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CICLO XXVI

A CHALLENGE OF APPLIED KINESIOLOGY (AK) THEORIES: NEUROPHYSIOLOGIC EVENTS ON UPPER LIMBS MUSCLES RELATED TO THE STIMULATION OF ACUPOINTS LOCATED ON THE FOOT

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1. SUMMARY

1.1 Perspective

Increased life expectancy and a challenging environment coincide with an also increased prevalence of chronic diseases affecting extensively both quality of life and health care’s costs in western society. Modification of the motor system in a variety of these ailments has emerged as a topic of growing importance. Accordingly, muscle’s activity and neurologically driven muscle’s activation have become a focal point of both clinical and research interests and it is hypothesized that complementary medical methods like acupuncture and manual therapies, may have a role in promoting those profound and dynamic medical progresses required to manage effectively such challenges (3). Many of these methods lack of scientific evidence to date. Among these, Applied Kinesiology (AK) is diffused worldwide and gather professionals in the field of medicine, chiropractice, dentistry, psicology, clinical nutrition and ostheopaty. AK theories relate manual muscle testing to an expanded view of the significance of muscle tone. Hence a rigorous description of the neurophysiologic phenomena in a controlled experimental setting investigation may, whether not, support the validity of the arguments of those advocating the adoption of methods like outlined above. Various somatosensory stimuli have demonstrated to affect the excitability of motor pathways (1). The effect of acupuncture in its specificity has been previously investigated by means of changes in motor evoked potentials and brain plasticity through trans-cranial magnetic stimulation (TMS) (7). The effects related to acupoints’ activation are apparently specific and different from those evoked by a similar somatosensory stimuli on a “non-acupoint”. In Applied Kinesiology’s procedures the activation of specific acupoints (meridian’s sedation point) is reported to gain a relative reduction of muscle tone as perceived manually according to specific muscle-meridian association (8,9,11). These variations seem to be different from the effects of fatigue or task repetition (5) on muscle function and EMG tracings.

1.2 Background

Applied Kinesiology is the discipline developed by chiropractor George Goodheart Jr. He expanded manual muscle testing significance to evaluate functionally the nervous system beside the standard strength grading (11). Since then a multitude of different "kinesiologies" have been developed even among lay people. The Austrian medical association recognize PAK (professional applied kinesiology) as advanced specialization. The theoretical model proposed within the AK community relates the motor performance to facilitation vs inhibition of the alpha-motorneuron spinal pools and thus labels muscles as conditionally facilitated muscles (eg normoreactive) versus conditionally inhibited (hyporeactive) muscles. AK examiners perceive the muscle test reaction as a "locking" of the joint which is moved by the tested muscle in the case of a normally facilitated muscle. This perception is of rather functional quality than of absolute strength (2). The AK muscle testing and interpretation differs from the graded muscle test interpretation. The distinctive feature of this motor response is that can changes instantaneously according to a number of somatosensory stimuli. Many past research designs failed at distinguishing weak vs strong muscles via EMG tracings and total strength parameters whereas the few that focused on "dynamic force" (a parameter that relates to stiffness more than strength) apparently succeeded in such a distinction (6,10). The only classical neurophysiologic study on AK phenomena has been an investigation of somato-sensory evoked potentials (SSEP) during muscle testing. In my investigations I had the chance to access to a tool that detects subtle changes in the motor-neuron pool's excitability: this methodology is the "*tran-scranial magnetic stimulation*" (TCMS). After the initials experiences in normal humans and neurological patients, the non-invasive method of TCMS has found applications to study motor cortex’s involvement during various motor tasks (1). Specifically postural performances and voluntary manipulation of objects by the hand were analyzed. Originally introduced to investigate non-invasively the corticospinal tract, spinal roots, and peripheral nerves in humans, the applications now range from therapy of neuropsychiatric disorders to rehabilitation and intraoperative monitoring. Single-pulse TMS and its variations like paired-pulse TMS, repetitive TMS, integration with structural and functional MRI, and neuronavigation allow a very accurate mapping of the motor output to a given body district. This tool has allowed important advancement in the understanding of motor control and functional connectivity thus is considered very valuable to investigate the motor output of voluntarily activated skeletal muscles. TMS studies allowed in the past to identify changes of motor excitability and cortical plasticity following acupuncture not related to nociception.

1.3 Aim of the study

The original idea was to investigate and quantify parameters in a typical AK muscle testing setting. The assumption was that a variation in any of the parameters of the tested subject would reflect an “objective” change in the condition of the subject itself. This was considered the key to understand the peculiarity of the “weakness” not related to reduction of global strenght expressed by the tested muscle as described by AK practitioners. Due to intrinsic difficulties in analysing and quantifing all the variables of manual muscle testing related events, we focused on a specific aspect related to AK theories. The analysis of muscle parameters of a subject tested by AK techniques is indeed biased by the presence of the operator. This is particularly critical for this discipline where the operator-subject interaction plays a recognized strong role that is not fully understood to date. In a study reporting on AK muscle testing it was described how only practitioners with about 5 years of experience where able to characterize consistently the peculiarity of the “weak muscle” phenomenon supported by objective data (force vs displacement parameter). In order to exclude the operator’s bias conscious whether not, we focused on a protocol that addresses a specific paradygm: this protocol investigates possible effects on upper limb’s muscles motorneurons excitability following the digital activation of the stomach and spleen meridian sedation’s point. There is no expected effect on upper limbs muscles following a sensory stimulation of spleen and stomach meridian’s sedation point as they are located on the foot (fig.1). Conversely, in most cases, according to AK paradigm the activation of the meridian’s sedation point should gain the following effects:

- The meridian’s associated muscle should gain a variable but univocal reduction of its excitability
- No effect should be recorded from the muscles non meridian specifically related (both the muscle related to the second muscle-meridian pair and the one non specifically associated to any known meridian).

A different scenario (no changes in the overall excitability, no specificity according to muscle-meridian association as well as increased excitability) would question the validity of the AK paradigm with respect to muscle-meridian association and effects on muscle tone related to acupuncture activation.

2. INTRODUCTION

2.1 A perspective on health and disease today

Modern medicine represents an excellent response to many sanitary challenges. Most of this success pertain to acute situations like trauma, infections and stroke related events. In these specific fields the perception of the amazing advancement related to technology and pharmaceuticals implementation is prominent and self evident to both insiders and lay people. Average life span also increased extensively in western society. Unfortunately, on the other side, there is an increasing awareness that since the beginning at least of the last century, possibly coinciding with massive industrialization and technicization, humankind has been challenged by new plagues. These are likely to be part of a global, complex and profound crisis affecting multidimesional aspects of our life: the quality of our health and our planet related health, the quality of our society, our economy and politics. In the field of medicine, heart related diseases, diabetes, cancer, autoimmune and degenerative diseases affecting the nervous or motor system have exploded like bombs of a silent insidious war. Not only the adult population's health is mined but also the youngest apparently are at risk of allergy or atopy related problems or even more worrysome neurodevelopmental disturbance like autism and related spectrum disorders like never before in the hystory. Many individuals, health care providers, and health care systems are integrating various practices with origins outside of mainstream medicine into treatment and health promotion. The integrative trend is growing among providers and health care systems. Driving factors include marketing of integrative care by health care providers to consumers who perceive benefits to health or well-being, and emerging evidence that some of the perceived benefits are real or meaningful even if scientific evidence is limited. In many instances, a lack of reliable data makes it difficult for people to make informed decisions about using integrative health care.

2.2 western and eastern approaches to medicine and a possible link within them

Our present approach to health and disease arises from a mechanistic and reductionist approach. In biology, Cartesio's perspective of living organisms as machines built on separate pieces provides the dominant conceptual framework. Reducing and understanding to minimum components and their interactions is still the basis of scientific research today to which medical doctors refer for treatment guidelines' development. There is increasing awareness of the failure of such a model in managing the sanitary emergencies outlined above. A parallel increasing interest in the understanding of a living organism's integrated activities and its relationship with the environment is responsible for a progressive shift of paradygm. For an increasing number of professionals, the optimal treatment is no longer directed to a specific disease (real whether not) but to a whole deemed human being inclusive of its psyco, social and biological dimension. Eastern world does not suffer the limitations of the biomedical approach. Ayurveda and chinese traditional medicine, the two major medical systems diffused in eastern countries are holistic since their inception. They both consider "ecologically" the relationship of the living unit and the environment whether internal or external. Acupuncture is possibly the most ancient medical practice worldwide diffused today. It is a complete system of diagnosis and therapy that uses needle, digital pressure and other forms of activation of specific points all over the body defined as acupoints. The gap between traditional chinese medicine and western medicine goes beyond the practice as it reflects huge distances in the way of thinking the world, nature and the relationship with mankind. It is not intention of this work to go deeper in the understanding of traditional chinese medicine. For our purpose we shall consider the theory of acupoints. Acupoints are spread all over body surface and follow specific channels in number of twelve pairs the principals and others. These channels, deemed meridians, convey the flowing of an “energy” (Qi) that is responsible for the subject’s referred condition of health or disease. In spite of outstanding and wide clinical indications, western description of human physiology does not consider the existence of meridians to date. The notion of a systemic circulation is limited to body fluids, blood and lymph and the idea of an impalpable highly regulated energy flow it’s somehow wierd and “resisted” at the academic level. We should probably remind that even blood circulation has been a concept hard to be accepted when William Harvey MD proposed it back few centuries ago. Now it is universally recognized and considered self evident. Besides its reknown clinical effects a few significant neurophysiology studies are showing a link between the meridian system acupoints and the central nervous system. Specifically changes in the excitability of muscles and plasticity at the cortical level was clearly demonstrated. A link between the motor system and the meridian system is part of the discoveries reported by G. Goodheart Jr. that are integral part of the AK framework. Among the various conditional stimuli capable of changing a given muscle performance as previously described there is also the activation of meridian acupoints. In Dr. Goodhearth’s original observations there is an association between muscles and meridian and specifically every meridian is associated to one ore more skeletal muscles. A further refinement in describing the kind of interaction is the prediction of a reduction in muscle tone gained by activation of the sedation point of the related meridian and the specular increase with the activation of the tonification point. Along a given meridian there are in fact specific acupoints whose effects upon stimulation are characteristically reproducible.

2.3 Applied Kinesiology (AK) background:

2.31 how did it start

AK as a (possible) scientific revolution started with the recognition of an anomaly by George Goodheart Jr. DC. Nature somehow violated the paradigm-induced expectations that leads the practice of normal science the day he observed a serratus anterior muscle causing a painful winged scapula going back to normal strenght following a robust massage of its origin-insertion. Following this initial observation he started to look for a common pattern in other patients. It is affirmed that "*the theoretical scientist must search for the most fundamental level of description possible, a description of behavior that is ubiquitous to all of the elements that make up the aggregate described*" (19). Goodheart theorized that what he percieved as muscle weakness was the result of the net facilitative and inhibitory gain of the alpha-motorneurons distributing to the tested muscle. He called his observations Applied Kinesiology. With such a foundation in place, the anomalies could be adequately explained and incorporated, such that the anomalous become the expected for him and the group of people he shared these informations and trained; muscle weakness defined in the terms outlined above became a tool to evaluate the integrity of the body's systems and apparatus, like endocrine balances and meridian system equilibrium to name a few. Today Applied Kinesiology is a diagnostic-therapeutic method worldwide diffused among medical doctors, chiropractors, dentists, ostheopaths and more although lacking of scientific evidence. It is presumed that AK expands the standard clinical exam and anamnesis collection through the adoption of the manual muscle test derived from Kendall and Kendall's descriptions and further developed by G. Goodheart Jr. According to the standards and operative procedures approved by the Board of Standards of the ICAK (International College of Applied Kinesiology) AK practitioners claim that they can differentiate between muscles conditionally facilitated or conversely inhibited (conventionally defined "weak"). Thus in relation to known anatomy and neurophysiology suppositions about the condition of organs and systems within the body are possible. Unfortunately since its inception in the sixties with the founder George Goodeheart Jr. DC from Detroit there has been no uniformity on the procedure to perform accurately and reproducibly this modified manual muscle test. Not to mention the wide variety of “kinesiologies” besides AK generated by various means especially in lay circles. This has originated a lot of misconceptions even inside the AK community itself, scepticism and doubts on the validity of a procedure that according to its users has proved outstanding clinical efficacy in so many patients. A few studies pretend to have highlighted the objectivity of the feel of an experienced AK examiner for a given muscle reputed “strong” or “weak” accordingly to AK conventions. It should be pointed out that a “strong” muscle is not necessarily a muscle that produces more power than a “weak” one: these labels are conventional terms that express other qualities of the motor performance that differ from global strength. Nevertheless the neurophysiological phenomena associated to this condition have not been extensively described yet. The identification and description of the mechanisms responsible for the possible changes in motor performance of a tested muscle is challenged in part with the TMS protocol described in this work. The accepted model that explains the perceived “weakness” or normal performance of a tested muscle according to AK standards refers to the integrative state of the spinal alpha-motorneuron as a result of the summation of facilitating and inhibiting afferent stimuli.

