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Daylong sitting posture measurement with a new wearable system for at home body movement monitoring

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***Abstract*— The ability to monitor seated posture at home is of significant importance; in fact, incorrect posture for a long time can lead to musculoskeletal disorders. This document describes a comparative analysis of a new wearable system for non-invasive daylong monitoring of seated postures in real life situations. The system is capable of measuring the subject's posture through an instrumented T-shirt that uses an inductive sensor sewn directly onto the fabric, making the system non-invasive for the user. This paper gives brief description of the wearable system and the method used for the measurement of Range of Motion (ROM) during seated activities. The experimental results are reported and compared with results obtained through an optical system, which measures the position of the markers on the back of the analyzed subjects. The results support the concurrent validity of the wearable system respect to the optical system, usually adopted for movement and posture measurement in the literature. Furthermore, the new wearable system was used for a monitoring activity of some hours at home aiming to test the wearable system in a real home contest.**

***Keywords*— daylong measurement; home monitoring; instrumented T-shirt; optical measurements; posture monitoring; smart vest; wearable system; wireless system.**

I. INTRODUCTION

Several spinal disorders may occur at different stages of a person's life, during the growth, jobs and aging. In the rehabilitation of these disorders, or to avoid a worsening of the spinal conditions, possible simple approaches are muscle-strengthening exercises to counteract postural deviations and improve proper postures. Several solutions for the control of postural activity during postural rehabilitation or reinforcement are reported in the literature. There are numerous methods for the posture analysis, from simple visual observation to more complex systems of movement measurements, usually used in the laboratory for medical research. In recent years, several devices have been developed to analyze the posture even outside the hospital [1-7]. However, many techniques cannot be easily used to develop wearable devices. In fact, some of these devices are relatively large and cannot be easily hidden or used for an extended period. Another problem appears to be the invasiveness of the measuring system, which instead must be accepted by the patients. The main drawbacks of wearable sensors available in the literature are their weight, the rigidity of the structures that support them, the size and other properties that make them uncomfortable to the patient and, therefore, hardly acceptable if used continuously throughout the day. In [8], busts with sensors are used for patients with lumbar scoliosis, patients with low back pain for the elderly and osteoporotic vertebral fracture. However, the use of these devices is limited by external factors such as invasiveness, physical restraint and, therefore, low level of acceptance. In [9], a monitoring system has been developed to manage patients with scoliosis. The system was used to monitor the posture of the spine and to provide feedback signals of patients in order to correct their posture. However, the device needs to fix with adhesive tape the sensor cable directly to the skin. This makes it difficult to apply without the aid of another person. In addition, the system does not seem to work properly if covered or crushed by other objects or clothing. The new wearable system analyzed in this work allows the monitoring of sitting postures of the trunk in the sagittal plane. The wearable system can give the patient feedback about his/her posture and can help facilitate his/her therapeutic approach, ensuring the continuous postural control. Although, this possibility was not addressed in this paper and it will be addressed with physicians. The system consists of an elastic T-shirt on which an inductive sensor is sewn. The measurement is performed by calculating the deformation applied on the T-shirt by means of a stretching and straightening of the back in the sagittal plane, for example during the execution of strengthening exercises of the muscles of the back. The main goal of this work is the comparative evaluation respect to a reference measurement system usually adopted in posture measurement and the analysis of the wearable system to assess its functioning in a real context. Therefore, different exercises have been carried out and monitored at the same time by the wearable system and by an optical system usually used as a reference for these measures in a number of works [4, 9, 10-15]. The wearable system was tested with different persons and in a sample of trials of short duration. As a further analysis, the system was used as a "Holter monitor" for postural movements of the trunk in the sagittal plane in everyday life activities. The wearable system is an easy way to track the sitting posture and to sensitize the patient to become aware of their postural state. Additional accessories are not necessary, just the simple sensor-T-shirt and the control board are needed. This simplifies the process at home for patients with movement problems. The simple construction that consists of a T-shirt with a copper wire allows a use in any environment, under other clothes, even for group therapy. These features do not seem to be present in other devices in the literature.

