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Analysis of Comfort and Ergonomics for Clinical Work Environments*

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Abstract— Work related musculoskeletal disorders (WMSD) are a serious risk to workers' health in any work environment, and especially in clinical work places. These disorders are typically the result of prolonged exposure to non-ergonomic postures and the resulting discomfort in the workplace. Thus a continuous assessment of comfort and ergonomics is necessary. There are different techniques available to make such assessments, such as self-reports on perceived discomfort and observational scoring models based on the posture's relevant joint angles. These methods are popular in medical and industrial environments alike. However, there are uncertainties with regards to objectivity of these methods and whether they provide a full picture. This paper reports on a study about these methods and how they correlate with the activity of muscles involved in the task at hand. A wearable 4-channel electromyography (EMG) and joint angle estimation device with wireless transmission was made specifically for this study to allow continuous, long-term and real-time measurements and recording of activities. N=10 participants took part in an experiment involving a buzz-wire test at 3 different levels, with their muscle activity (EMG), joint angle scores (Rapid Upper Limb Assessment – RULA), self-reports of perceived discomfort (Borg scale) and performance score on the buzz-wire being recorded and compared. Results show that the Borg scale is not responsive to smaller changes in discomfort whereas RULA and EMG can be used to detect more detailed changes in discomfort, effort and ergonomics.

I. INTRODUCTION

Many tools are developed each year to make tasks easier, more accurate and more ergonomic. There are, however, still many tasks and jobs that lead to issues such as musculoskeletal disorders in the long run. Clinical jobs in particular require day to day activities involving postures and work that are uncomfortable and non-ergonomic, which if not noticed, can lead to work related musculoskeletal disorders (WMSDs). The main issue is that comfort is not easily defined, is subjective and is therefore difficult to compare. Different scoring systems have been developed to quantify comfort and attempt to improve it. In clinical environments, a popular method is the Borg scale [1]. This method, in its modified form, consists of

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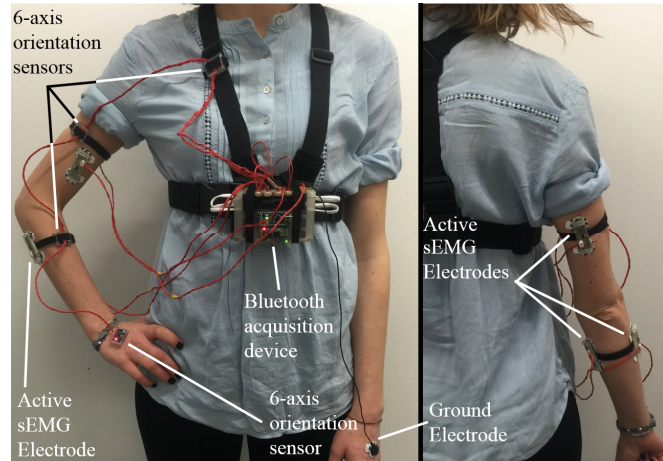
Figure 1 – The wearable muscle activity and joint angle estimation device used in this work to study correlation of different comfort and ergonomics assessment techniques.

a scoring band starting at 0, representing rest, to 10, representing maximal discomfort. Borg is a measure of perceived discomfort. For ergonomics, other scoring systems exist that are based on the posture required to complete a task. One popular method is Rapid Upper Limb Assessment (RULA). RULA assigns scores based on joint angles of a given posture, mainly in the upper body. These points are then combined using a look-up table to give a final overall score, with lower numbers representing a more ergonomic posture [2]. RULA is a commonly employed ergonomic risk assessment tool which has proven successful in assessing real-world case studies in manufacturing environments [3]. Concerns have been raised however, regarding the capacity of RULA to assess WMSDs in dynamic tasks, particularly if heavy load lifting is involved [4].