2.32 AK muscle testing: practice and theory

AK muscle testing reproduce the procedure described in Kendall and Kendall’s original textbook with a single main distinction. In AK muscle testing the operator does not evaluate the overall force expressed by the tested muscle. It is reported that whether starting from the operator or the tested subject the muscles contractions lead to an isometric equilibrium of the two opposing forces. Then the operator performs an extra effort (approximately 10% more) so that what is analyzed is the reaction, the “adaptive force” exerted in this specific condition. Weakness is defined not only like the inhability of the tested subject to maintain the original position but also to clues of recruitment of sinergistic muscles to meet the extra demand on the muscle. AK is intended as a system that evaluates structural, chemical and mental aspects of health using manual muscle testing with other standard methods of diagnosis. The doctor using AK finds a muscle that is unbalanced and then attempts to determine why that muscle is not functioning properly. The doctor works out the treatment that will best balance the patient's muscles. Treatments may involve specific joint manipulation or mobilization, various myofascial therapies, cranial techniques, meridian and acupuncture skills, clinical nutrition, dietary management, counselling skills, evaluating environmental irritants and various reflex procedures. AK uses the “Triad of Health” concept in terms of chemical, mental and structural factors that balance the major health categories. The Triad of Health is interactive and all sides must be evaluated for the underlying cause of a problem. A health problem on one side of the triad can affect the other sides. For example, a chemical imbalance can cause mental symptoms. AK enables the doctor to evaluate the triad's balance and direct therapy toward the imbalanced side or sides. AK skills are developed and approved by the International College of Applied Kinesiology Board of Standards. These skills are refined from many disciplines including Chiropractic, Osteopathy, Medicine, Dentistry, Acupuncture, Biochemistry, Psychology, Homeopathy, and Naturopathy etc. Members of these professions share knowledge through the publications and conferences of the International College of Applied Kinesiology (ICAK).

2.33 Association between muscle function and visceral, structural and energy function

A same spinal nerve innervates skeletal muscles, viscera and skin of a same body district. Thus this common innervation is responsible for phenomena like the viscero-somatic convergence of stimuli and the interaction between visceroception and motor activity whether at the visceral or somatic level. This interlink between visceral activity, muscles and skin rooted in anatomy and physiology notions is seldom understood and investigated in the clinical practice. In chinese medicine most meridians' names equals organs and viscera described in standard anatomy. There is a liver, a bladder, a spleen meridian and so on. Meridians' distribution is not limited to the anatomical organ indeed. For instance the stomach meridian starts on the face underneath the eyeball on the zygomathic arch and ends up down on the foot's second finger's commissure. The stomach's function in this view is wider than our idea of a bag that starts dissolving food and digestion. An alteration of its function is not limited to the stomach area and to digestive symptoms. According to AK there is an association between meridians and one ore more skeletal muscles. This association is used to evaluate the balance in the system through muscle testing and apparently confirm the link between the meridian system and the motor system.

2.34 AK muscle testing over-extrapolating data risk

In the actual shared opinion among professionals using AK manual muscle testing the test is a challenge on the patients' system through interpretation of the patient's muscle contraction. The general idea is that the examiner detects an anomaly whether normality in the subject's muscle contraction. The examiner's muscle contraction as a source of bias is considered but overlooked according to the author. It is recommended that the examiner avoid preconception in performing the test , but chances that the examiner’s own motor function changes according to the task also independently from his or her will is not considered. It is analogous to the change in muscle tone and specifically in gamma tuning in hand grip muscles in case we look for our keys in a pocket or plan to grab a glass of water on the table. That is the nature of this tuning in the motor system of the examiner is conditioning the result of the interaction between his own and the tested subject’s muscles. Perceived differences in the test outcome could be related to both changes in the examiner and tested subject and the direction in which these changes happen is arbitrary according to the physiology of motor control. The outcome of a muscle test should be considered than as a two variable equation. If the founder of this discipline was right when saying: “*you can find only what you know*” it means that the nature of the information we consider revealed by muscle testing a subject is already present somehow in the examiner’s “archives”. This is not a trivial detail as AK muscle testing in this perspective may allow the practitioner to access a personal established knowledge at different consciousness levels. This can be seen as a big limitation in respect of actual accepted concept in AK circles but on the contrary, if correct, could unleash the true potential of the technique.

3. MATERIALS AND METHODS

3.1 Biases on the recruitment of a proper representative population due to considerations on actual health's definition

Many people today suffer from invalidating conditions that find no place in the diagnostic tool-box of a standard medical approach. After a clinical examination and a battery of imaging or laboratory exams these same people are often dismissed with vague diagnosis and therapeutic indications. These people belong to the "healthy" population when considering their official status for cohort epidemiological studies. They don't feel good because in pain or not functioning properly in society or because in mental distress but they are considered healthy. In a definition of health that goes beyond the absence of disease and considers soundness in terms of work and leisure capability, fulfilling eating, sleeping and sexual activity, these people have to be considered sick. In this case, they don't belong any longer to the group considered healthy, as they are not, even if have no diagnostic label yet or possibly are going to be considered sick in the nearby future when their complaints might cause anatomical detectable changes. This fact may account for the difficulties in finding a common pattern in a group of subjects that is apparently healthy but is actually characterized by a variety of different functional alterations. As soon as we have a tool that detect these alterations, the subject is no longer respecting the "healthy category" inclusive criteria and should be matched with opportune "unhealthy" subjects. In order to overcome these difficulties, a series of different experimental settings have been elaborated but as we cannot properly manage the variables of both the tested subject and of the examiner, we finally tested a paradigm where the examiner is ruled out.

3.2 Experimental designs to objectivize the “weak muscle” phenomenon

A couple of experimental designs were specifically planned to identify possible muscle weakness patterns as detected by muscle testing in a controlled experimental setting. The collected data were inconclusive and are not reported but strengthened the idea in the author that there is a fundamental ideomotor component affecting the subjective feel for a given AK muscle test result. Specifically, in a first series we performed an EMG analysis of the double blind tester and tested subject following a vibratory challenge. We recorded from the operator’s pectoralis major and triceps muscles and from the subject’s rectus femoris the EMG activity during muscle testing in baseline conditions and following the application of a vibrating tuning fork (3 different frequencies of vibration for few seconds) above the patellar tendon. The experiment was performed under two different conditions: in one case the operator was blind to the stimulus applied, in the other not. When the operator was not blind with respect to the stimulus applied he could clearly describe which stimulus was indifferent whether not. Interestingly this capability was no better than chance when he was blinded. In a different experiment the subject performed an isokinetic test of the quadriceps at three different speed in standard condition and following the application of a strong magnet over the associated meridian’s sedation point. We recorded the EMG tracing and the pressures from the load-cell. We tested two subject that apparently displayed an opposite trend in the test condition: one subject apparently increased the overall power and the other conversely apparently reduced its performance. These observations drove to the research of an investigative model where the variables due to an operator performing a muscle test were excluded.

3.3 Final experimental setting: TMS study of upper limb muscles during digital pressure activation of acupoints located on the foot

3.3.1 Aim of the study

According to AK theories there is a relationship between skeletal muscles and meridians and each meridian as one or more muscles associated (see Table 1). Over time some of these association have changed or have to be considered provisionally.

Lung	Deltorids, serratus anticus, levatur scapula, coracobrachialis, flexor pollicis lungus* and brevis*
Large intestine	Hamstrings, tensor fascia lata, quadratus lomborum
spleen	Lower and middle trapezius, latissimus dorsi, triceps brachii, anconeus
stomach	Byceps brachii, brachialis, pectoralis major clavicular division, brachioradialis, supinator, pronator teres, pronator quadratus, opponens pollicus, adductor pollicis, opponens digiti minimi, sternocleidomastoideus, neck extensors, medial neck flexors
Heart	subscapularis
Small intestine	Quadriceps, abdominals, flexor digiti minimi brevis
bladder	Tibialis anterior, peroneus tertius, peroneus longus and brevis, extensor allucis longus and brevis, sacrospinalis
kidney	Psoas, iliacus, upper trapezius
Circulation sex	Sartorius, gracilis, adductors, gluteus maximus, medius and minimus, piriformis, gastrocnemius, soleus, tibialis posterior, flexor allucis brevis and longus

Triple heater	Infraspinatus, teres minor, occasionally Sartorius and gracilis
Gallbladder	popliteus
Liver	Pectoralis major sternal division
Conception vessel	supraspinatus
Governing vessel	Teres major

Table 1. "muscle-meridian" association as reported in Walther's "Synopsis 2nd edition". *identifies provisional associations.

This association predicts muscle changes of tonus as detected through manual muscle testing when specific points of the associated meridian are properly activated for a limited time followed by return to normal status within seconds from removal of the stimulus. Specifically the activation of the meridian's "sedation point" should gain a reduction of tonus exclusively in the associated muscle. An exception is the governor vessel meridian whose effect is generalized on all muscles. Our protocol was aimed at identifying changes in excitability of the cortico-spinal system (CSS) on three upper limb muscles following the activation of two different meridian's sedation point. The selected muscles were the biceps brachii (BB), the flexor carpi radialis (FCR) and the first dorsal interosseous (FDI). While BB muscle is associated to the stomach meridian, FDI and FCR muscles have no official association to meridians but as part of the distal upper limb muscles possibly could be associated to the stomach meridian. The aim of the present study was to investigate the possible effect of a non-painful activation of these acupoints and its eventual specificity in terms of modulation of the response measured from the selected muscles.

3.3.2 Subjects

Twelve healthy adult volunteers (5 female and 7 male, ages 21–27 years, mean age 22.2 years), with no history of head trauma or neurological disease, participated in the study. All participant gave written informed consent. Experimental procedures were conducted in accordance with the ethical guidelines set forth by the Helsinki declaration. All subjects were Europeans and right-handed, as measured by the Edinburgh handedness inventory.

3.33 Stimulation and recording

Before the experimental session, a standard neurological examination including investigation of sensitivity (touch and vibration), motor function and deep tendon reflex responses was carried out aimed at identifying possible abnormal tonus condition, e.g. spasticity or flaccidity, and or loss of pallesthesia. Subjects presenting abnormal findings were rejected. After that, subjects lay comfortably in a supine position, with their head immobilized by a polystyrene-bead vacuum splint, moulded on the neck and posterior part of the head (Fig. 1).

Fig. 1. The experimental setup.

Acupoints’ activation was performed by the main investigator. The skin above the BB, FCR and FDI muscles was prepared for proper electrodes positioning. A cuff with references for reproducibility of handle location was positioned on the skull centered midway between nasion and asterion and between the ears. According to the aim of the present study, two distinct stimulation acupoints were chosen. These sites were ‘*st45*’ and ‘*sp5*’. Both are well-known classical sedation points, as described in traditional Chinese medicine, located on the lower limb. In particular, st45 is placed on the second toe laterally to the nail, while sp5 is placed in the fovea located antero-inferiorly to the medial malleolus (Fig. 2). The selected points belong respectively to the stomach and spleen meridian. Both these points are seldom used therapeutically. Theoretically their stimulation is indicated in case of the presence of an excess of energy in the related meridian as their function is to lower the meridian’s related energy level. In clinical practice the adoption of different strategies and principles whose detailed description goes beyond the scope of this work are adopted. According to described associations, st45 should be relevant for the response of the byceps brachii, while sp5 should be indifferent. Before starting the experimental session, both tested points were marked with a pen according to anatomic landmarks to ensure accurate stimulation.

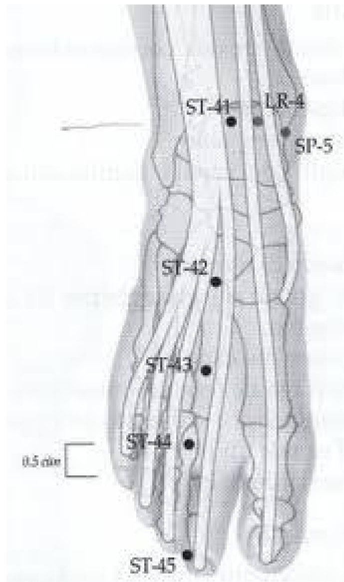


Fig. 2. Spleen and stomach's meridian's sedation points.

