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Surface EMG and Heartbeat Analysis Preliminary Results in Surgical Training: Dry Boxes and Live Tissue

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Abstract—**The training in the surgical practice is of paramount importance to prepare the residents in performing surgical procedures on human subject and to provide exercise on new techniques for experienced surgeons. Usually, these trainings are carried out on live animals or in virtual environments and dry boxes; the complexity of the exercises is identical in both of the case, but the pressure in operating with a living subject could change the attitude and the movements of the trainee. Until now, it has not been possible to analyze this stress in details together in the surgical animal training and dry boxes. In this work we propose an innovative portable system that can measure two physiological parameters, the heartbeat and the surface electromyography, during a session of training in both of the environment. The preliminary results, for one subject, show a bigger average power in the shoulder muscles during the living operation together with a higher but stable heartbeat rate.**

I. Introduction

THE training of surgeons is an essential process, in particular during the period of residency: it is required to prepare the surgeons and enhance the competencies needed to operate on human subjects. Additionally, it is necessary for experienced surgeons to keep the manual dexterity for basic and more complicated operations. Besides, more and more countries are recently adopting a competency-based training in surgery, in which the residents are evaluating on their acquired skills eliminating the concept of years-in-training [1]. This model gives autonomy to each trainee to proceed based on her capability, with some intermediate steps to provide evidence of the mastery of what is required: finally, only the residents who proved a real professionalism should be allowed to practice in the field of surgery. One of the goals of the competency-based training is to create a professional surgeon able to perform independently [2]. This concept becomes more significant for the laparoscopy, one of the practices of minimally invasive surgery (MIS), in which the surgeons are affected also by an augmented mental stress [3], increased technical difficulties [4] and forearm fatigue [5], compared to the open operation. In particular, the technical effort is a consequence of the laparoscopic tools [6] and the procedure itself, which consists in operating within minimal space without direct vision, but using a video projecting the image in two dimensions, differently from the three dimensions of the open surgery. The mental and physical stress are the results of the technical effort: the limited vision requires additional concentration compared to an operation with direct visualization, while the force to be applied during a laparoscopic surgery is bigger than the one in an open surgery and the tools, due to their lengths, require more force [7].

A structured training could help also to overcome the mentioned side effects in the laparoscopic practice. Usually, the medical universities provide mixed trainings with live tissue, as animal laboratory training, together with virtual environment and the dry boxes. In particular, the last ones are indispensable to limit the use of living subjects, with all the ethical issues that are correlated [8], and to reduce the learning curve, because of the possibility to practice continuously, without limits in schedules.

Both the live tissue and dry boxes training present the same level of complexity in term of exercises, such as cutting, suturing and tying; additionally, the Virtual Reality in medical applications is making huge steps and it is a very hot topic in the engineering and medical research, with over 1500 articles found on PubMed with the keywords *Virtual Reality Training* and over 3500 with the only *Virtual Reality*. However, still the Virtual Reality and dry boxes cannot simulate the real stress that a surgeon is feeling during an operation on living subject, mainly due to the fact that any error is not affecting the life of the patient, and cannot simulate all the contingencies that could happen during live tissue operation.

Objective of this research is the comparison between the virtual environment and live tissue training from physiological point of view; until now, there has not been a detailed analysis of the practices in both of the cases. In this

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paper, we present the preliminary results, based on one subject, with an innovative portable system able to measure the sEMG and the heartbeat rate. Accordingly, we have analyzed the two physiological parameters of a trainee going on a two days training with mixed, box and live tissue, training on minimally invasive surgery at Kyushu University Hospital [9]: 1. surface Electromyography (sEMG) of the arm, forearms, shoulder and facial EMG, considering that the laparoscopy is very demanding in term of muscle fatigue [10], 2. heartbeat, that is indicative of the level of stress [11]. Finally, we show the results in term of average muscle power and heartbeat rate variation.

