy of NMT for treating edema and pain secondary to a total knee replacement surgery; patient evaluation items included: lower limb size, range of motion (ROM) and pain (Numerical Rating Scale NRS).

Results: Over the treatment period we discovered that the experimental group had a statistically significant reduction of edema ($p<0,01$), statistically significant reduction of pain ($p<0,01$) than the control group. Conversely, there were no significant differences regarding ROM. We recorded a statistically significant improvement in cognitive performance and activation of frontal cortex in patients who carried out attentional feedback exercises with decompressive NMT on their operated knee ($p<0.01$). Evaluation of EEG wave amplitude showed a greater cognitive activation for the experimental group's patients: total average amplitudes of alpha, beta and gamma waves were higher and statistically significant ($p<0.05$) in patients with decompressive NMT. While total average frequencies of alpha, beta and gamma waves did increase all together they did not show a significant variation across all three.

Conclusion: The objective of this study was to investigate treatment options for improving post surgical rehabilitation creating faster track protocols for an ever increasing joint prosthetic population. This study has underlined significantly improved reduction of edema and pain in a rehabilitation context and allowed us to hypothesize the effects generated by a decompressive tape application (NMT) upon circuits delegated to the cognitive-attentional processing of stimuli.

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Keywords: *Total knee arthroplasty TKA; Brain Computer Interface; NeuroMuscular Taping; postoperative rehabilitation; Physical therapy; Physiotherapy.*

Abbreviations: NMT: NeuroMuscular Taping; TKA: Total knee arthroplasty; BCI: Brain Computer Interface (BCI)

Introduction

Total knee replacement arthroplasty (TKA) is considered an effective intervention for the treatment of chronic knee pain and disability (Wylde *et al*. 2007). Total knee arthroplasty is known for being one of the most successful surgeries that medicine offers today and is performed in increasing numbers every year all over the world (Culliford *et al*. 2015). With the aging population and mounting obesity epidemic, rates of TKA have increased dramatically over the last two decades such that TKA now constitutes one of the most common and costly medical procedures in the US (Burns et asl. 2015) and in Europe. According to the Agency for Healthcare Research and Quality, more than 600.000 TKA surgeries are performed every year alone in the US and is expected that more than 4% of all people over fifty will undergo a TKA. As outlined by Bandholm in Rehabilitation strategies for optimisation of functional recovery after major joint replacement there is a major need to improve functional recovery after TKA. According to their study, PROMs (patient reported outcomes) report that generally speaking results after surgery are positive while performance based functioning show limitations and postoperative activity is very low (Bandholm T et al. 2018). Post operative chronic pain is reported in 5 to 20% of patients (Beswick et al. 2012) which strongly influences active rehabilitation and outcomes.

Complications associated with TKA have been significantly reduced over the last years with improved surgical techniques and reduced hospital recovery. Remaining complications may occur during surgery or delayed after surgery when the patient has already begun physical therapy or physical exercise. Delayed complications most commonly include: deep vein thrombosis 1.5% (Januel JM et al. 2012), pulmonary embolism 0.7% (Cho SE et al. 2015), arthroplasty implant dislocation 0.5% (Sharkey PF et al. 1992) site infections 1.8% (Garvin KL et al 2011) and surgical edema. Pain and edema reduction overcome consequent difficulties in the execution of the first rehabilitation exercises after surgery (Zeng WN et al. 2014), which encourage faster recovery improving hospitalization cost/benefit ratio (Nekoroski T et al. 2013). Edema management commonly includes manual lymphatic drainage, exercises and compression therapy through multilayered bandage however, this kind of care can have significant economic consequences in terms of material cost (compression bandage and frequent changes) and time costs covering from 45 minutes to 1 hour for a complete manual lymph drainage treatment (Smykla A, et al. 2013). Over recent years there have been new advances in the study of therapeutic approaches to lymphedema (Warren AG et al. 2007). Specific NeuroMuscular taping treatment is one of the new approaches that could be a valuable support for temporary post-surgical lymphatic system insufficiency enhancing faster conduction of lympha in the vessels notwithstanding reduced patient mobility (Blow D. 2010).