Surface electromyograms (EMG) were simultaneously recorded from the selected muscles, ipsilateral to the acupuncture sites, by means of silver chloride electrodes in bipolar configuration (interdetection spacing of about 2 cm). Signals were amplified 1000x in the bandwidth 0.2 Hz to 1 kHz. EMG was digitally converted (PCI-MIO-16E-4, National Instruments, Austin, TX, USA) and sampled at 4 kHz on a personal computer. MEP waveforms were logged and analysed off-line by means of custom-written Labview software (National Instruments). Single-pulse TMS was applied to the motor cortex, contra laterally to the EMG recorded muscles, with a Magstim Super Rapid magnetic stimulator (Mag-1450-00, Magstim Co. Ltd, Whitland, UK), using a figure-of-eight double coil (Ø 70 mm) (Fig. 1 and Fig.3).

Fig. 3. The TMS.

The coil was oriented at 45° oblique to the sagittal plane to induce a current flow perpendicular to the central sulcus estimated alignment. The scalp site at which MEPs were elicited in BB muscle at the lowest stimulus strength was determined. Once the optimal scalp site was found, the coil was securely fixed in place by means of an appropriate mechanical device. The response threshold was defined as the stimulus intensity at which 5/10 consecutive single stimuli at the optimal site evoked a MEP of at least 100 μV in the relaxed muscle. Stimulus intensity during the entire stimulation paradigm was set at 1.2 times the BB motor threshold. The mean stimulation intensity across subjects was 68% of the maximum output of the magnetic stimulator. This stimulation intensity at the optimal scalp site for ADM also allowed to evoke MEPs in FCR and FDI muscles in almost all the experimental sessions, although these MEPs generally occurred at a considerably lower amplitude. However, to ensure that excitability changes following AK procedure were measured against a reliable baseline for each muscle, FDI and FCR data were included in the analysis only if their MEPs had an amplitude greater than 100 μV in 10/12 stimuli delivered during the control phase of the experimental protocol, i.e. before the manipulation of sedation points. This acceptance criterion was always fulfilled by FCR recordings; by contrast, FDI data were rejected in 3/12 experimental sessions. Furthermore, attention was paid that all TMS sequences were performed with subjects keeping their muscles in a condition of mild isotonic contraction. To this end, during TMS phases the participant held in his right hand a weight and maintained the forearm slightly raised. MEP amplitude was defined as the peak-to-peak amplitude of the mean response obtained by averaging 12 consecutive TMS trials, delivered with an interstimulus interval of 5 seconds while the subject kept in the hand a 445 g weight with an angle of about 120° between arm and forearm. This sequence of test stimuli (STS) had an overall duration of 1 min and was employed as our standard procedure to measure cortical/spinal excitability to TMS at baseline (control conditions) and during the AK manipulation.

3.34 Experimental protocol

The experimental protocol was designed to identify possible effects induced by a slight activation of the selected meridian's sedation points (deemed AK manipulation) versus a baseline condition with no stimulation at all. This situation resembles to testing for normo-reactivity of a muscle according to AK conventions. In most cases, there is a temporary (few seconds) muscle weakening following a corresponding few seconds procedure of activation of the muscle associated meridian's sedation point. To this end, we divided the experimental session into five phases (Fig. 4). In the 'control phase', MEP amplitude at baseline were measured by two STS applied at 3-min intervals. Following a resting period of 3 min, the 'AK1' phase began, which consisted in a light digital activation of one sedation point. Changes in muscle excitability to TMS were assessed by means of one STS starting 10 s after the beginning of the manipulation. A new 'control phase' followed and after 3 min of rest, TMS stimulation was applied again by delivering one STS. Three minutes after the last TMS pulse the 'AK2' phase began, consisting in the manipulation of the other selected sedation point. Again, an STS, which started 10 s after AK2 phase beginning, matched the sedation point's manipulation. The entire stimulation protocol therefore had a total duration of about 21 min. The sedation points selected for the AK1 and AK2 phases were randomized among subjects.

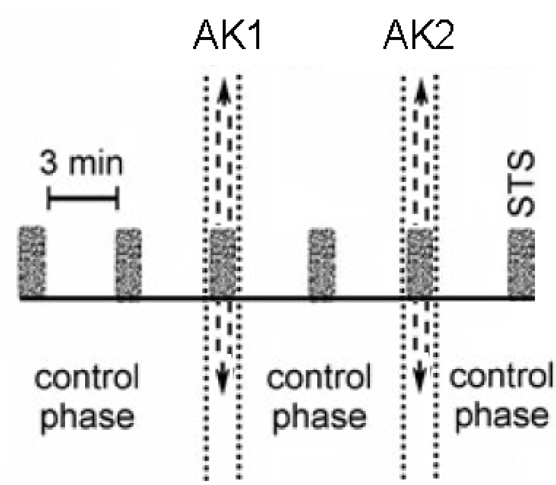


Fig. 4. Above the experimental paradigm showing control and manipulation phases. Pointed lines indicate the AK interval, and the time period in which the sedation point was manipulated (arrows). The rectangles labeled STS represent the 1-min sequences of test stimuli, in which 12 consecutive TMS trials were delivered with an interstimulus interval of 5 s.

In 4a red lines at the bottom show the periods of activation of the 2 sedation points (AK1 and AK2). In the middle the 1-min sequences of test stimuli, in which 12 consecutive TMS trials were delivered with an interstimulus interval of 5 s. At picture's top yellow lines following the arrows represent the beginning and duration of the TMS procedure with rest phases in between. In 4b a single phase timeline is displayed with the 12 stimuli along the stimulation (red) or rest (yellow) phase.

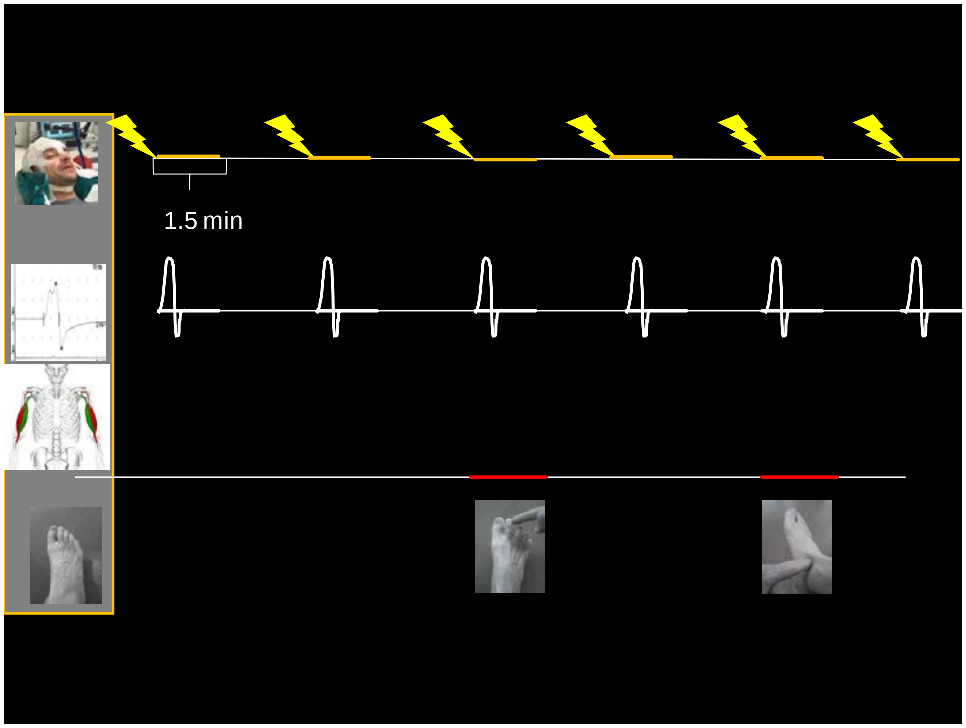


Fig 4a

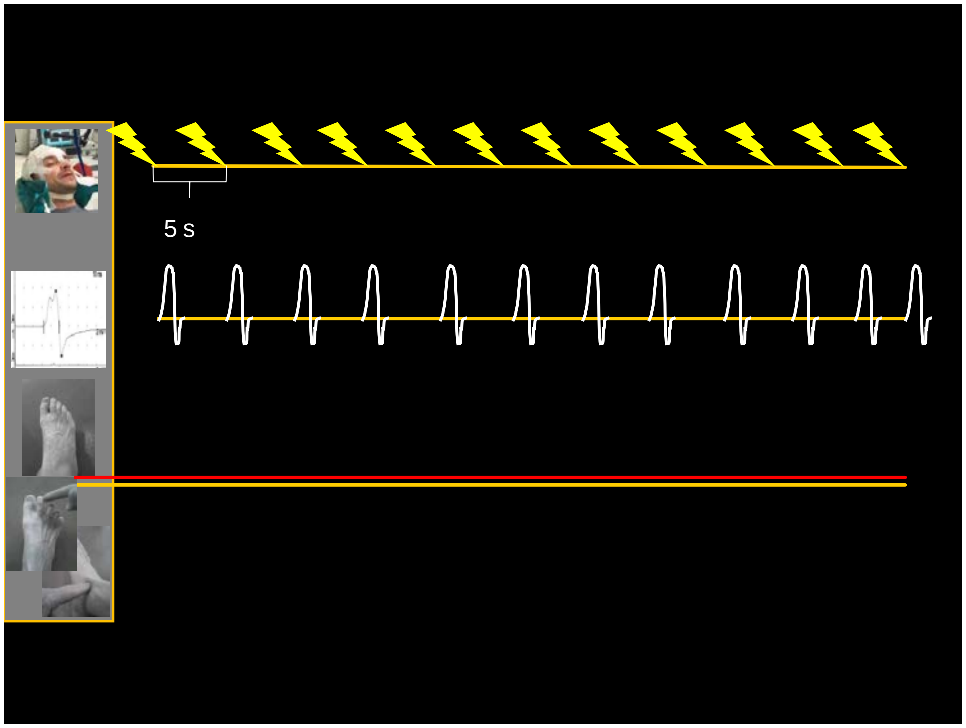


Fig 4b

3.35 Statistical analysis

MEP amplitudes are continuous variants characterized by a very large variability among subjects in the mean and standard deviation of their statistical distribution. As an example of this variability, Figure 5 shows the averaged motor responses recorded from the FDI muscle during a 'control phase' in two representative participants. Row mean data (expressed in millivolts) collected across the experimental phases, separately for each muscle, for each subjects are shown in the 'Appendix'.

Therefore, data transformation was required in order to compare data from different subjects and apply the opportune statistical significance tests. For each subject, raw data were transformed as follows:

$$X = x/\mu_b$$

where "*X*" is the standardized measure, "*x*" is the original experimental value and μ_b is the mean of the values recorded at the first two control phases of the experimental protocol. This transformation was applied for each subjects separately for each recorded muscle. In this way a direct data comparison among subjects was allowed.

In order to test the AK manipulation's phase statistical significance on MEP's amplitude, a paired t-Test was performed on the average MEP amplitudes computed for each subject for the AK manipulation phase and for the control phase foregoing it. Moreover, to test the statistical significance of the the MEPs variations during the digital activation of the selected acupoints we performed a Two-Way ANOVA for repeated measurements on the average MEP amplitudes computed for each subject for a given AK condition. The factors were 'AK phase' (st45 vs. sp5) and 'TMS block'. The 'block' factor was split in 3 equal subunits, each consisting of 4 consecutive TMS pulses. Each subunit was compared to the other and to the baseline condition data to investigate a time-specific effect of the AK procedure on the corticospinal excitability. When required, post-hoc analyses were run within the block condition. Analyses were performed separately for each recorded muscle.

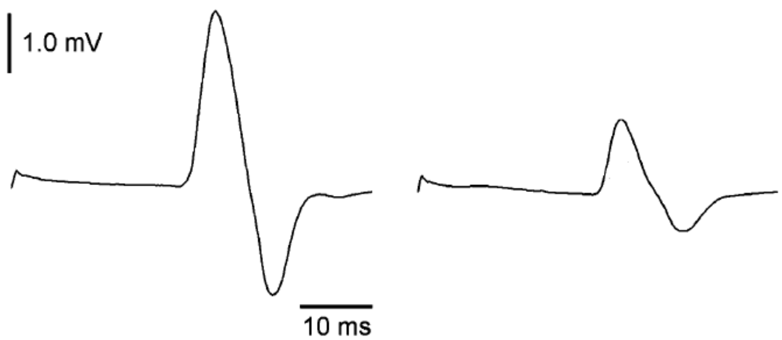


Fig. 5. Average EMG recordings obtained at the first 'control phase' from FDI muscle in two representative participants showing the variability of MEP amplitude among subjects. Each trace is the average of 12 responses obtained in a STS. Trace onsets correspond to the time of delivery of the TMS pulse.