A more intuitive way to look into dynamic tasks and effort involved in them, is using electromyography (EMG) to identify the level of muscle engagement. In [5], the relationship between the mean power frequency (MPF) of the EMG signal of the upper trapezius muscle and the perceived exertion is studied by subjecting participants to 6-minute shoulder elevation endurance tasks. Results show a significant linear correlation between the MPF and the perceived discomfort ratings. Similarly, [6] and [7] study the correlation between MPF and Borg scale for lumbar muscles. In both cases, a decrease in MPF is accompanied by an increase in perceived exertion ratings as well as a decrease in endurance time. Alternatively, [8] and [9] found significant associations between the percentage of maximum voluntary contraction (%MVC), heartrate and perceived discomfort ratings.

Studies combining EMG and RULA have also been conducted. In [10], two types of laparoscopy, traditional laparoscopy (LAP) and laparoendoscopic single-site surgery (LESS), are compared by means of EMG, RULA and a motion

capture data glove to measure angles. Though LESS approach heightened muscular activity in trapezius and wrist extensor muscles significantly, the RULA scoring system showed an improved wrist position in LESS approach compared to traditional laparoscopy, in which RULA scores classified LAP as hazardous.

Another study examining the relationship between EMG signals, perceived discomfort, RULA scores and job attitude questionnaires was conducted among twenty participants who performed typing tasks in three postures with differing risk levels, each 30-minute long [11]. EMG results showed no statistical significance except in the response of forearm extensor muscles to task duration. This however can be due to the low amount of EMG signal samples, six 1-second samples taken for the 30-minute task, which gives a very limited observation of muscle activity. The review in [12] concludes that simple observational methods are the best match for the needs of practitioners and occupational safety providers. Filling in questionnaires and going through look-up tables allows for a quick assessment and requires minimal training. This is in contrast to using EMG, which provides objective measures of a person's behaviour and effort [13], but remains mostly exclusive to hospitals and laboratories and is not used as a day to day tool due to its complexity and obtrusiveness. However, with advances in implementing electrophysiological sensors as wearable devices [14], their regular use in the near future seems possible. It is therefore necessary to better understand the present methods to assess and analyse comfort and how other techniques such as EMG can be used to enhance them.

This paper reports on a study to explore different measures of comfort and ergonomics, both subjective and objective, and how they correlate. These measures are EMG, Borg and RULA. The aim is to investigate if a new scoring system can be developed that provides a better measure of comfort by adding real-time muscle activity monitoring to previous models.

II. Materials and Methods

In order to achieve the aims set out in §I, an experiment is designed to consider the effects of different postures during a task requiring focus, on EMG, RULA and Borg scale self-reports as well as overall performance. A buzz-wire test is created and settled on as the focused task, as it involves different arm postures, can be easily monitored and scored and is simply adjustable at different heights to change the difficulty of the task. In order to continuously record muscle activity and joint angle data, a set of sensors were created and implemented in the form of a wearable device specifically made for this study.

A. EMG acquisition and analysis

A 4-channel EMG acquisition device was designed and created for these tests. Each channel consists of an instrumentation amplifier, followed by a 4th order Butterworth high-pass filter and gain adjustment block and a 4th order Butterworth low-pass filter for anti-aliasing. The overall EMG gain is set to 1000 V/V and the bandwidth set out by the above filters is 20-450Hz. In order for the EMG design to be in line with validated and established standards in EMG acquisition,

the recommendations of "Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles" (SENIAM), a European Union project focused on setting standards for EMG sensor design, placement and data analysis, were closely followed [15]. Active electrodes are used for better isolation of the skin-electrode interface and the instrumentation amplifier inputs, in order to relax impedance matching constraints. These electrodes are visible in Figure 1. The output of the system is fed into a Bitalino® data acquisition device, which samples the data at 1 kHz, and transmits over Bluetooth.