II. Materials And Methods

A. sEMG HW Setup

The sEMG signals have been recorded from Extensor Carpi Ulnaris (ECU), the Flexor Carpi Radialis (FCR), the Biceps Brachii (BB), the Triceps Brachii (TB), the Left Trapezius (LT), the Right Trapezius (RT), in addition to two electrodes on the Corrugator Supercilii (CS) and Zygomaticus Major (ZM) for the facial EMG analysis, often used to investigate the mental stress in defined exercises. DE-2.1 sensors from Delsys Inc. have been used and the signals were amplified by a Bagnoli TM 16-channel system (Delsys Inc.) with a Gain K=1000: the connection between the sensors and the amplifier has been done by a long cable, 10m, in order to give more movement freedom to the trainee. The skin was cleaned by mildly scrubbing it with 70% isopropyl alcohol. The sensors were attached to the skin with a double-sided adhesive interface and located in the midline of the muscle belly between the nearest innervation zone and the myotendinous [12]. Elastic bands have been applied to limit the possibility of sensor displacement. A Dermatrodes HE-R (American Imex) electrode (5.08 cm dia.) was located on the iliac crest to provide a reference. Sampling rate was set at 1000 samples per second using a 16-bit A/D converter board (National Instruments, USA, PCI-6034E) connected to the notebook by the PCI Bus Expansion Chassis ECH(PCI)SF-H4B from Contec Inc through a PC card bus, as showed in Fig. 1. The acquisition software showing the data in real time has been developed in Microsoft Visual Studio, while the post processing has been done with MATLAB 7.7 (R2008b).

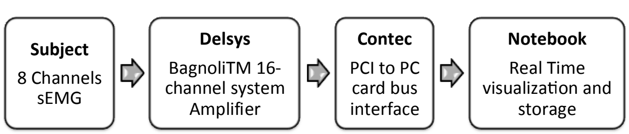

Fig. 1. sEMG setup: the signals are amplified by the BagnoliTM system and sent to a PC through a PCI to PC card bus interface, where they are visualized and stored for further analysis.

B. Heartbeat Measurement Setup

The heartbeat has been recorded by using the heart rate monitor system FR60 from Garmin Ltd. It is composed by: *1)* the heart rate monitor to be worn directly on the skin just below the breastplate; *2)* the fitness watch to be paired with the heart rate monitor via the wireless ANT+ protocol [13]: it has the function to store the data and transmit offline to a computer through a dedicated USB receiver. The synchronization with the computer has been performed before the experiment manually, reading the time on the notebook internal clock; even if the manual synchronization is affected by errors in the range of hundreds of milliseconds, it doesn't impact the analysis, because in any case the output of the heart rate monitor is an average of the heartbeat rate on 5s.

C. Experimental Setup

The measurements have been taken during the "Standard Course" for basic endoscopic surgery skills at the Kyushu University Hospital [9]: it consists in a combination of oral lectures, box training, Virtual Reality simulator training, tissue training and live tissue training designed for bi-hand coordination. The schedule is divided in two days, with the animal training experiment held in the second half of the second day, before the final evaluation. Please refer to [9] for the details of the training schedule and protocol. The protocol for live tissue training has been approved by the Animal Care and the Committee of the Graduate School of Medical Sciences, Kyushu University.

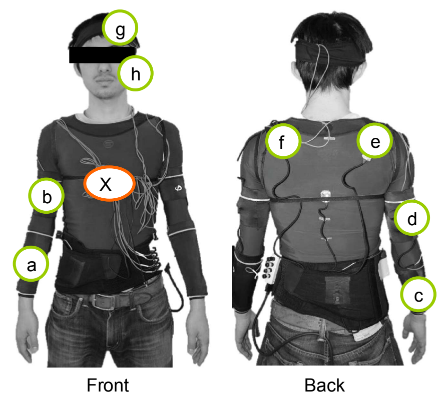

Fig. 2. Experimental setup: sEMG sensors a) ECU, b) BB, c) FCR, d) TB, e) RT, f) LT, g) CS, h) ZM, and X) heart rate monitor

The trainee, after signed an informed consent, was prepared with the heartbeat monitor and sEMG apparatus in the morning, as showed in Fig. 2. Each day, before starting the training, the Maximum Voluntary Contraction (MVC) has been recorded for each muscle under measurement, in order to normalize the signals during the post-processing: the procedure has been done with a muscle positioned within its midrange length, against manual resistance. After lunch, the status of the sensors and eventual displacements has been checked again; also, in order to minimize the disturbance during the training and reduce the awareness of the equipment, the conversation to the trainee has been limited. Fig. 3 shows the trainee during a dry box practice.