4. RESULTS

In each recorded muscle, the comparison (t-tests) between the control and the AK procedure did not reach a statistical significance (Fig. 6). This result applies for both manipulation of sp5 or st45 sedation acupoints ($P > 0.22$).

On the other hand, the Two-Way ANOVA revealed that the activation through light digital pressure of the acupoint located on the tip of the foot's second finger (st45) induced a statistically significant change in the average MEP amplitudes recorded from the BB muscle ($P = 0.01$). Specifically, mean MEP amplitude obtained at the end of sp5's manipulation is larger than the one recorded after st45's manipulation (Fig. 7).

Moreover, the analysis conducted on the MEPs recorded from the FCR muscle, showed a statistically significant interaction between the tested variables ($P = 0.042$). A One-Way ANOVA conducted on the average MEPs recorded during sp5's manipulation showed that the "block" factor was not statistically significant (Fig. 8, lefts panel). On the contrary, the ANOVA conducted on the average MEPs relative to st45's manipulation revealed that the "block" factor was significantly different ($P = 0.032$). Post-hoc analyses (t-tests) showed that the mean MEP amplitude obtained during the first sub-phase (i.e., the averaged values after the first 4 TMS pulses of STS delivered during st45's manipulation) was significantly larger ($P = 0.008$) compared to the last one (i.e., the averaged values after the last 4 TMS pulses of STS delivered during the manipulation) (Fig. 8, right panel).

Finally, in FDI muscle no statistical effects were found.

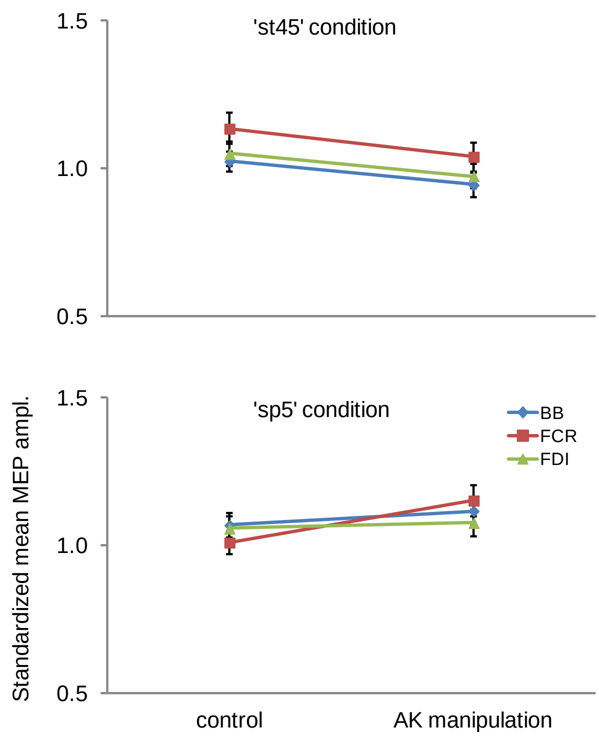


Fig. 6. Amplitude modulation of MEPs in BB, FCR and FDI muscles before ('control') and after the "test" phase (AK manipulation). The upper panel shows the average values across subjects for the experiments in which st45 was activated, while the lower panel refers to data recorded when sp5 was activated. No significant changes occurred, in both conditions, between control and AK manipulation phases. Error bars represent the mean's standard error.

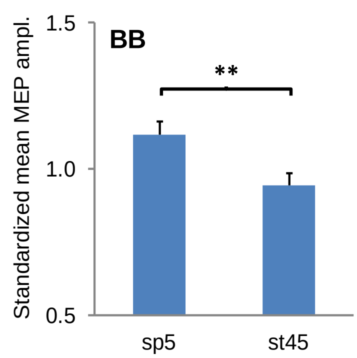


Fig. 7. In BB muscle, average MEP amplitude after activation of sp5 and st45 respectively (asterisks denote a statistical significance, $P < 0.05$). Error bars represent the mean's standard error.

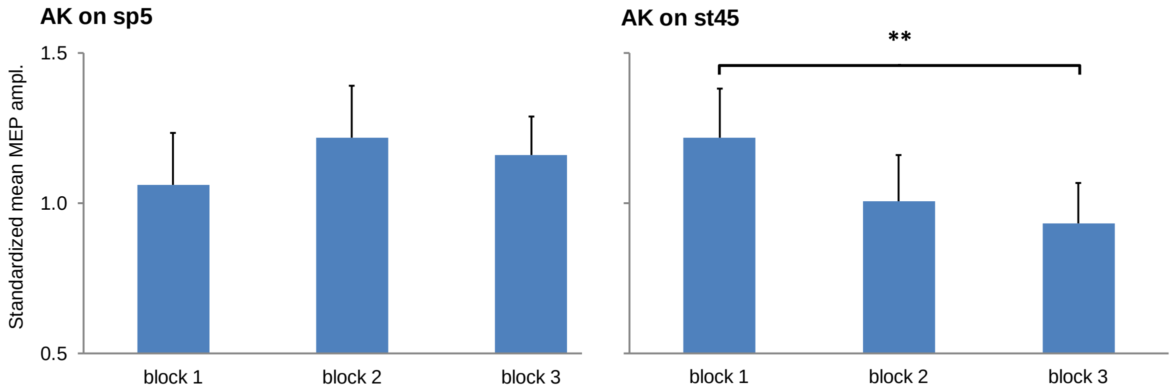


Fig. 8. Average MEP amplitude recorded in FCR muscle across the three sequence of 4 TMS pulses ('block 1', 'block 2', 'block 3') delivered during the AK procedure on st45 (left panel) and sp45 (right panel). Asterisks denote a statistical significance, P < 0.05. Error bars represent the mean's standard error.

5. DISCUSSION

5.1 Physiology of motor control

In the years the hypothesis related to the nervous system functioning and motor control referred to models of increasing complexity. Complexity, integration and plasticity emerge from known anatomy and circuitry within the nervous system. The motorneuron is supplied by many afferents carrying sensory, proprioceptive, visceral and behavioral information that influence its activity. At the same time the motorneuron activates muscle fibers belonging to different muscles and to a different extent. Analogously the peripheral spindle cell seems to play a role in fine tuning of motor functions related to different tasks. It was described how the muscle proprioceptive information may be modulated by the behavioural context and how this modulation is directly performed by the CNS via a muscles spindles sensitivity change through a selective control of static and or dynamic Y fusimotor neurons. Hence the Y-gain is under central control and can be modulated independently on the basis of the required motor task. These evidences on complexity and elevate inputs integration modulating motor control disrupt the simplistic model of a cortical compartimentation relative to motor areas and monosynaptic control. Modern notions related to the anatomy and physiology of the nervous system can either apparently support or conversely deny the theories advanced by applied kinesiology practitioners. It was suggested that the fusimotor drive is largely dependent on the subject’s internal attitude towards particular tasks and contexts and this can affect the required neutrality of the AK operator.

5.2 Understanding the regulatory actions of the human stretch reflex and motor control

Muscle splindle cell function has been explained as a mechanism that pairs the lenght of the intrafusal and extrafusal fibers in order to mantain a gain at the different muscle lengths. Lengthening of the muscle generates an increased tone of the gamma circuit that consequently increases the alfa-circuit tone. According to authors (12) modifications of the stretch reflex are not produced by servo actions. They are produced by triggered reactions occurring at both short and long latencies with properties resembling the movements produced in a reaction-time task. According to this theory the function of the stretch reflex is to compensate for variations in muscle mechanical properties (internal disturbances) rather than for changes in mechanical load (external disturbances). The hypothesis that stiffness is a regulated property predicts that controlled changes in the gain of length and force feedback should alter the particular stiffness, which is then maintained by reflex action. These notions raise profound doubts on the nature of muscles interplay between tester and tested subject during manual muscle testing. Several authors have described differences in stretch responses which result when the instructions given to the subject are changed. In such a scenario the idea of a steady setting with invariable muscle reactivity or response is not realistic.(13)

5.3 Non neurologic biases of muscle tone control: thixotropy and tensegrity

Thixotropy refers to the change in passive stiffness of muscle that mimicks the behaviour of certain gels which can become fluid when mechanically solicited and go back to gel properties when allowed to stand. Thixotropic behaviour characterizes both extrafusal and intrafusal muscle fibres. Specifically intrafusal thixotropy can dramatically alter the discharge of primary and secondary spindle endings. The ‘initial burst’ from a primary ending in response to abrupt ramp stretch, a phenomenon deemed an acceleration-like response (14,15) is sustained by the thixotropic properties of intrafusal fibres. This is due to the formation, break down and and re-formation of actin-myosin bonds in the intrafusal fibres, with consequent changes in stiffness of the fibres and an alteration in the stretch placed on spindle endings. Prolonged stretch or fusimotor activity will cause bonds to form at the prevailing muscle length. In human subjects, the gamma activity associated with a voluntary contraction can induce long-lasting enhancements in spindle discharge that persist long after the contraction is over. Apparently the enhanced spindle discharge can be explained as a lasting memory of past gamma efferent activity and not an evidence of the current level of fusimotor drive. The enhanced discharge can be abolished by a stretch stimulus sufficient to break the persistent actin-myosin bonds. As a matter of facts, tendon jerks recorded at the same test muscle length can be enhanced or depressed after a voluntary contraction when the contraction is performed at a shorter or longer muscle length than the test muscle length. On the other end, tensegrity theories predict that cells are hard-wired in order to respond istantaneously to mechanical stresses transmitted over cell surface through receptors that physically couple the cytoskeleton to the extracellular matrix or to other cells. The cellular response to stress is more similar to that of a guitar string to tuning than a conventional stimulus response coupling in which the signal, a growth factor for istance, is absent before it is added externally. Experimental studies suggest that cell surface adhesion receptors like integrins or cell-cell adhesion molecules, interconnected citoskeleton networks, and associated nuclear scaffolds function as a structurally unified system. Tensegrity provides a mechanism to mechanically and harmonically couple interconnected structures at different size scales and in different locations throughout living cells and tissues. Indeed cell and tissue tone may be tuned by altering the prestress in the system. This may be accomplished by altering the architecture of the system or the level of citoskeleton tension. In either case, increasing the stiffness of the network is going to modify vibration frequencies and associated molecular mechanics of all the constituent support elements. This fact could explain how the part (molecule, cell) and the whole (cell, tissue, organ, organism) can function as a single mechanically integrated system (16). These concepts expand the complexity of the tonus regulation from the neuro-muscolar level to a systemic phenomenon.

5.4 Muscles and acupoints' association paradigm analysis

In AK theories the muscle's response induced by a stimulus may determine a change in tone whose direction is not fully predictable. It is presumed that what is beneficial, a substance or a mechanical change, increase the chance for a muscle to meet the demand at manual muscle testing, conversely what is not beneficial. The concept of hyper-reactivity, a muscle that becomes "to strong" following a challenge is a further complication when trying to distinguish changes more or less desirable. The only univocal response described in AK texts is referred to the activation of specific acupoints. For a meridian that is associated to a specific muscle the activation of the meridian's sedation point induces accordingly a reduction of that muscle's capability to perform normally at muscle testing. The muscle may or may not (in specific cases) test as a weak muscle but never "stronger" or "hyperreactive" (this latter concept being controversial yet). In our experiment we confirm previous observations describing a measurable effect on upper limb muscles due to non painful activation of acupoints on the foot. In our model the corticospinal excitability of the investigated muscles was not selectively decreased through activation of either one of the two selected sedation points. The collected data are interesting indeed as a significant interaction emerged relatively to the activation of the two different points and when considering the early phase of activation of one point versus the baseline conditions.