II. System Description

The wearable system is accurately described in previous papers [16-17]. The wearable system can be divided into two parts: the instrumented T-shirt and the readout unit. An inductive sensor, a conditioning electronic and transmission board (circuit board) and a feedback system to the patient (vibro-feedback) constitute the instrumented T-shirt. Whereas, the readout unit is the receiving data unit. In fig. 1, two images (front and rear) of the wearable system is reported.

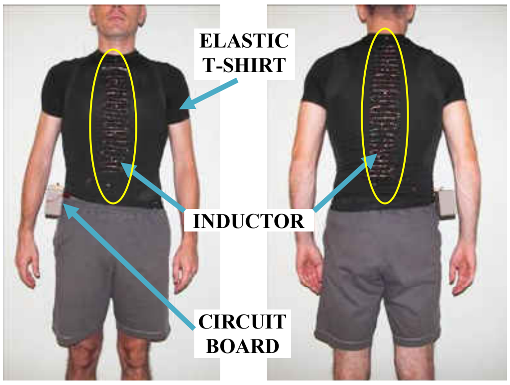

Fig. 1. Wearable system image (front and rear).

The data is transmitted wirelessly to the readout unit that can be connected to a PC (Personal Computer) or directly to the Internet. The posture of the patient is monitored using an inductive sensor properly sewn to the T-shirt across the back and chest of the patient. The detection technique is simple: a change in posture causes a variation of the geometry of the inductive sensor, generating a change in impedance across the sensor. The impedance variation is measured using a dedicated conditioning circuit supplied by rechargeable batteries, and transmitted to the dedicated readout unit.

The circuit board allows measuring the variation of the sensor impedance and transmitting wirelessly the data to the readout unit. The data transmission between wireless wearable electronics and the readout unit is via Bluetooth 2.4 GHz (EDS200) marketed by Parani. The T-shirt weighs is about 175 g as a normal T-shirt. The sensor is an enameled copper wire, properly sewn to the T-shirt around the patient's back and chest. The circuit board, powered by rechargeable batteries, incorporates conditioning and transmission circuits and it is housed in a box about 13x7x5 mm attached to the pants. The two terminals of the sensor on the T-shirt are two metal hooks that are used to connect the sensor to the circuit by means of a snap connector. By means of two buttons, you can start or stop the measurement phase, or make a calibration operation to fit the response of the system for each person.

III. Methods

A. Participants

Four postgraduate students physically fit to wear the same T-shirt took part in the study, below called form Participant_A to Participant_D. Participants have a mean age of 25.6 years, an average height of 178 cm and absence of disease to the spine. Informed consent was provided to all participants by ensuring both the ethical purpose of the research and the total degree of safety of the wearable system under study that has no conductive element in contact with the skin or effects of radiation of some kind.

B. Instrumentation and placement of spinal markers

A simple experimental apparatus for the characterization of the system has been prepared. The system, which includes the inductive sensor connected to electronics, was characterized by means of an optical measuring system (Cartesian Optoelectronic Dynamic Anthropometer - CODA) [18]. The optoelectronic system is made of CX1sensors (marketed by Codamotion), which acquires the signals from active markers that emit light in the infrared spectrum. The active markers are IR LED connected to a transceiver for the communication of the unique identifier. The sensors at each end of the unit CX1 solve horizontal movement and settle the vertical. This means that one unit CX1 can allow the measurement in 3D space. However, having more CX1 (three are used in the course of this research work) increases the volume of analysis and reduce the occlusion marker (periods of time in which the markers are not visible from any of the array). Each sensor determines three values that represent the position of the marker with respect to a fixed reference at very high resolution (0.05 mm at 3 m). The average variation of static CODA positioning marker in ten acquisitions is less than 0.1 mm achieved in a pyramidal volume between 2.0 m and 4.5 m from the CX1 Coda [18]. Having active marker, which emits infrared light (without interference with ambient lighting), despite the cost, allows greater precision and provides an ID intrinsic to each of them, being able to solve confused or fragmented trajectories even when the markers are positioned close to each other. Two CODA cameras were placed 1 m distant each other and the third camera about 2.2 m posterior to the participants. Light Emitting Diode (LED) indicators were positioned with double-sided adhesive tape on the surface of the T-shirt.