Among the different tasks performed during the training, we have been focused on the suturing and knot tying executed in both the dry box, following defined as virtual environment, and live tissue practices: the segmentation has been done in post processing by watching the video recording of the exercises.

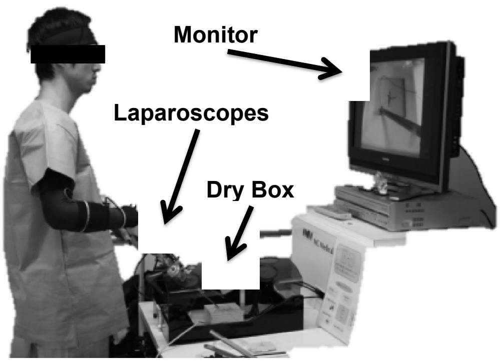

Fig. 3. Trainee during the dry box practice: suturing.

D. Evaluation Method

The sEMG data has been processed in the following way: at first they have been filtered with a band pass filter 5Hz-450Hz and denoised using a modification of Wavelet Denoising Algorithm based on Donoho technique [14], developed by our group [15], with soft threshold, Daubechies db2 mother wavelet and forth decomposition level, that have been proved, in case of myoelectric signals, to have the lowest mean square error [16]. The filtering and denoising process is showed in Fig. 4.

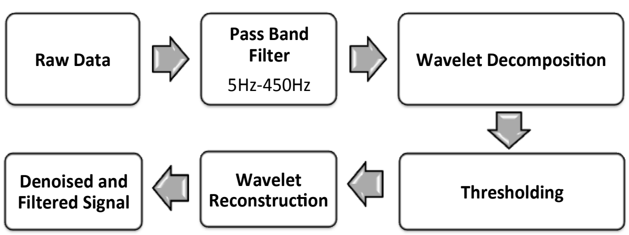

Fig.4 Denoising and Filtering process for the sEMG signals

After, for each channel, the average powers of the MVC, P_{MVC}, and signal, P_{SIG} have been calculated: the choice of the average power over other parameters is justified by the fact that the practices have taken different time lengths in the dry box and animal training. Finally, the Average Power Ratio (APR) has been calculated following the formula

$$APR(i) = \frac{P_{SIG}(i)}{P_{MVC}(i)} \qquad i = 1..8 \qquad (1)$$

The APR is a normalized value indicating the relative power of the muscles under observation, in relation to the maximum value: it is a non-dimensional value that could be expressed in percentage. *i* denotes the muscle, in this case 1: ECU, 2: FCR, 3: BB, 4: TB, 5: RT, 6:LT, 7: CS and 8: ZM.

The data coming from the Heart Rate Monitor have been transferred to the PC through the software Garmin Training Center.

III. Results

The results for the sEMG are shown for the arm, forearm and shoulder in Fig. 5: the first evidence is that the muscles that are more stressed during the suturing and tying, for both the practices, are the ECU, the RT and LT, while the FCR and the Biceps are less stressed compared to the value calculated during the MVC: the values of APR for the BB and TB are less than 2% in both of the exercises. Considering, alternatively, the difference between the live tissue practice and virtual environment, for all the muscles the values are higher in case of live tissue training.

Fig. 6 shows the results of the average power ration for the facial sEMG: they are showed in another graphics, because they are very small compared to the MVC and they could not be appreciated together with the muscles of the arms, forearms and shoulders. Also in this case the wet experiment shows a value of the APR that is much bigger than the dry one: it can be due to an increased concentration of the trainee during the operation with the living subject [17].

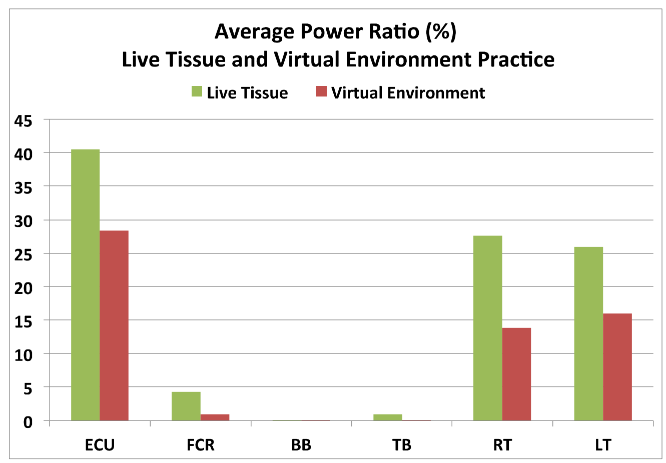

Fig.5 Average Power Ratio in percentage compared to the maximum power from MVC for the muscles of forearms, arms and shoulders during the animal surgical traing and virtual environment.