Postoperative rehabilitation difficulties experienced by patients, noted in our physical therapy care unit, include: severe joint stiffness (in flexion and/or extension), edema and/or hematoma on the operated lower limb, acute pain (often intense making even a gentle passive mobilization difficult) and chronic pain reducing the patients collaboration with self exercise and mobility. Our unit often deals with swelling and pain which increases stiffness of the operated knee slowing down and delaying the rehabilitation and exercise process.

Outlined in a recent systematic review, many modalities following total knee arthroplasty are used but optimal rehabilitation strategies remains to be determined. The authors identified over 11,000 studies over the past 5 years but only 70 met inclusion and exclusion criteria while only 20 remained for analysis (Iciar M. Dávila Castrodad et al. 2019). None of these studies dealt with a taping application or with cognitive strategies to enhance rehabilitation outcomes.

Over the last few years, NMT technique has shown effective in the rehabilitative treatment of neurological (Camerota F et al. 2014, Costantino C et al. 2012) and orthopedic (Kalron A, et al. 2013) conditions. In another paper, NMT application plays a role in pain reduction in systemic sclerosis patients with Raynaud's phenomenon and it has been hypothesized that NMT application may induce increases in micro vascular circulation (Parisi, C et al. 2017).

Even though "popular" in Italy, Europe, Asia and America, central and peripheral mechanisms which are the basis for "improvements" using NMT methodology have not yet been identified with certainty. The aim of this study is to investigate the effects generated by a standardized decompressive NMT application in TKA not only on swelling, pain and range of movement but also on cognitive attentional processes. Our surgical/rehabilitation hospital, not having Functional Magnetic Resonance Imaging (f-MRI) available, we decided to base our study on a Brain Computer Interface (BCI) device, easily available, cost effective and operator friendly.

Materials and Methods

Patients

The study was performed over 12 months; all patients were operated on, attended physical therapy and data was collected at Quadrante (COQ) Orthopedic Center, Omegna, Italy. Inclusion criteria covered: patients that underwent TKA by the same orthopedic surgeon took part in the study, over 60 years old and having partial weight bearing on the operated leg 24 hours after surgery; right-handed dominance as different brain dominance is to be considered a variable in EEG data analysis (Klimesch W et al. 2008). Exclusion criteria covered the following: important comorbidity using the American Society of Anesthesiology evaluation (with a score equaling 3, 4 or 5); revision knee arthroplasty; surgical site infection (SSI); deep vein thrombosis (DVT before the surgery or after surgery during their hospital stay); fever (>38°C); delay in the patient's verticalization due to orthopedic or internal medical contraindications; skin disease; active cancer or metastases; cognitive impairment and communication/comprehension difficulties enabling inappropriate patient compliance with cognitive performance testing.

Participants were randomly assigned to two groups by odd/even day: the physiotherapist coordinator assigns each patient, without knowing him/her, to the therapist who will execute the physical treatment; the physiotherapist coordinator has allocated patients who underwent the surgery in an odd day to the experimental group and patients who underwent the surgery in an even day to the control group.