The adopted markers were placed to the patient as shown in fig. 2. Six markers (B1 to B6) are placed on the back and six on the abdomen (F1 to F6). The distance between the markers is constant and it is approximately 90 mm. The markers are connected to two transceivers placed on both shoulders of the participant to be visible from the cameras. The measured data are processed by proprietary software (Codamotion). The positions of the markers were monitored, and the distance between the points was calculated. The CODA system has the possibility to provide a signal synchronous with the acquisitions and at the same time, it accepts a start signal as input. These characteristics have been used to synchronize the acquisition of the wearable system and the optical measuring system.

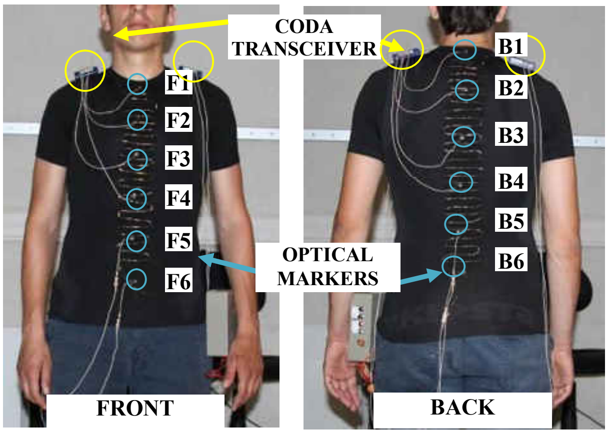

Fig. 2. Active markers positioning.

C. *Laboratory Experimental protocol*

The activities carried out in the laboratory have the aim to validate the wearable measurement system compared to the traditional system for movement analysis, described previously. Therefore, this study assesses the concurrent validity of the wearable system in the monitoring of activities that affect the movement of the trunk in the sagittal plane.

The wearable measuring system was calibrated for each patient. Each patient wearing the measurement system initially performs a series of exercises in a sitting position with the aim to establish the range of elongation and straightening of the trunk in the sagittal plane. Initially, the subject sits for five seconds as straight and tall as possible, in a hyperextended position (Phyper-ext), then fold it in a completely "slump" (Pslump) position without bending forward at the hip, holding for five seconds, after which the hyper-extended position is repeated. Before the test, in order to minimize the degree of natural variation in the way in which the subject performs the task, they are asked to perform the exercise a couple of times for practice. Therefore, each subject performed the exercise with the protocol specified above and the positions of the markers were monitored and recorded by the optical system. At the same time, the voltage signal was measured and the synchronization channel on the Codamotion hardware was used to synchronize the two acquisition systems.

In many applications, the postural information is not required in terms of millimeters, but in terms of Range of Motion (ROM) [15, 19-20]. Therefore, in this work, the posture is expressed as a percentage of the Range of Motion (ROM) in order to standardize the results and to compare them with other results from other posture monitoring systems in the literature [19-20]. Therefore, the degree of flexion / extension is expressed in relation to a reference ROM, for example, ROM bending the back by sitting. This reflects the clinical evaluation of patients, where the sitting posture is often considered in relation to the individual ROM [15]. Each posture or activity was performed for 60 s, with 30 s of data in the middle captured simultaneously by both systems. Posture and tasks were practiced three times before data collection. Below, the list of selected tests, which recall some daily activities in which the body moves in the sagittal plane by performing flexion-extension, is reported. (I) Sitting on a stool, flexion-extension of the trunk (test 1 called "stool"). (II) Sitting on a chair, bending-stretching forward of the trunk, hands resting on a table and return (test 2 called "table"). (III) Sitting on an armchair with trunk extended. Partial flexion of the trunk, forearms resting on the armrests and back (test 3 called "armchair"). Since the data are expressed as ROM, CODA data were converted to ROM to allow an easier comparison. A comparison of the measurement data was assessed using the correlation coefficient (Rs) and the mean difference (d), as shown in other papers reported in the literature [19-20] in order to standardize the results and to compare them with other results from other posture monitoring systems in the literature.