Independently from a speculation related to Applied Kinesiology's theories this fact confirms that a non-painful stimulus on the foot's skin can affect the excitability of muscles belonging to a far away and different innervation territory. The kind of stimulation adopted in our protocol does not use needles indeed. Nociception activation cannot be part of the explanation of the possible effects described while to date activation of delta-fibers related to pain receptor has been the theoretical framework to explain the physiology of acupuncture. We could not clearly identify a pattern, whether related to the direction of tonus changes (increase of tonus vs decrease) or to muscles specificity of the effect. This could be due to an excess of variability of the distribution of our data. An initial statistical analysis applied on about 2400 motor evoked potentials globally recorded revealed an excessive variability of the baseline conditions itself. This fact did not exclude the existence of a specific effect on the upper limb muscles as a consequence of activating the selected acupoint but apparently the power of our sample was not adequate to express a conclusive theory. We then further refined our statistical analysis in order to do not miss an effect emerging in a more limited time's window. The rationale is that the variations possibly related to the conditional stimulus adopted are present in a limited interval of the overall sequence of 12 TMS stimuli delivered every 3 secs (average duration of the phase is 1 minute). Every single phase of the test condition was consequently divided in three equal subunit each accounting of 4 motor evoked potentials. This procedure allows to detect a possible pattern distribution in the initial whether intermediate or later phase of the sequence of interest. Our experiment demonstrated a statistically significant increase of FCR's MEPs upon activation of st45 in the first phase of the test condition compared to the third phase and no significant effect on the biceps and on the hands' muscles. When confronting the two test conditions there is also an overall significant higher MEP's value for the sp5 condition compared to the st45 one. This significance is not confirmed when comparing each test condition with the baseline. The available data don't show a clear muscle's specificity of the stimulation's effect as expected in AK theories. On the other hand it is hard to give a straight forward interpretation due to MEPs significant variability. We cannot support AK theories but on the other hand we cannot exclude that what is reported by AK practitioners as a subjective feel could be related to an objective EMG change.

6. FUTURE DIRECTIONS

6.1 Possible directions for professionals referring to AK related techniques

The classical AK paradigm relating skeletal muscles and meridian does not find an evidence in our study design. We did not identify a specific association between the biceps muscle and the stomach meridian. Indeed we found an association between the stomach meridian and the FCR. We neither observe a decreasing effect on muscle excitability following stimulation of the relative sedation point but on the contrary we obtained in line with previous literature results an increase in the excitability in an upper limb muscle (FCR). Our data differ from previous observation as we had an increase of FCR excitability versus no change in hands' muscles excitability. These results question the validity of the AK paradigm but even if indicative cannot be considered absolute or definitive since the intrinsic limits outlined above. It could be speculated that the actual explanations of AK related phenomena are not adequate or at least don't find confirmation in our data. It is relevant indeed that we have further evidence from our study of the link between the motor system and the meridian system. This should stimulate further efforts in the investigation of motor correlates of pathologies that fall into the idiopathic category according to standard medical diagnosis today. Muscles' impairment and arthritis for instance could find in a contextual alteration of the meridian system a relevant missing link in terms of understanding etiology and consequently shifting treatment strategies from the actual end stage disease symptomatic approach.

6.2 A new interpretation: the neurophysics of AK muscle testing

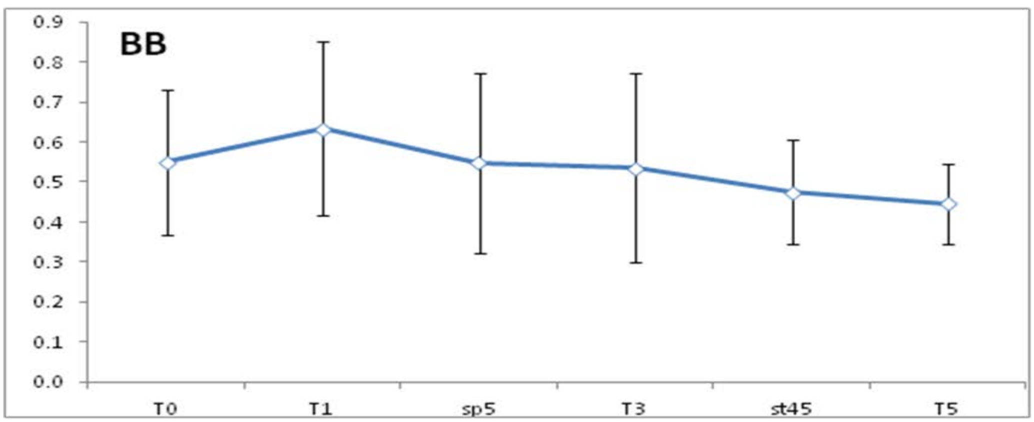
AK muscle testing's related phenomena have always been explained through a neurologic related approach. As the alpha motor neuron is the final output responsible for a muscle’s fibre contraction it was supposed that changes in its activity could be responsible for muscle's performance changes detected at AK manual muscle testing. The complexity of motor control how partially exposed and the uncontrollable biases related to the tester’s own motor system suggests to eventually look for models not in open contrast with universally recognized notions of motor control's physiology. If there is any objective change in the examined subject when referring to istantaneous muscle's performance changes as in AK descriptions this could be related to a phenomena that goes beyond the nervous system's control. Pietsch, in “Shufflebrain” (17), describes how a unicellular organism can change its motor program according to the environment (specifically a source of food). By shifting from random locomotion to movement relative to the stimulus the organism would be shifting from random phase variations in its flagella to the equivalence of harmonic motion as is from cacophony to melody. A shift in phase could represent a new model of investigation for muscle changes as described in AK. In this new scenario the examiner’s system and the examined subject’s system are considered like two dynamic “tuning forks” each vibrating at specific frequencies and thus generating harmonics during reciprocal muscle contraction. Muscle contraction generates waves that undergo physical laws. Specifically interferometry adopts the principle of superposition to combine separate waves in a way that will cause the result of their combination to gain some meaningful property that is diagnostic of the original state of the waves. This fact is a consequence of the resulting pattern from the combination of two waves with the same frequency. Waves that are in phase will undergo constructive interference while waves that are out of phase will undergo destructive interference. The phase difference between the two waves generated by muscles’ activity could represent the property that is perceived as a distinctive features of muscle’s contraction by the AK examiner. Therefore the various challenges, mechanical pressure on a joint, insalivating substances or meridians' activation, could be considered as introducing variables affecting the waves’ phases. This is not different conceptually from modern models explaining complex living forms’ behaviors. One example is the “TOTE” (test-operate-test-exit) as the smallest unit of behavior that replaces Pavlov’s S-R (stimulus-response) model (18). In this paradigm an organism starts a behavior only when a test performed in one of its control systems sends a feedback signal called an error condition. An error signal is considered as a sensed difference between an internal reference condition referred to some controlled quantity and the current perceptual condition as reported by one or more sense organs or body receptors. An error signal is fed back and the behavior goes on as long as the reference condition and the perceptual condition tested for some controlled quantity do not match. Once the two conditions match, and the second test is complete, the system exits, that part of the behavior stops, and the system tests for a new operator (behavior). Analogously the motor system can be considered differently tuned according to the environmental conditions; perceived changes in the environment might set differently the motor system in an effort to optimize a possible favorable outcome. This could explain other “unexplained capabilities” like rhabdomancy. The water diviner possibly amplifies his or her motor system changes due to water’s presence transmitting oscillations to the stick. In any event, the elaboration of a new model is not a trivial detail in the development and acceptance of a new and possibly revolutionary theory. The “Einstein/Minkowski solution” is considered a major criterion that must be satisfied for the proper development of a paradigm theory. This concept theorizes that the complex interaction among aggregates must be represented or representable in a visual form because the translation process not only assists understanding, but also allows an increase in the scope and precision by which the theory can be applied. The way AK muscle’s weakness phenomena is actually explained by AK promoters appears largely insufficient possibly representing a lack of understanding of the underlying phenomena. This fact does not mean that the methodology is invalid to aid in the diagnosis and treatment of health related issues. Nevertheless there is no way to ascribe to AK muscle testing technique and not to other operator’s skills the reported favorable clinical results. Considering AK muscle weakening peculiarity as an operator learned skill possibly and not necessarily related to an objective change of the tested subject’s motor system could assist in clearing out an almost 50 years old mistery.

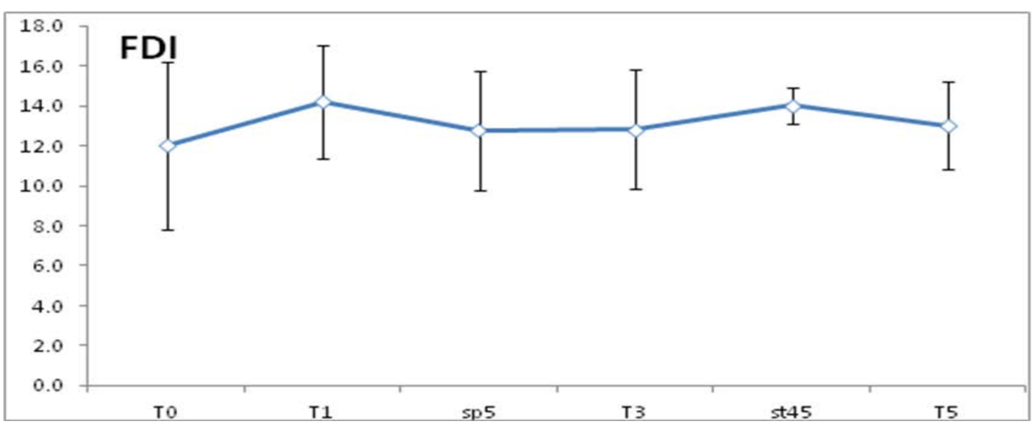
Appendix

Mean row data (in mV) collected across the experimental phases are shown separately for each muscle for each subject. The label 'T' refers to control phase. Error bars represent the standard deviation.

For technical reasons, in Subject 9 the recording of BB muscle during the 'T3' control phase failed, thus this subject was rejected for statistical purposes.

Subject 1





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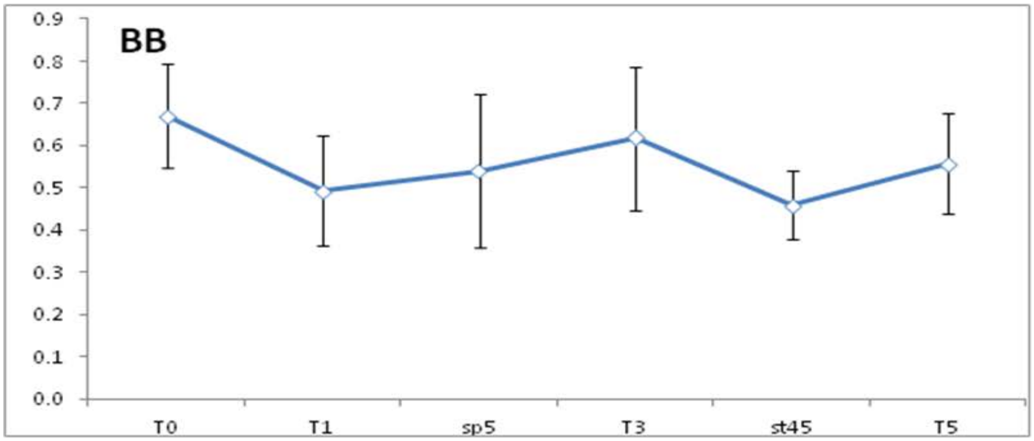

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0.2
0.1
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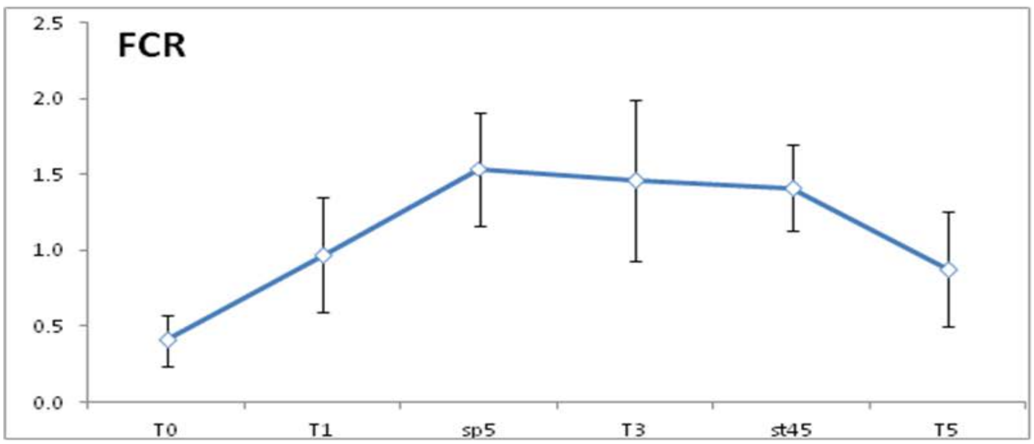
T0
T1
sp5
T3
st45
T5