Treatment

2 groups were selected; Experimental Group comprising physical therapy and a standardized NMT application; Control Group comprising physical therapy and a standardized sham tape application. Patients from both groups received a routine standard physical therapy treatment following TKA surgery comprising passive and active mobilization of the lower limb on a treatment table; lower limb muscle strengthening exercises on a treatment table; mobilization and muscle strengthening exercises in standing position; continuous passive mobilization; hurdles and stairs; training in using crutches in conjunction with active mobilization exercises with the operated knee while sitting (3 sets of 5 repetitions). The routine treatment was performed every day, 2 times daily (a total of 1 hour per session), 5 times weekly for two weeks. Patients wore the MindWave device during the treatment session. The experimental group received the following NMT lymphatic drainage application: a standard protocol was created using 1cm wide and 35-45cm long strips of elastic paperbacked kinesiology standard tape; the knee was placed in a flexed position (what was possible respecting pain threshold) while the patient maintained a sitting position; the skin over the anterior aspect of the thigh was stretched towards the groin and the tape strips were positioned following the skin longitudinal elasticity lines spacing one centimeter from each other; the tape strips were applied without tension (NMT decompressive 0% tension mode) over the anterior knee joint not covering the surgical dressing (it was requested that the size of the surgical dressing be reduced to minimum necessary); the strips were also applied over the posterior aspect of the knee (knee extended) with the patient in a standing or lateral prone position (Figure 1); the tape was applied during second, fourth, seventh and eleventh day after surgery; the tape was applied and remained until the following application; tape was applied by the same therapist. However in the control group we applied the same tape strips but following a vertical direction stretching the tape (sham compressive tape). We decided to stretch the 35cm long tape by 4cm giving a theoretical 25% tension on the tape (based on a tape which has 40% elasticity). Stretching a tape is often reported in research papers. Stretching an elastic tape is extremely subjective relating to the innate elasticity of that particular brand of tape, relating to the width of the tape (wider tape has more resistance than a 1cm, and less, narrow tape) and the capacity from a self-regulated learning and application perspective of the operator.

Figure 1: *NMT lymphatic drainage tape strip application.*

In our study we used a 0% tension application of tape which objectively separates the operator as an influential variable in the tape application and hence evaluation process.

Evaluation

We chose MindWave as it allows to record the electroencephalographic activity (EEG) of the person who is wearing it, showing, in real time, the tracing of each EEG wave and providing immediate feedback of the cognitive performance. The BCI MindWave device is a computing technology direct communication instrument between the CNS and an external device and its scope is to record EEG power spectrums (alpha, beta and gamma waves) and has been evaluated as reliable and applicable in experimentation and research (Ekandem JI. Et al. 2012). Low cost and non-invasive neural interfaces devices are frequently used for research purposes due to their simplicity. MindWave (NeuroSky®) uses two electrodes: the active one is placed on the skin of the forehead of the subject (so as to record the electrical activity resulting from cognitive processes elaborated primarily from the frontal lobes), while the indifferent electrode is worn by a clip applied to the external ear (Figure 2).

Figure 2: *MindWave by NeuroSky®.*

The BCI device made it possible to compare the two groups of patients following TKA (experimental and control group) using the cognitive-attentional performance and the intensity and frequency values of EEG waves as parameters. The patient's cognitive performance score was recorded at time t0 (first physiotherapy session, 24 hours after surgery), and at time t1 (complete discharge of patient, fifteenth day after surgery). Evaluation of intensity and frequency of each EEG wave comprised only the averages of all the recordings (taking only the best clarity of 3 tests signals daily).

Clinical Evaluation. To assess the volume of lower limb, we used a multi-point measuring system as suggested in literature (Ebert JR et al. 2013). We measured the circumference at metatarsus, ankle, half-calf, mid-patella and half-thigh, of the operated limb at time t0 and t1. Passive knee Range of Motion (ROM) in flexion and extension at time t0 and t1 was also assessed. Pain was assessed using the Numerical Rating Scale (NRS) at time t0 and t1.

Physiotherapist (A) was responsible for the physical therapy treatment, NMT application, exercises with MindWave and registering data collection, while a second physiotherapist (B), blinded to patient group selection, coded the database and processed the data. The statistical data analysis was performed by using descriptive (mean and variance) and inferential (Chi-squared test) statistics methods. Intensity and frequency values of each EEG wave, recorded with MindWave, were also analyzed with the open software OpenVibe.

Results

In total, 23 individuals were qualified to participate in the treatment, but only 20 completed the study protocol (1 patient reported a DVT at 6th day after surgery, 2 patients were not right-handed): after randomization 11 patients were included in the NMT group and 9 patients in the control group (Figure 3).

The 2 groups have shown statistically homogeneous demographic and clinical characteristics (Figure 4) using Wilcoxon test for small samples.