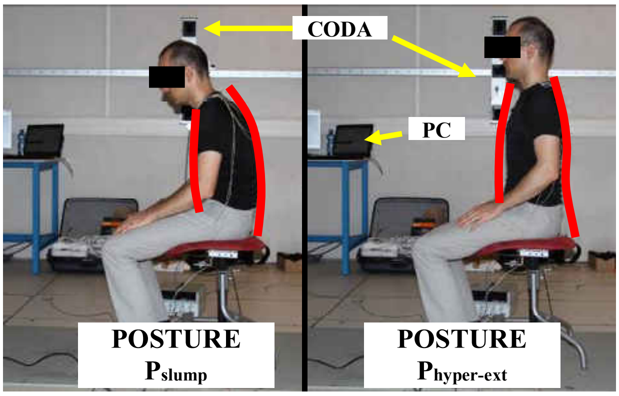

Fig. 3. Images during a trial session with the stool (Participant A).

D. *Home experimental protocol*

The new wearable measurement system was also tested in a real environment by one of the previous participants (Participant_D). The goal was to test the system in a real context and to assess the possibility of monitoring the sitting postural activity for a long time at home. For this purpose, two "Holter postural records" were arranged, one lasting for two hours and the other for about three hours. During the tests, a second person recorded all those movements considered significant according to the type of measurement made by the system. Therefore, compound movements have been neglected, i.e. those that take place on many levels and only movements of the trunk in the sagittal plane were considered. The activity of calibration as described above was performed before the Holters.

In fig. 4, the Participant_D in a Pslump position wearing the new system at home is visible. The two Holter records consider two typical situations: the first when the person is sitting at table and the second when the person is sitting at desk for working. The activities performed at home have been identified based on the above two situations and consist for example in writing, reading, eating, watching television, typing keyboard, and so on.

In fig. 5, the Participant_D is sitting at table in the house and wearing the measurement system. Participant_D is photographed in two different moments of the monitoring during two different activities. Furthermore, the observer recorded the movements and the execution time.

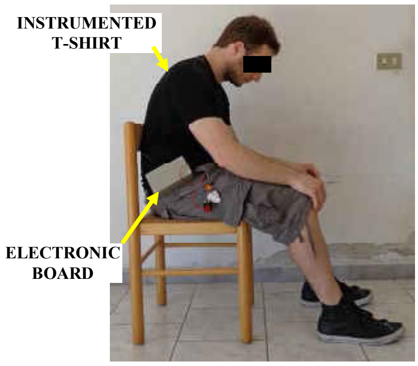

Fig. 4. Participant_D during an activity at home.

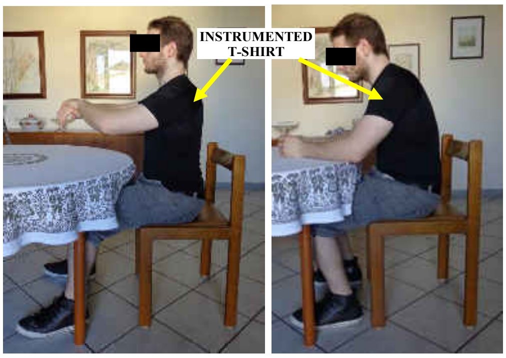

Fig. 5. Images of Participant_D performing the "table task" in two different moments during Holter record.

IV. Experimental Results and Discussions

In this chapter, the results obtained in the laboratory tests of comparison between the wearable measurement system and the optical system are presented. Subsequently, a graph, which shows the posture monitoring carried out at home, is reported.