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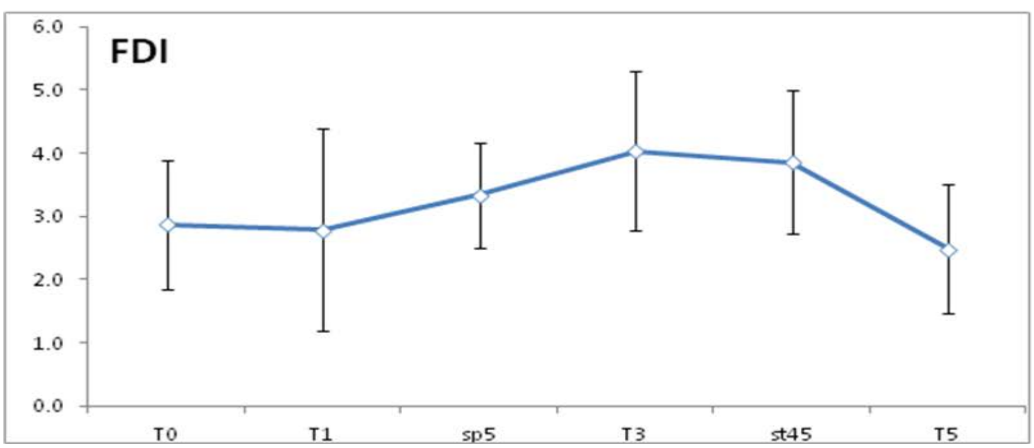
1.5
1.0
0.5
0.0
T0
T1
sp5
T3
st45
T5



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2.0
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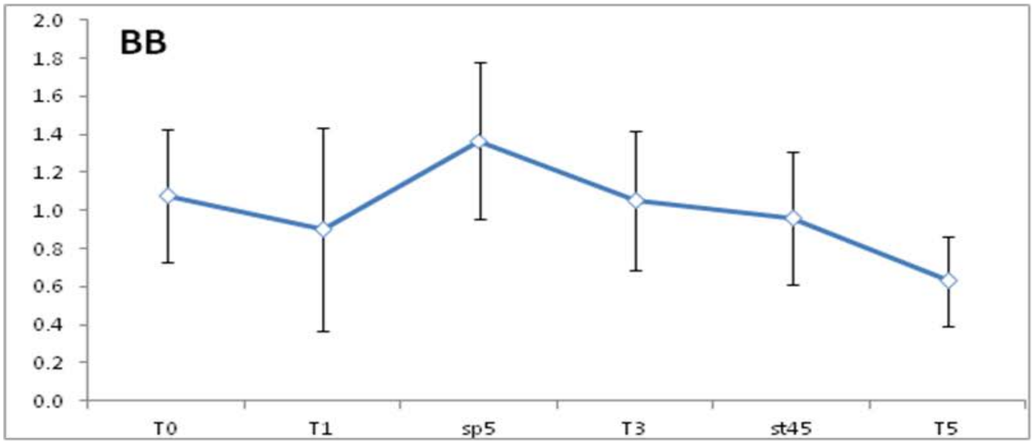
0.0
T0
T1
sp5
T3
st45
T5

Subject 3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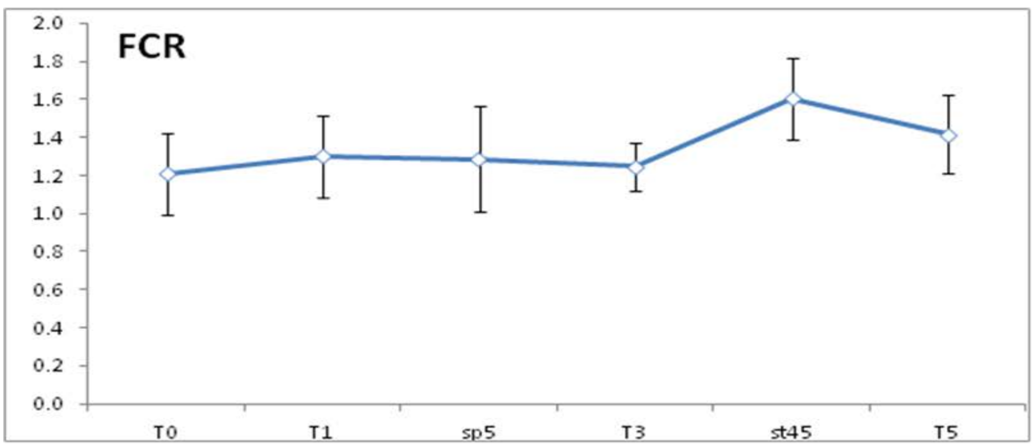
T3
st45
T5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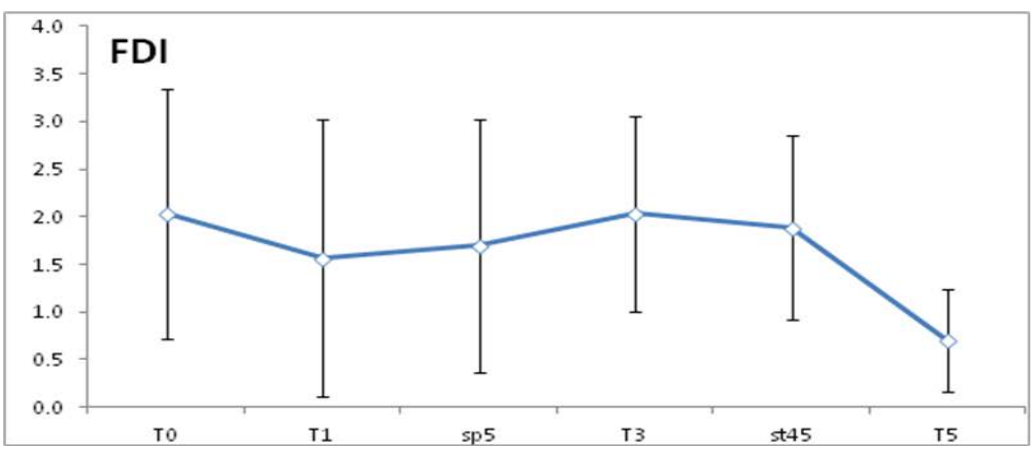
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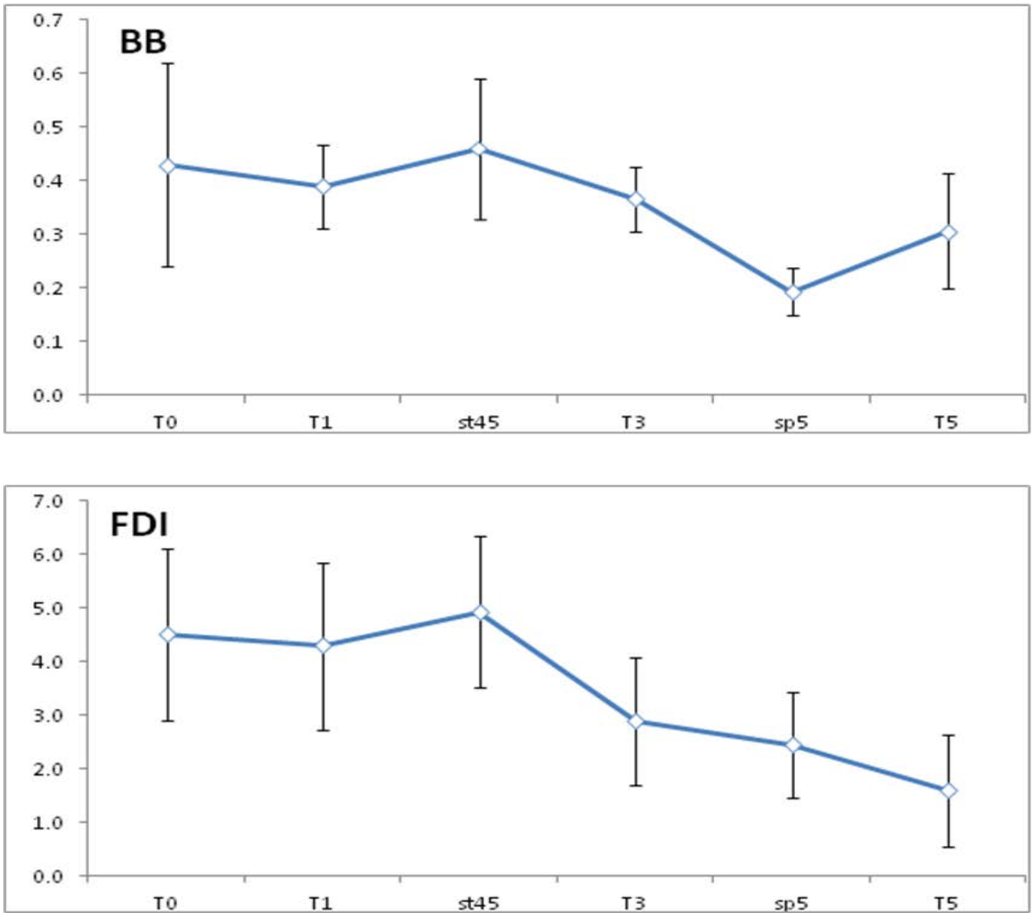
T3
st45
T5

Subject 4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T5
FDI
7.0
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T1
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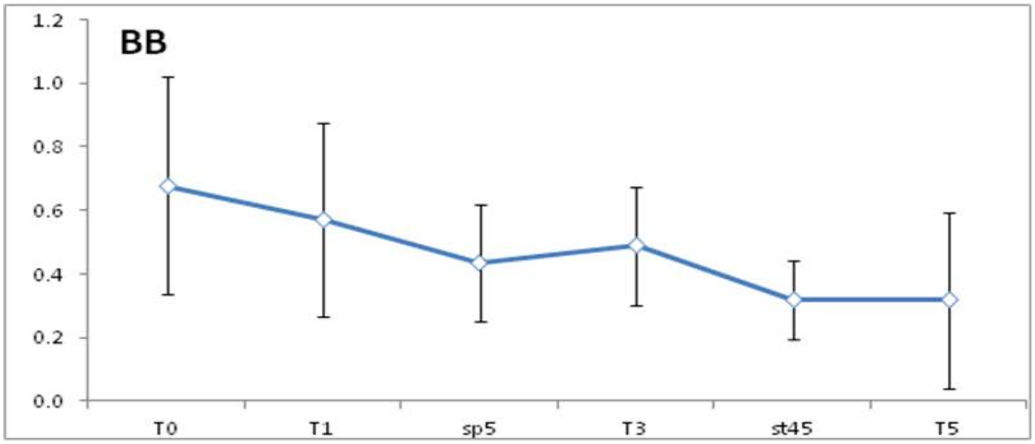
T3
sp5
T5