A MATLAB script is created to perform the EMG signal analysis after acquisition. The script initially removes the signal's dc level and normalises it to the relevant muscle's maximum voluntary contraction (MVC – recorded at the end of each participant's experiment). In this manner, the signal can fairly be compared with signals from other participants. The signal is then high-pass filtered with a 4th order Butterworth filter (f_c=20Hz) to remove any remaining motion artefacts. The signal can now be rectified. A sliding window (200ms) root mean square (rms) method is then used to obtain the EMG rms waveform. The average of the rms waveform is considered as a measure of muscle effort during the task.

B. RULA acquisition

The RULA model relies on joint angles in the upper limbs. For the sake of this study, only the joint angles in the dominant arm are considered for real-time acquisition as the experiment task involves limited movement. The RULA worksheet as described by ErgonomicsPlus®[1] is used for scoring. The worksheet describes 4 steps to identify the RULA score for the arm, looking at the upper arm, lower arm, wrist position and twist respectively.

To implement this, the InvenSense® MPU6050 breakout board is used. This board houses a 3-axis accelerometer and a 3-axis gyroscope and outputs the data on an Inter-Integrated Circuit (I^2C) bus. The board is interfaced with an Arduino Nano for acquisition. The Arduino code relies on the 'I2C' and 'MotionApps' libraries developed by J. Rowberg and available in open source format[2]. The on-board digital motion processor (DMP) is used to acquire yaw, pitch and roll values directly. Using 4 boards, placed on the chest, the upper arm, the forearm and the hand respectively, it is possible to calculate joint angles for the arm using a forward kinematics approach. The Arduino Nano applies the RULA calculations on board and transmits the RULA score via Bluetooth to a nearby computer. A video camera is present to record the participants' movements during the task as a further confirmation of the recorded RULA values. Once the waveform resulting from the real-time changes in RULA score is obtained for the duration of the task, its average value is used for comparison.

C. Buzz-wire test

The Buzz-wire test is implemented using a thick wire. The participants use a loop mounted on a handle to follow the wire which is connected to a buzzer circuit that beeps if there is collision (referred to as an '*error*' from now on). The participant is thus forced to keep a steady hand while following the curves in the wire, which is shaped to enforce different joint angles. The number of errors are recorded using the

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[1] http://ergo-plus.com/wp-content/uploads/RULA.pdf

[2] http://www.i2cdevlib.com/

circuit, as well as a manual counter and the video recorded on the camera for further confirmation. Performance is scored using a time-penalty approach where each participant's score is their elapsed time on the task plus 10 seconds added for each error. Thus, a lower final number means a better performance. The buzz-wire path can be seen in Figure 2.

III. EXPERIMENTS AND RESULTS

The experiments in this section are designed to allow a simultaneous acquisition of muscle activity and joint angles in the arm, as well as Borg scale assessments through questions in between trials. N=10 participants have taken part in the experiments. They consist of 6 male and 4 female healthy participants, with an age range of 28.5±5.5. The EMG and orientation sensors' acquisition circuits, are placed in a housing box mounted on a chest strap belt (refer to Figure 1). A video camera is also used, subject to the written consent of the participant, to record their activity throughout. Ethical approval for these experiments was obtained previously, reference number: BDM/13/14-123 (KCL Research Ethics).

The EMG sensors are used on 4 muscle areas in the participants' dominant arm (right hand for all 10): The *wrist flexors*, the *wrist extensors*, the *triceps brachii* and the *biceps brachii*. Electrode locations are selected within the guidelines of SENIAM. A ground electrode is placed on the back of the non-dominant hand. The orientation sensors are placed individually on the links of the dominant arm: the upper arm, the forearm and the back of the hand. Double sided tape is used to fix the sensor housing down, with a hook and loop strap added for robustness. The participants are asked to hold their arm straight in front of them at a 90° angle, with the palm of the hand parallel to the sagittal plane. The sensors for the upper arm and forearm are then placed along a straight line connecting the shoulder joint to the wrist joint. The sensor for the hand is placed on the back of it. In order to calibrate the sensors, the participants are initially asked to keep their arm at a 0° angle pointing downwards, called the *zero* position. The yaw, pitch and roll readings for all the sensors are mapped to 0° at that point. Then, to calibrate the upper arm RULA thresholds (step 1 in the RULA worksheet), the participant is asked to hold their arm at 20°, 45° and 90° locations, following a degree marking placed on the wall and adjusted to their height. The participant is then asked to hold their upper arm in the zero position, and rotate their lower arm to 50° and 100°, to calibrate for step 2 in the RULA worksheet. Finally, the participant is asked to hold their arm straight at a 90° angle with the palm of the hand facing and parallel to the ground, to calibrate the wrist values.