A. Laboratory experimental results

In fig. 6, part of the traces obtained for the monitoring of Participant_A during the three activities identified and described previously is reported. As it can be seen, for all the activities there is a good repeatability of each exercise. This aspect guarantees that the degree of natural variation in the way in which the subject performs the task was minimized. In fig. 6, the activities carried out on the stool has a ROM that goes from about 10% to about 95%, whereas the activity "table" ranges from about 10% to 100%. This is probably due to the fact that Participant_A's arms on the table help him in the push or as a reference for a complete extension of the trunk. The last activity called "armchair" starts 5% up to 85%; this may be due to the presence of the backrest and armrests that on one hand direct and accompany the movement and on the other constrain to certain levels of ROM. In fig. 7, the ROMs obtained with the wearable system are correlated with the respective ROMs obtained with the optical system. The synchronization between the acquisitions of the two systems allows correlating the two values of ROM. From the graphs, it can be seen that the movements for all three activities are different with a higher correlation for the third activity probably due to the more constrained movement. Interesting results are the two parts of the graphs between 20% and 50% for the "table" and "stool" in which the two values of ROM are different. This phenomenon is probably due to movements in the sagittal plane. The data collected by the optical system and the wearable system for the different tests from the four participants were analyzed and compared. The results of comparison obtained with all the measured values (correlation coefficient - Rs and average difference - d) are reported in Table 1. As it can be seen, the values of the correlation coefficient are all greater than 0.97, with the best results for the task "armchair" (the maximum values is 0.993). The monitoring of the movement with the person sitting on the stool had the values of correlation coefficient lower. A similar argument can be made for the mean difference values. This can be explained by considering that a movement on a stool and then without backrest and armrests is freer and therefore more subject to small movements not in the sagittal plane. In addition, the deviation of the data of average difference for the tests with the stool all in one direction can probably be assumed to incorrect calibration operation.

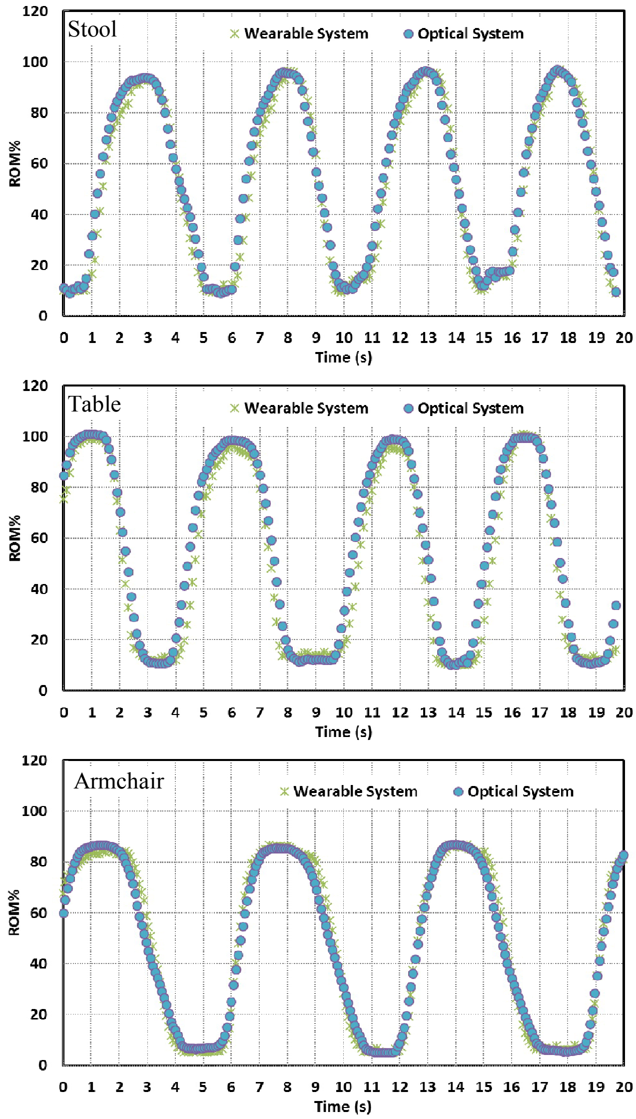

Fig. 6. Range of Motion (ROM) in Flexion/Extension (anterior pelvic tilting and lunbar extension 0%ROM and full forward bending 100%ROM) Participant_A.