Subject 5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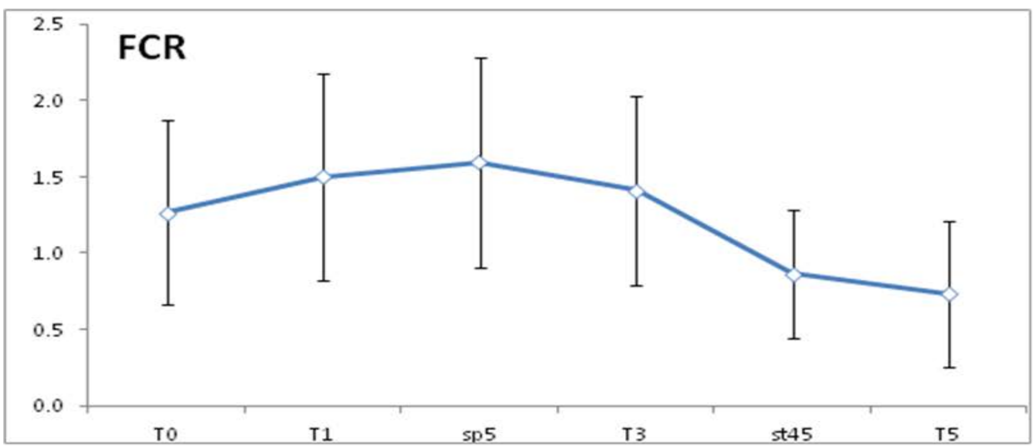
T5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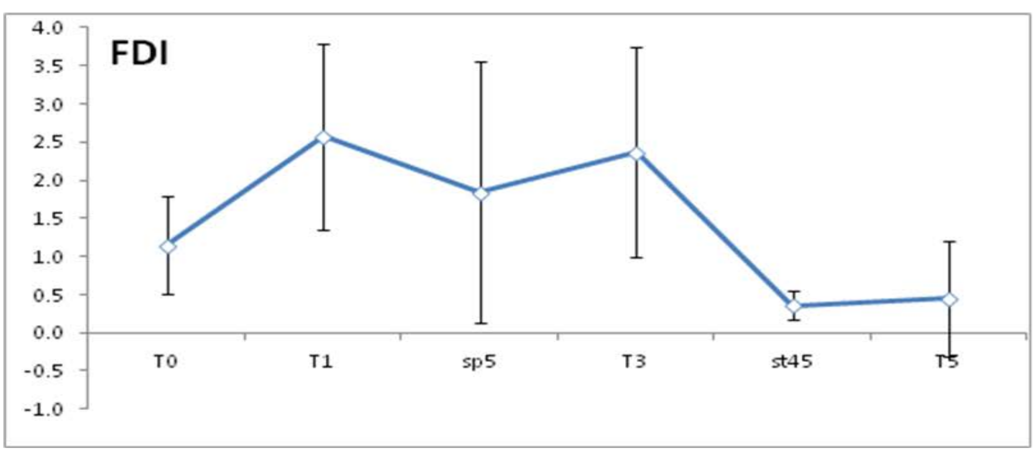
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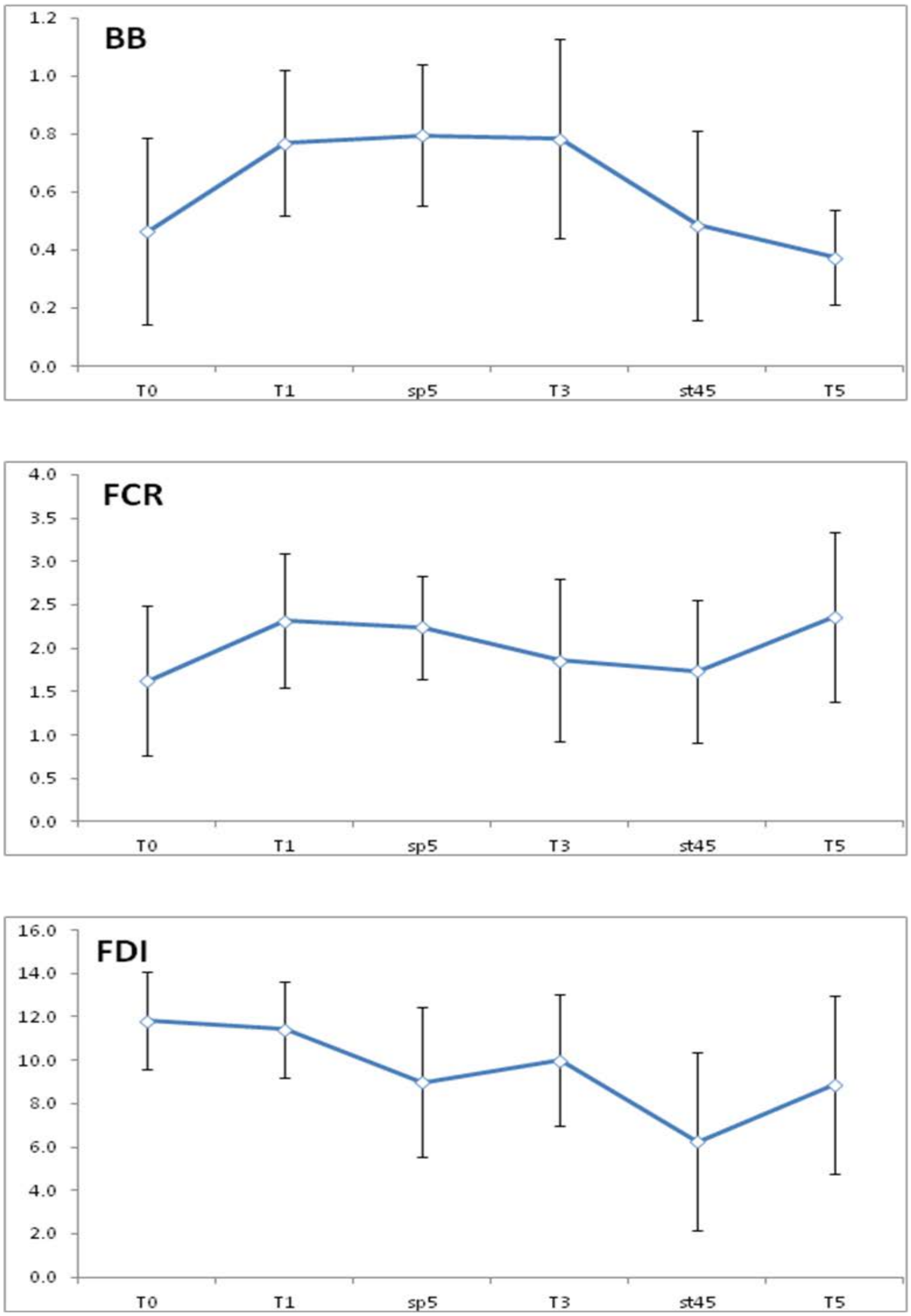
T5

Subject 6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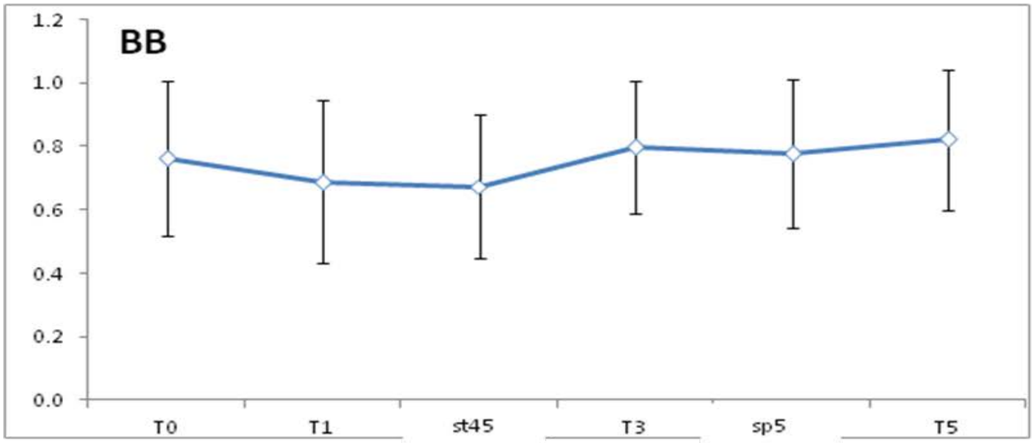
Subject 7



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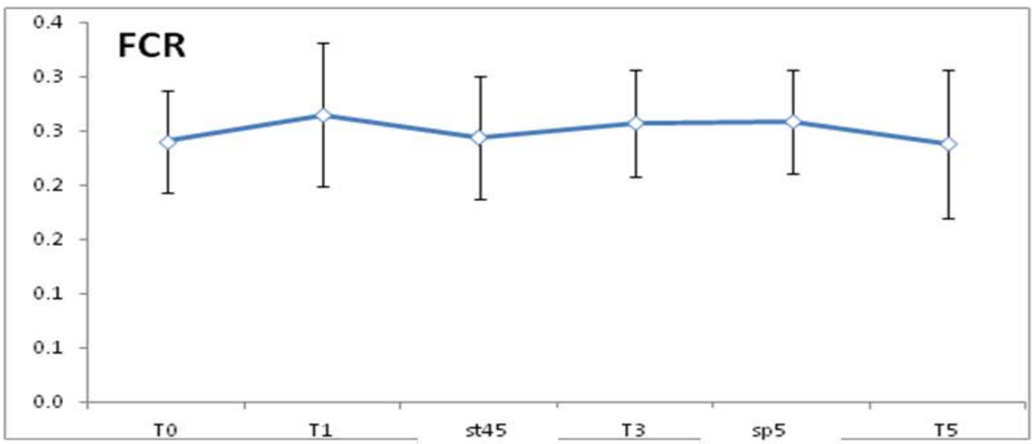

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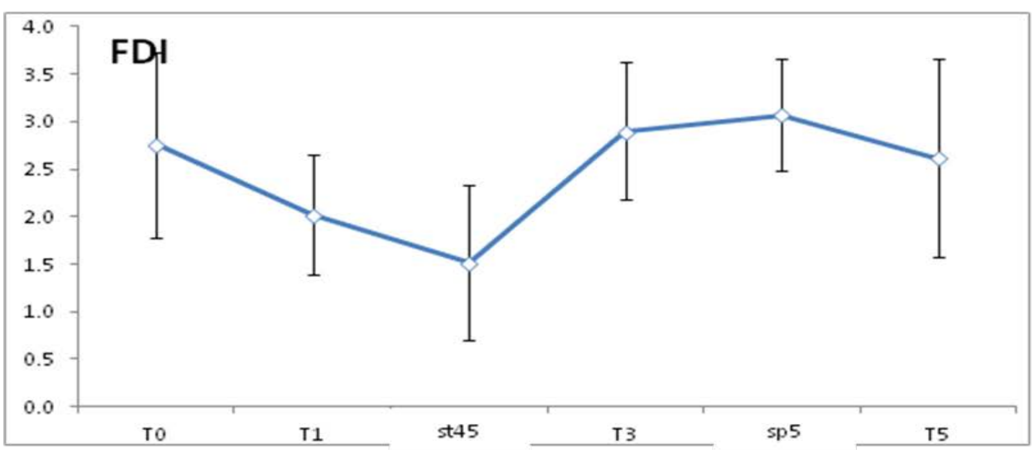

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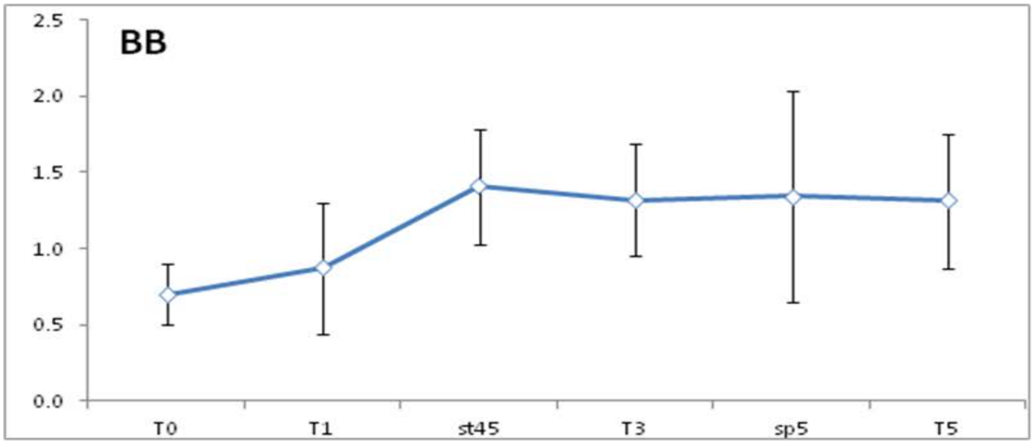
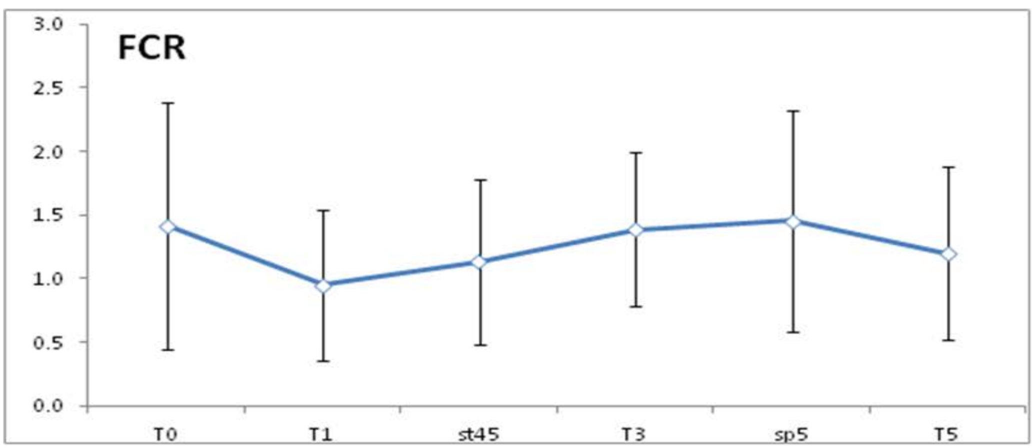
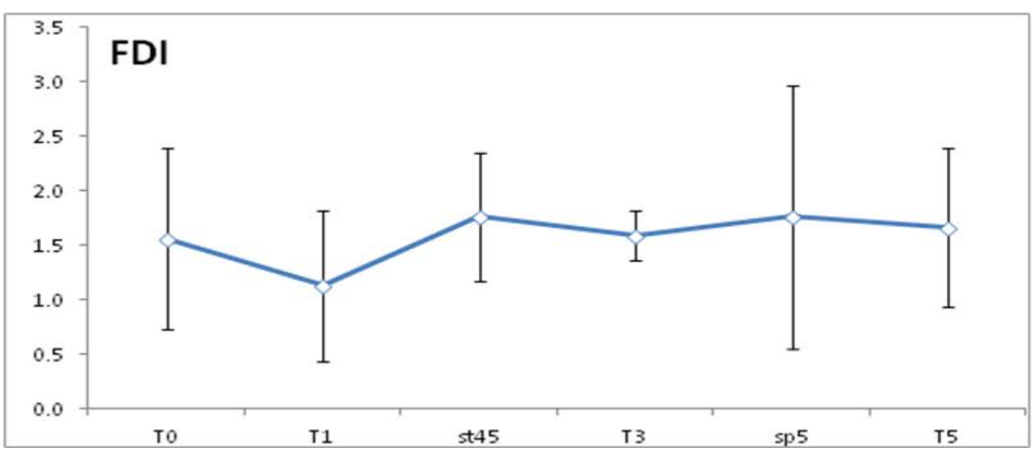
sp5
T5