The participant will then sit in front of the buzz-wire. The chair is adjusted so that its midpoint is aligned with that of the buzz-wire and that it is close enough to the table so that the participant's closed fist on the dominant arm barely touches the edge of the table if the upper arm is kept in the zero position and the lower arm is at a 90° angle. The height of the straight arm with respect to the table is measured and rounded down to the nearest product of 10 as the lowest height level of the buzz-wire, i.e. if the measured height is 23cm, then the selected height is 20cm. The two higher levels will be apart by 20cm each, i.e. in the case of this example, the three levels will be Level 1: 20cm, Level 2: 40cm and Level 3: 60cm.

At this point, the participant is introduced to the concept of the modified Borg scale. A colour-coded Borg scale chart is
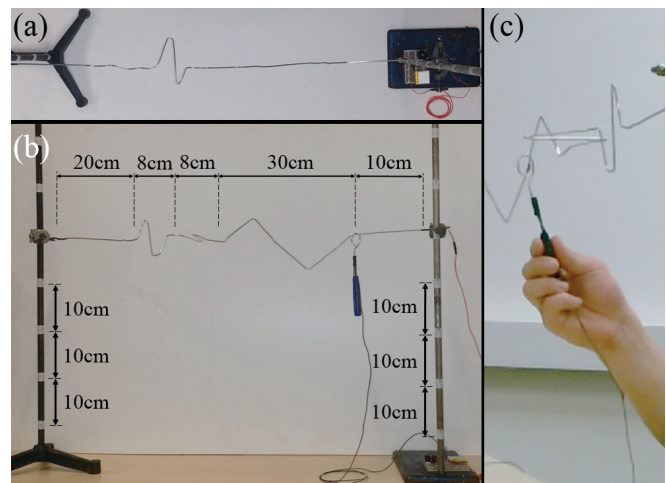

Figure 2 – Experiment set-up. (a) The buzz-wire top view, (b) the buzz-wire frontal view, (c) a participant passing the loop on the buzz-wire.

hung in front of the participants for reference. The participant is asked to describe their current level of discomfort as a baseline before any of the test activities have started. This question is repeated between every two trials and values recorded to describe the discomfort during each trial.

The participant is initially given a chance to do a practice run on the buzz-wire to get familiar with how to manipulate the loop, before moving on to the actual test. There are 3 height levels in total for each participant and they are asked to repeat each level 3 times. The levels sequence is randomised for each participant to limit the effects of learning.

Trials take 20 seconds to 2 minutes depending on the participant and the level they are working on. In between every two trial, a resting time of at least 1.5 minutes is given to avoid effects of fatigue. The resulting data is analysed as described in §II.A-C to obtain comparable values for EMG, RULA and performance. For statistical analysis, ANOVA is used to check for differences across trials of the same level and Wilcoxon Signed Rank (WSR) is used for differences across different levels (alpha=0.05). The latter is chosen as the sample population cannot be assumed to be normally distributed and thus non-parametric tests are required. Regression is used to find relationship and correlation between the different measurements above. Table 1 shows the results of the experiment averaged across all N=10 participants.

When looking across trials at a single level (e.g. height level 1, repeated trials 1 to 3), there is no significant difference in Borg scale ratings, RULA scores or any of the muscle EMG. This follows theoretical understanding of the tasks, as trials are at the same height level, no change in comfort, ergonomics or muscle effort is expected. There is, however, a significant difference for the performance score across trials of height level 3 (p=0.029). This shows that there is some learning involved within this particular level, causing further trials to lead to significant performance change.