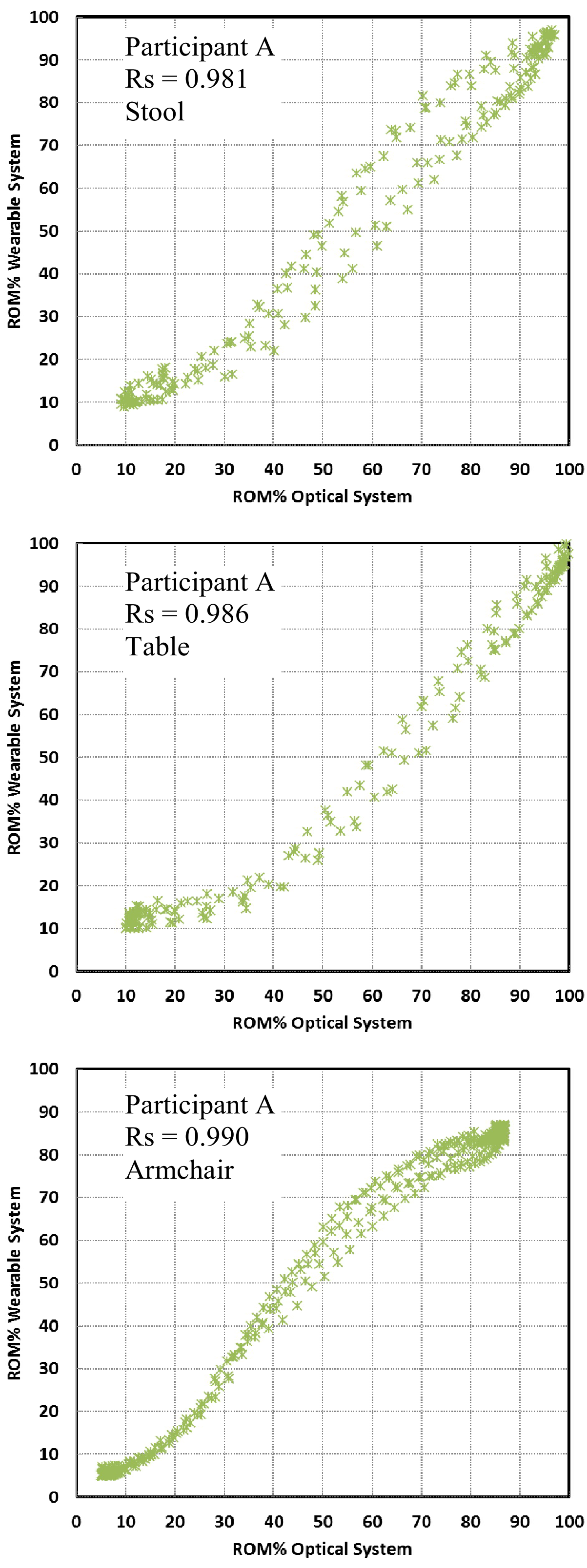

Fig. 7. Range of Motion (ROM) obtained with the wearable system and compared with the optical system's one. The three activities are reported and the correlation coefficients are shown (Participant A).

In the literature, the experimental results obtained with wearable systems and compared with optical measurement systems are in accordance with the values obtained in this work. For example, in Lucy E. Dunne et al. [10] and [21], the average value of the correlation coefficient between the measures made with a wearable system and measures with the optical is equal to 0.913 (the maximum value corresponds to 0.962, the minimum is equal to 0.837). Jonathan M. Williams el al. in [22] have obtained values between 0.97 and 0.98 and WY. Wong and MS. Wong in [23] values from 0.829.

TABLE I. CORRELATION COEFFICIENTS AND MEAN DIFFERENCES BETWEEN THE WEARABLE SYSTEM AND THE OPTICAL SYSTEM.