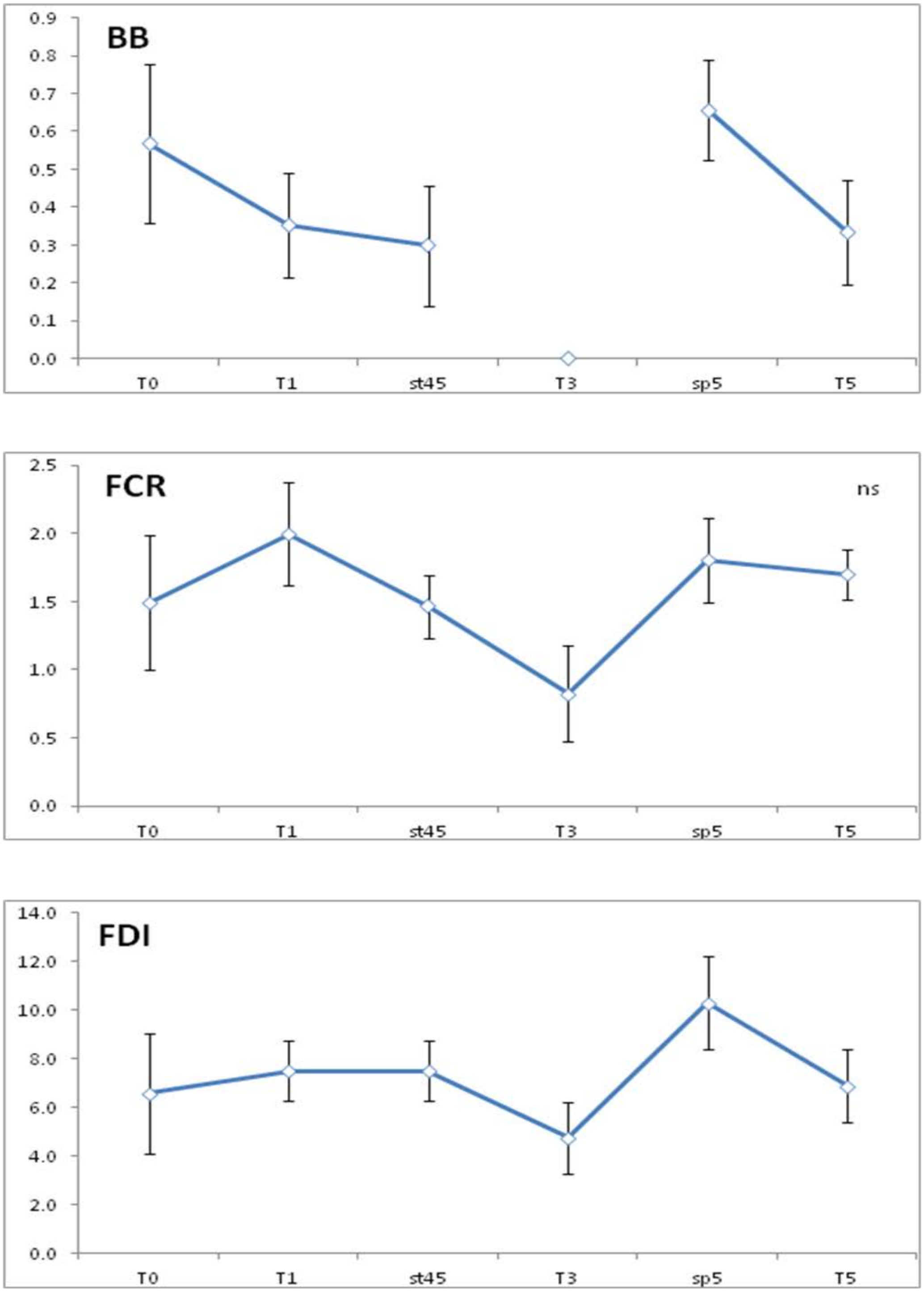
Subject 8


BB
2.5
2.0
1.5
1.0
0.5
0.0
T0
T1
st45
T3
sp5
T5

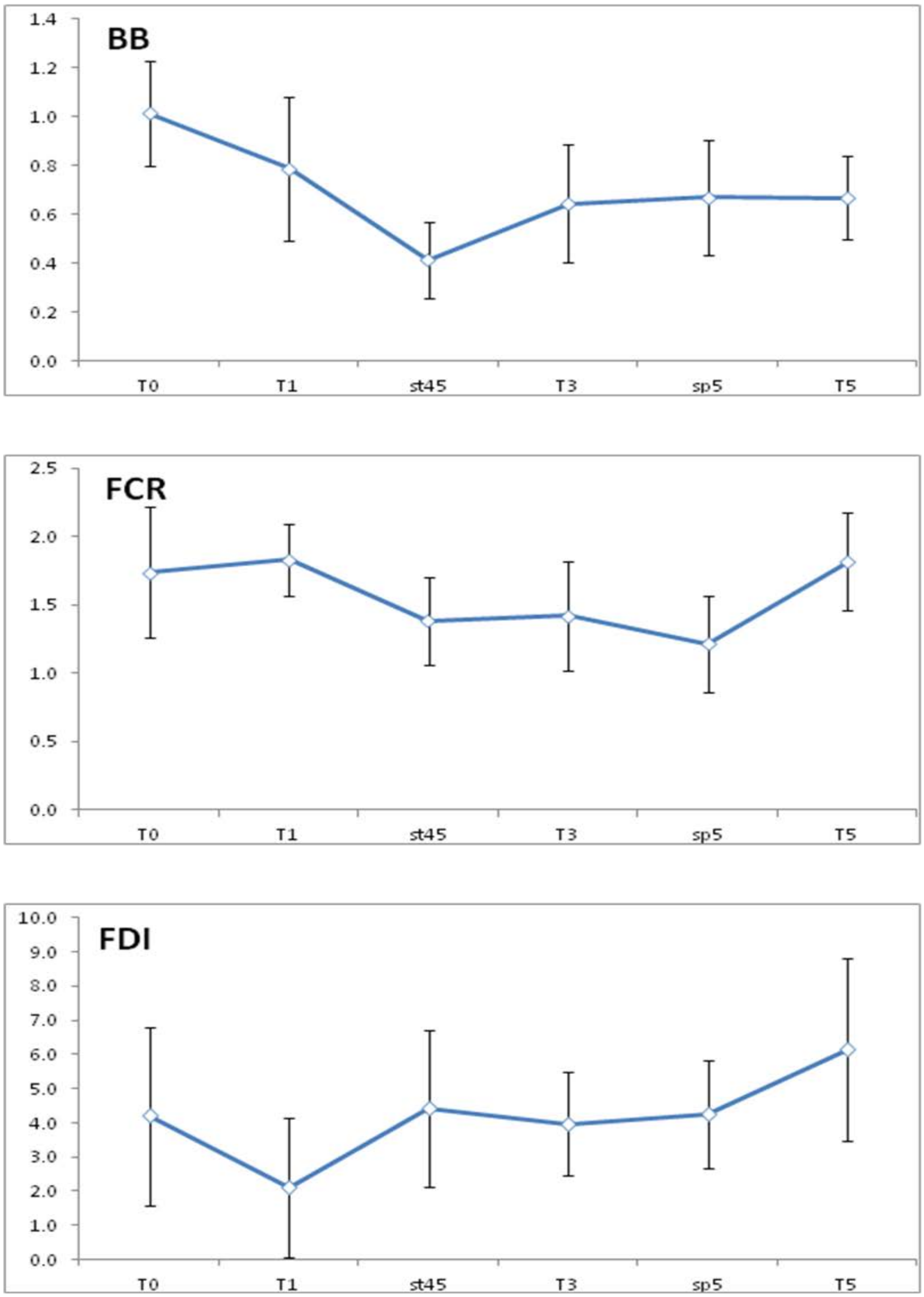

FCR
3.0
2.5
2.0
1.5
1.0
0.5
0.0
T0
T1
st45
T3
sp5
T5


FDI
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
T0
T1
st45
T3
sp5
T5

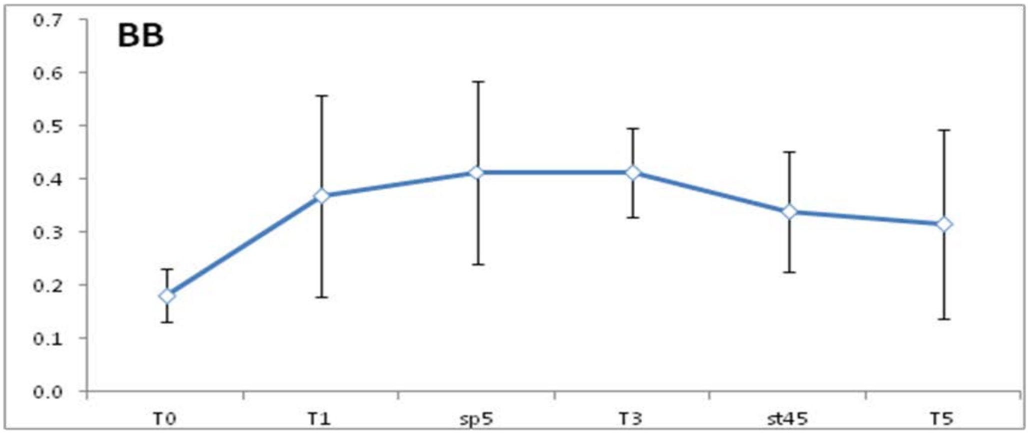
Subject 9

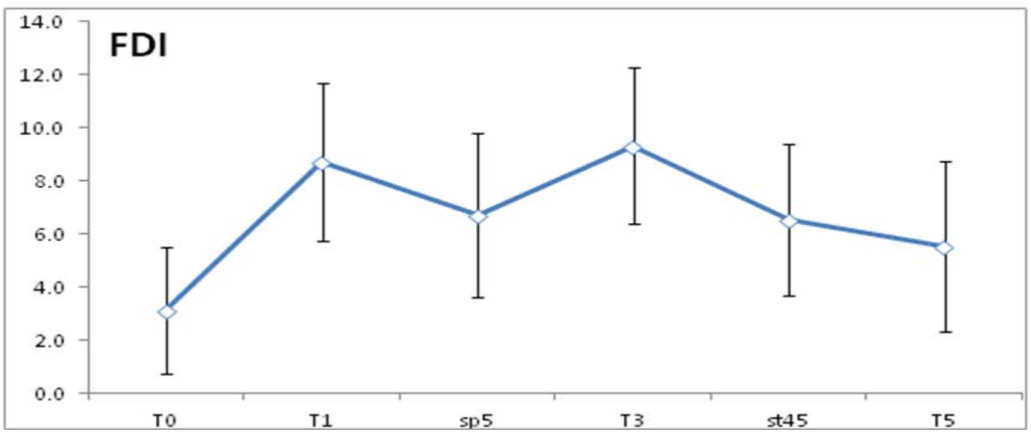

BB
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
T0
T1
st45
T3
sp5
T5
FCR
ns
2.5
2.0
1.5
1.0
0.5
0.0
T0
T1
st45
T3
sp5
T5
FDI
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
T0
T1
st45
T3
sp5
T5

Subject 10


BB
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
T0
T1
st45
T3
sp5
T5
FCR
2.5
2.0
1.5
1.0
0.5
0.0
T0
T1
st45
T3
sp5
T5
FDI
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
T0
T1
st45
T3
sp5
T5

Subject 11


BB
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
T0
T1
sp5
T3
st45
T5


FDI
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
T0
T1
sp5
T3
st45
T5

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