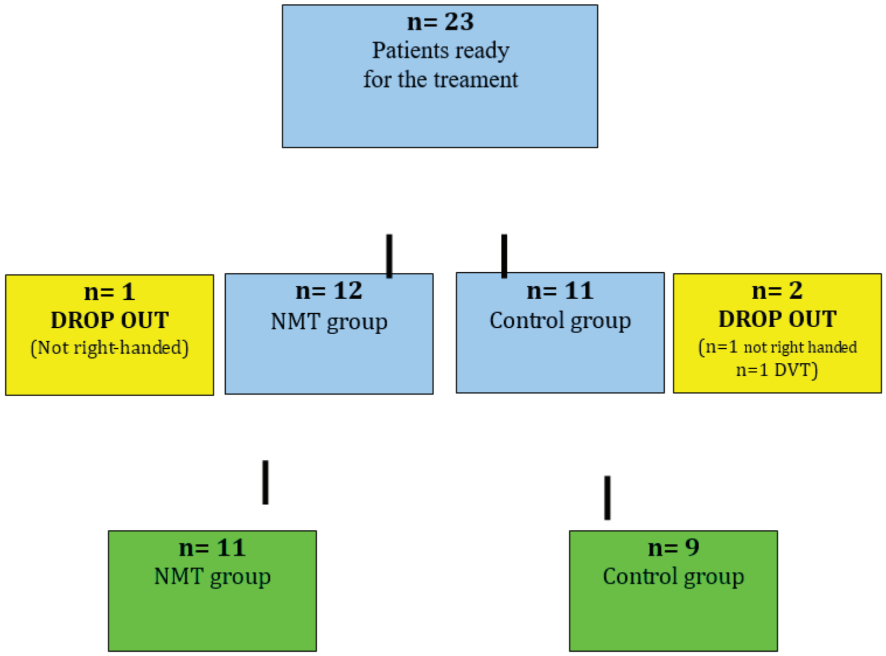

Figure 3: *Participant flow chart.*

	NMT Group	Control Group
Men	3	3
Women	8	6
Age (average)	66,17	66,37
Left TKA	6	5
Right TKA	5	4

Figure 4: *Patient data at time t0.*

Cognitive performance with attentional feedback was substantially comparable between the two groups (Figure 5) at time t0 (57.4 for the NMT group and 57.9 for the sham-tape group). At time t1 the average score of cognitive performance was 80.4 in the experimental group compared to 71.4 for the control group (Figure 5, 6A and 6B). Our study observed a statistically significant improvement in cognitive performance in patients who carried out attentional feedback exercises with decompressive NMT on their operated knee (p<0.01).

	NMT Group	Control Group	NMT Group	Control Group	p-value
	t0	t0	t1	t1	
Cognitive Performance Score (average)	57,4	57,9	80,4	71,4	p < 0,01
Frequency ALFA waves (average - cycles/seconds)	-	-	3,8	3,4	p > 0,05
Frequency BETA waves	-	-	20,9	19,5	p > 0,05
Frequency GAMMA waves	-	-	57,9	55,1	p > 0,05
Amplitude ALFA waves (average - milliVolt)	-	-	28,8	24,6	p < 0,05
Amplitude BETA waves	-	-	18,1	15,9	p < 0,05
Amplitude GAMMA waves	-	-	1,4	0,9	p < 0,05
ROM Flexion (average °)	44,1	42,5	94,2	83,5	p > 0,05

ROM Extension	9,6	9,2	0,8	2,9	p > 0,05
NRS (average)	7,92	7,75	2,92	5,1	p < 0,01
Total Lower limb circumference (average)	289,26	285,67	264,5	273,3	p < 0,05

Figure 5: *Patient data at time t0 and t1.*

Evaluation of amplitude of EEG waves showed a greater cognitive activation for the experimental group's patients (Figure 5, 6A and 6B) at discharge: total average amplitudes of alpha, beta and gamma waves were higher in patients with decompressive NMT statistically significant (p<0.05). However total average frequencies of alpha, beta and gamma waves did not show a significant variation. We observed statistically significant reduction (p<0,05) of swelling and edema (Figure 5) in patients undergoing NMT.