	Stool		*Table*		*Armchair*	
	Rs	*d (%ROM)*	*Rs*	*d (%ROM)*	*Rs*	*d (%ROM)*
Part. A	0.981	5.938	0.986	2.889	0.990	-0.918
Part. B	0.976	7.646	0.983	5.187	0.983	6.355
Part. C	0.979	7.809	0.983	-0.669	0.984	2.748
Part. D	0.980	7.214	0.983	-1.400	0.993	4.476

The correspondence during the individual specific tasks was also assessed with the fig. 8, as reported in different works in the literature [19-20]. In fig. 8, the graph of the mean difference of the extreme average positions for the four participants for the three types of activity is shown compared to the mean values. The dashed lines indicate the uncertainty of the mean difference between wearable system and optical system with a confidence interval of 95%. The extreme positions were calculated and obtained starting from any single path and identifying the maximum and minimum relative to each task. The average difference between wearable system and optical system never exceeds 4% of ROM. The differences between the two methods are not constant, but depend on the value of the mean ROM. It follows that when the ROM is large the average difference is greater. This would be in line with what was found in [17], in which for high elongations there are greater measurement uncertainties. However, the value of 4% turns out to be a good result for the target applications of wearable system. In fact, in the literature, values below 13%-19% can be considered acceptable errors [20].

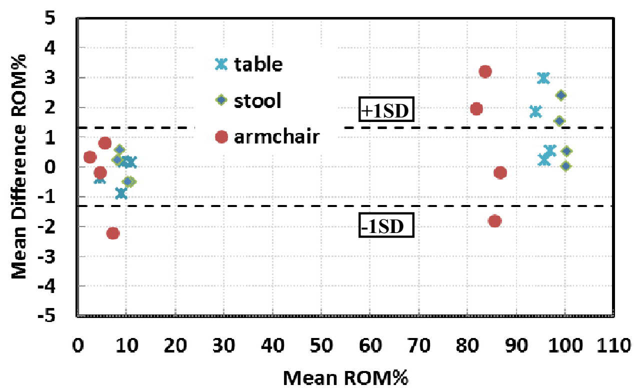

Fig. 8. Bland and Altman plot of all four participants for the three types of exercises on the two extreme positions reached for each exercise.

B. *Home experimental results*

In fig. 9, a graph relating an area of the track of the overall monitoring is reported. The track is part of the monitoring of the activities at the table. This chart allows observing in detail the evolution of data over time and corresponding to the change the relative activity is given. From the graph, the posture variation is clearly visible and for some activities, the ROM variation is significant. However, with the wearable system, it is not possible discretizing the different activities in the first instance; in fact, the "reading" activity has a clipping almost similar to the activity of "writing", as well as other activities. Furthermore, for some people, identify individual activities may be considered an infringement of privacy. The aim of the system is to identify the subject's activity but monitor the postural behavior.

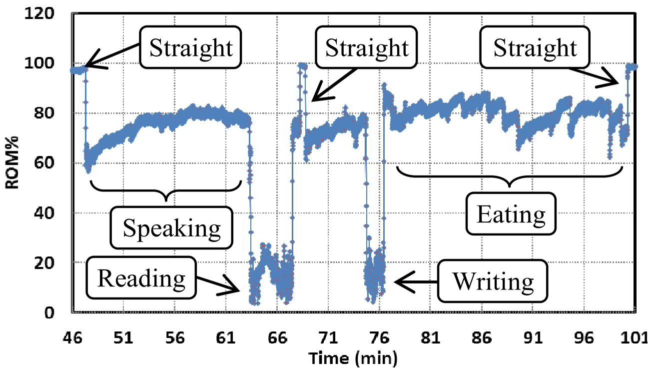

Fig. 9. An extract form the "postural Holter" recorded at home (Participant D).

V. Conclusions

The correlation coefficients obtained in this paper range from 0.95 to 0.98, in line with the values reported in the literature. Therefore, from the results of comparison it is observed that the wearable system can be used with validity in the monitoring of posture and movement of the trunk during a variety of functional activities both in hospital and at home. The T-shirt with the sewn copper wire is washable; it was washed because of its use and then no variation in the operation was observed, the enameled copper preserved its characteristics. Furthermore, this wearable system has characteristics of non-invasiveness and ease of use higher than the devices present in the literature. In this study, only motor activity of the trunk in the sagittal plane were considered, movement outside this plan like twisting and bending side will be evaluated later. In the following research activities, several tests will be arranged with the clinicians in order to have a greater number of cases and perform evaluations on a large number of patients.

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