Looking across different height levels, further significant differences are observed. For the Borg scale, there is a significant difference when comparing level 2 vs. level 3 and level 1 vs. level 3 (WSR positive sum=6, and 1 respectively. Critical value=8). The difference is not significant however, when comparing level 1 vs. level 2. The Borg scale thus shows success in identifying a large expected change in discomfort, but where differences are small, i.e. level 1 vs. level 2, the scale does not provide a quantifiable difference. RULA however

shows a significant difference across all levels (WSR positive sum =8, 0 and 0 respectively. Critical value=8), proving to be a better measure of change in comfort and ergonomics. For the performance score, the only significant difference is seen when comparing level 1 vs. level 3 (WSR positive sum=3, critical value=8), whereas subsequent levels are not proving difficult enough to significantly affect performance.

For EMG however, in the case of wrist extensor and flexor muscles, there is no significant difference across levels. This is to be expected, as the change in height levels does not cause a change in the force that the wrist needs to apply. Therefore, the contraction of the relevant muscles will not be changing significantly. In the case of the biceps brachii there is a significant difference when comparing level 2 vs level 3 (WSR positive sum=8, critical value=8) and for the triceps brachii the difference is significant across all levels (WSR positive sum=8, 7 and 0 respectively, critical value=8). This makes sense as to lift the arm to higher levels, the biceps and triceps muscles are engaged and have to apply the force to lift the arm and keep it steady. In terms of correlation identified through regression, Borg and RULA show significant correlation (p=0.035). The biceps brachii EMG has a significant correlation with both RUL A and Borg as well (WSR p=0.013 and p=0.048 respectively). These correlation results are in line with the significant difference results but differ from previous findings in [11], which is possibly due to limited EMG data obtained in that study.

It is therefore observed that, while the Borg score is useful in detecting large changes in comfort level (and not so useful for small changes), RULA and EMG are able to provide more detailed information. The RULA score is able to identify different ergonomics across all levels, and EMG provides details on how muscles are engaged and which muscles are the ones being affected by increasing difficulty in the task, filling in the gaps within the RULA method.[3]

IV. Conclusion

This paper reports on an experiment specifically designed to identify how different measures of comfort and ergonomics, namely Borg scale, RULA and EMG correlate with each other. Based on the results of the experiment, attended by N=10 participants, the RULA score and EMG measurements showed the best performance in detecting task difficulty and discomfort. The Borg scale was able to detect large changes in difficulty, but was inconclusive in minor changes.

While the Borg scale and RULA techniques are widely popular in medical and industrial fields alike, they are limited in their scope. As the results above show, the Borg scale is not suitable to identify minor changes in discomfort, nor is it suitable for use in a low population sample. Subjectivity was a major issue with the Borg scale throughout the experiment. It was difficult for some of the participants to identify with the scale and we received different reactions to the Borg interview question. The RULA method however has a more objective approach and the results show that it has been suitable in detecting the differing levels of discomfort in detail; but it is limited to steady postures and not applicable in highly dynamic tasks nor does it consider specific muscle engagement and effort. The muscle activity results show how EMG can be beneficial in forming a new, more accurate comfort and ergonomics scoring system. New wearable

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TABLE 1.   Averaged results across n=10 participants shown per height levels 1, 2 and 3. The values with significant mean difference within each column, are highlighted (EMG values are RMS of normalised signals, thus no unit).

	Ext.	Flex.	Tri.	Bi.	Borg	RULA	Perf.
1	0.08012	0.031	0.0143	0.027	2.63	4.062	120.3
2	0.07610	0.033	0.0173	0.028	2.90	4.176	129.7
3	0.07583	0.030	0.0231	0.032	3.96	5.082	145.5

devices and sensors can provide such data without adding to the difficulty of comfort and ergonomics assessment.

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[3] Experiment data and analysis details will be made available upon request.