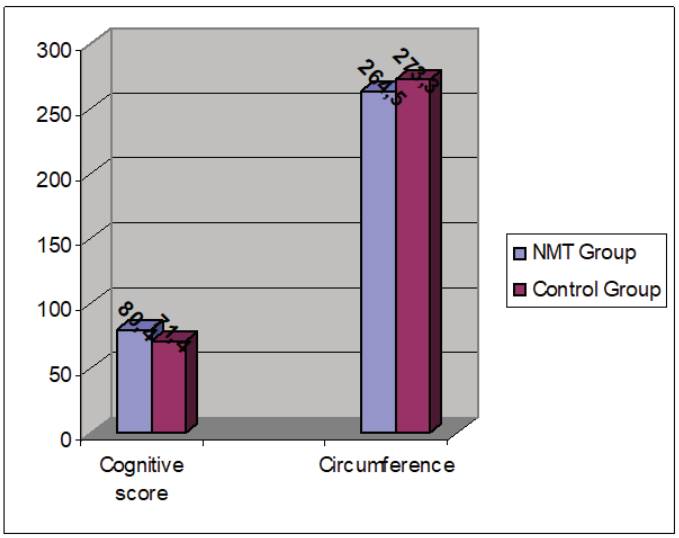

Figure 6A: *Patient data at time t1 (*Cognitive score better if higher, Circumference better if lower)*

Regarding ROM (passive knee flexion and extension) the values recorded in the two groups (Figure 5) showed a more favorable result in the NMT group but not statistically significant. Comparing pain, the NRS score evidenced a statistically significant pain reduction (p<0,01) in the NMT group.

Discussion

We have to emphasize that there is a general shortfall of well-conducted, randomized, well documented controlled studies of specific taping application methodologies. Many studies in taping show a general lack of scientific methodology (Kalron A, et al. 2013) often using non standardized application techniques. While using levels of stretch applied to the tape which is based on the capacity of a self regulated learning and application perspective. Articles generally place taping methods under the same umbrella – "they are more or less the same thing" resulting in non productive scientific evidence about taping techniques in general, be they positive (Aguilar-Ferrándiz ME et al. 2014, Tsai H-J et al. 2009) or indifferent (Smykla A, et al. 2013, Kalron A, et al. 2013). Our objective was to use a specific standardized taping application methodology based on a repeatable process using a non-stretched taping technique.

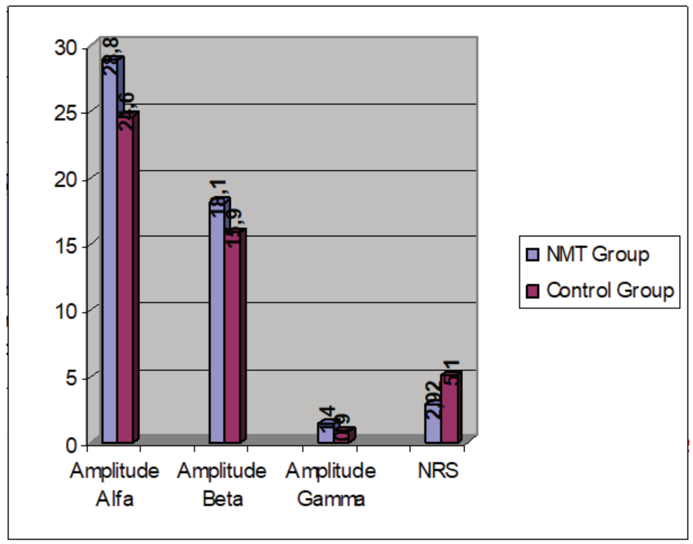

Figure 6B: *Patient data at time t1.*

Figure 6B: *Patient data at time t1 (*Amplitude better if higher, NRS better if lower)*

Our study showed a statistically significant reduction of pain in patients treated with NMT. Recent meta-analysis (Kalron A, et al. 2013) also showed a moderate level of evidence in support of a better pain management in patients treated with taping techniques. Pain reduction is considered a primary objective in fast track recovery encouraging patient compliance during therapy and self-guided exercises.