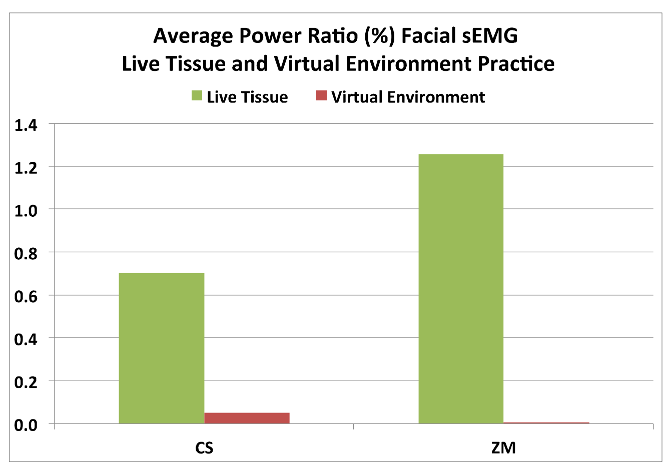

Fig.6 Average Power Ratio in percentage compared to the maximum power from MVC for te facial sEMG during the animal surgical traing and virtual environment.

Finally, in Fig. 7 the heartbeat rate is presented for the exercises, live tissue training and virtual environment. The total duration was around 700s. The averaged values, with the standard deviation, are:

HBR Live Tissue average = 81.3±3.02

HBRVirtual Environment average= 64.5±4.15

The graphic shows additionally the linear trend. The heart beat rate during the exercise with the living subject is higher compared to the dry practice, but stable denoting a higher level of stress combined with high level of concentration by the trainee [11].

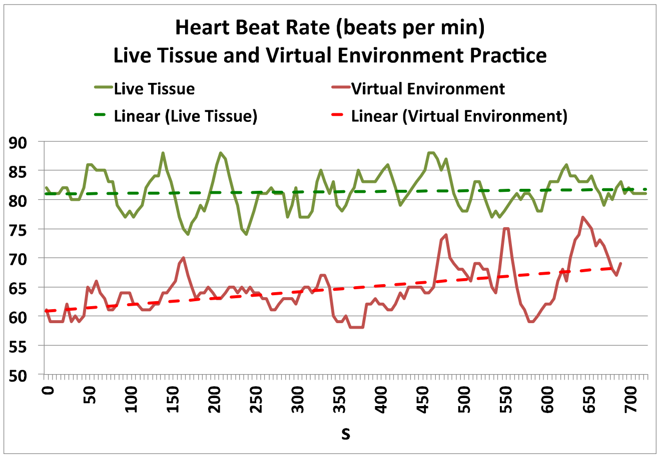

Fig.7 Heartbeat rate with during the animal surgical training and virtual environment with the linear trends.

IV. Conclusion

In this paper the preliminary analysis of sEMG of right arm, forearm, shoulder and face, in addition to the heartbeat rate has been presented for a subject going through training in minimally invasive surgery with dry boxes and live tissue. The results show that the average power ratio for the foreams and shoulders in case of live tissue practice is much higher than the one in virtual environment; same result is showed for the heartbeat rate. Even the subject under analysis has been only one, it can be consider that the training on living subject impacts, in case of young trainee, the muscles and mental activity. In particular the facial EMG showed a very huge difference, resulting in a higher level of concentration during the experiment with the animal.

Further works can be done in many directions: 1. to increase the number of subject to be analyzed, eventually involving experienced surgeons; 2. to add measurements of motion, with Inertial Measurement Units, considering that we have already a good know-how in our group [18] ; 3. to reduce the cables and the dimension of the apparatus for the sEMG, now consisting in amplifier and various interfaces, by working on low power wireless system, with the final goal to have a system easier to wear and lighter.

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