Edema control is also a primary objective during rehabilitation influencing outcome which can be supported by several studies analyzing taping effectiveness in lymphedema limb's volumetric reduction (Smykla A, et al. 2013, Tsai H-J et al. 2009). In our opinion, contrasting some authors it is difficult to attribute reduction in limb circumference as a placebo effect and related to perceived reduction of pain. Mechanisms that may explain the greater and statistically significant reduction in lower limb circumference are probably to be found at a peripheral level: during body/limb movement, tape strip application using the decompression method causes skin folds or skin undulations. This continual "wave non wave" action modifies underlying pressure facilitating lymphatic drainage and blood vascularization (Blow D. 2013). After TKA surgery the patient's leg is swollen and stiff, indicative of increased pressure and compression between skin, connective tissue, fascia and muscles producing a restriction on the free movement of lymphatic fluid. Resulting compression creates pressure on skin pain receptors which respond by communicating distress signals to the brain and influencing cognitive performance.

ROM changes were not evident between the groups studied and we envisage that range of mobility improvement is more determined by the type of orthopedic surgery and not by pain, edema or proprioceptive factors.

An important aim of this study was to evaluate the effects that NMT treatment may have on the frontal cortex in assisting the patient to create cognitive strategies during the post-surgical phase re-establishing joint motion and muscle strength. There is an almost total lack of possible comparisons regarding taping and cognitive performance. Several authors (Camerota F et al. 2014, Chisotti L. et al. 2011) have suggested mechanisms of action explaining NMT functioning. It is thought that NMT application using a decompression model may induce a neuronal modulation mechanism able to produce an "inferential activity on neurons of the posterior horns of the spinal cord (Blow D. 2012)". Possible neuromodulation induced by non-compressive NMT taping techniques would be able to depolarize the neurons of the posterior horns of the spinal cord preventing the discharge of pain impulses. At the base of this assumption there is "gate theory" (GCT) proposed by Melzack and Wall (Melzack R et al. 1965) in the Sixties; this theory applies not only to pain sensations, but also to other exteroceptive and proprioceptive afferences, likewise involved in NMT application as the tape is able to provoke a non compressive stimulation of nervous receptors (exteroceptors and proprioceptors).

No hypothesis, instead, has been clearly advanced about the possible effect of NMT at the cortical level, regardless of the physiological activation of areas responsible for sensory stimulus elaboration. From these areas somatosensory information concerning the entire body surface are sent to the primary motor cortex for the elaboration of a possible motor response. Moreover, somatosensory areas are connected to the posterior parietal cortex (Brodmann areas 5 and 7) involved in the construction of the body image (Kandel ER et al. 2001) and integration of information from multiple areas. Finally, they also share information with visual areas of the occipital cortex, encephalic trunk, thalamus and frontal areas involved in attention and cognition processes.

We can say that in our study, cognitive performance has increased in both groups, although starting from almost identical initial scores: patients learn through visual feedback exercises gradually placing more attention to the operated leg and are actively concentrated on how to perform the exercise correctly (Ekandem et al. 2012). The statistically significant better cognitive performance of patients treated with decompressive NMT could have several explanations. Physiological activation of the areas responsible for processing sensory stimulation indicate a faster and more efficient elaboration of motor response by the motor cortex, in response to accurate peripherial somato-sensitive information. Increased activity of the somato-sensitive areas due to continuous undulation of the tape strips adhered to the skin over the surgical site modifying underlying pressure may improve body image construction, which is always more or less severely damaged after a neurological or orthopedic motor lesion. Post surgery, cortical areas are anatomically or physiologically involved in the loss of function and tend to go towards atrophy, due to the competitiveness mechanisms typical of neuronal plasticity (Merzenich MM et al. 1983, 1987).

Moreover, patients treated with decompressive tape have verbally reported a feeling of "lightness" to the operated knee and a greater freedom of movement. This has also been observed, although concerning neuro-dysfunction, from Camerota (Camerota F et al. 2014) and Constantino (Costantino C et al. 2012) and may explain the greater cognitive-central ease for these subjects in "paying attention" to their lower limb.

Regarding the statistically significant greater amplitude of the alpha, beta and gamma waves in the experimental decompressive NMT group. Gamma waves are involved in complex tasks that require interconnection of different brain areas. Larger amplitudes in EEG waves correspond to a greater cortical activation (especially if the proposed task is cognitively relevant) while it is not always true that higher frequencies are synonymous with increased activation (Klimesch W ET AL. 2008). Klimesch also suggests to compare the frequency increase of a single wave with what happens to the frequencies of other waves, the greater significance is determined when the frequency increases for more than a single wave simultaneously. Our research suggest also a greater cognitive significance in that the frequency was greater for all the three types of waves investigated, during the simple exercise proposed (Figure 6).

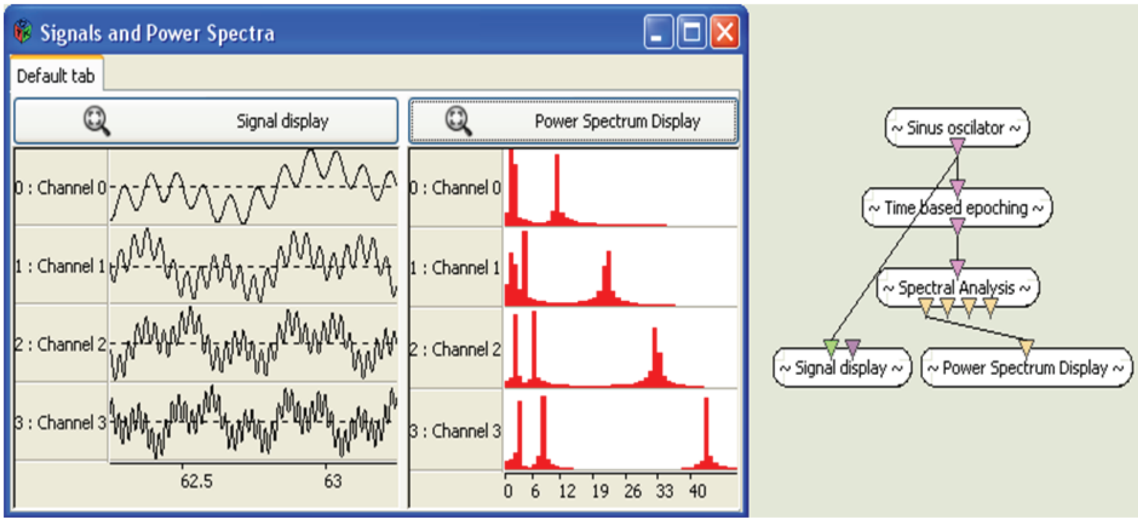

Figure 6: *Example of comparison between amplitudes (left) and frequencies (right) of different waves types, analyzed with free software OpenVibe.*

Conclusions

The objective of this study was to investigate treatment options for improving post surgical rehabilitation creating faster track protocols for an ever increasing joint prosthetic population. This study has underlined significantly improved reduction of edema and pain in a rehabilitation context and allowed us to hypothesize the effects generated by a decompressive tape application (NMT) upon circuits and areas delegated to the cognitive-attentional processing of stimuli. We have explicitly described how a repeated taping protocol intentionally applied using a distinct decompression modality (NMT) generates effects different from the application of a compressive stretched tape that does not follow lines of skin elasticity. NMT technique seems to have a significant impact on the cortex, assisting to make it easier for the patient to "pay attention" to his limb and to help building a better body self image while facilitating freedom of movement, which according to Maturana and Varela, indispensable for cognitively "know and understand the world" (Varela FG et al. 1974).

This is the first study covering rehabilitation of post surgery patients using a NMT protocolled treatment and evaluation of their cognitive performance by a BCI device. We would advise using a larger cohort of patients together with clinical examinations through f-MRI in the future. There are no other comparable studies at this time. A follow up over 4 weeks would be advised to ascertain the full recovery possibilities of faster track rehabilitation of TKA.

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