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Tetherless Ergonomics Workstation to Assess Nurses' Physical Workload in a Clinical Setting

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Abstract—**Nurses are at risk of physical injury when moving immobile patients. This paper describes the development and testing of a tetherless ergonomics workstation that is suitable for studying nurses' physical workload in a clinical setting. The workstation uses wearable sensors to record multiple channels of body orientation and muscle activity and wirelessly transmits them to a base station laptop computer for display, storage, and analysis. In preparation for use in a clinical setting, the workstation was tested in a laboratory equipped for multi-camera video motion analysis. The testing included a pilot study of the effect of bed height on student nurses' physical workload while they repositioned a volunteer posing as a bedridden patient toward the head of the bed. Each nurse subject chose a preferred bed height, and data were recorded, in randomized order, with the bed at this height, at 0.1 m below this height, and at 0.1 m above this height. The testing showed that the body orientation recordings made by the wearable sensors agreed closely with those obtained from the video motion analysis system. The pilot study showed the following trends: As the bed height was raised, the nurses' trunk flexion at both thoracic and lumbar sites and lumbar muscle effort decreased, whereas trapezius and deltoid muscle effort increased. These trends will be evaluated by further studies of practicing nurses in the clinical setting.**

I. INTRODUCTION

NURSES are at physical risk when they move immobile patients [1], [2]. The height of the working surface relative to the subject doing the work is a major determinant in risk of musculoskeletal injury [3]. Integrated systems have been developed for laboratory studies of physical exposure to work-related musculoskeletal risks that include multi-camera video motion analysis coordinated with force platforms, electromyogram (EMG) signals, and other inputs [4]. This paper describes the development and testing of a tetherless ergonomics workstation that will take the assessment of the physical workload experienced by nurses out of the laboratory and into the actual clinical setting. The workstation was motivated by the success of an ergonomics workstation developed previously to study the physical and mental stress experienced by surgeons performing minimally-invasive surgery [5]. As part of the testing of the new workstation, a pilot study of nurses' workload was carried out with student nurses in a laboratory equipped with video motion analysis capability. The laboratory testing was to validate the body posture and motion measurements made by the tetherless ergonomics workstation relative to those obtained by video motion analysis and to test and refine the protocol for planned clinical studies.

II. TETHERLESS ERGONOMICS WORKSTATION

The tetherless ergonomics workstation consists of a battery-powered wearable module and a base station laptop computer. The wearable module consists of sensors, preprocessing electronics, a miniature computer (ViA, Burnsville, Minnesota) worn in a belt across the lower back, and a custom-designed adjustable vest. The module can operate for up to 6 hr before recharging. For the present study, the sensors consist of two small, lightweight 3DM triaxial orientation sensors and three channels of skin surface EMG. The wearable computer controls signal acquisition, preprocesses the signals, and continually telemeters the results to the base station. The base station acquires the telemetered data and displays and saves the signals. For the actual clinical studies, the ergonomics workstation additionally will use multiple miniature 2.4-GHz wireless cameras to record audio and video of the subject's actions.

Figure 1 shows a subject fitted with the wearable portion of the ergonomics workstation. The wearable computer and electronics are on the lower back beneath the vest. One orientation sensor is visible on the middle of the upper back, and the other is below it, mostly covered with tape. The electrodes for the three EMG channels are placed over the right lumbar, right trapezius, and right deltoid muscles, and the electrode cables are routed in Velcro channels on the vest to the electronics located under the vest. Lacing on the sides of the vest allows it to be fitted to individual subjects.

For maximum development flexibility, both the wearable computer and the base station laptop computer use custom-written LabVIEW (National Instruments) programs. The LabVIEW program on the wearable computer samples the EMG signals at 200 Hz per channel using a 16-channel, 16-bit analog-to-digital converter PCMCIA card (DAQCard-AI-16XE-50, National Instruments, Austin, Texas), and, in order to reduce the bit transmission rate, computes a moving-average true root-mean-square (RMS) value for each EMG channel. At a 10-Hz rate, the LabVIEW program

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polls the two orientation sensors via two-way RS-232 links for their roll, pitch, and yaw values and uses User Datagram Protocol (UDP) and a 2.4-GHz, frequency-hopping, spread spectrum wireless 11-Mbit/s local area network (LAN) PCMCIA card (Orinoco Gold, Lucent Technologies, Murray Hill, New Jersey) to send time-multiplexed floating-point values for all nine signals, i.e., the six orientations and three EMG channels, to the base station.

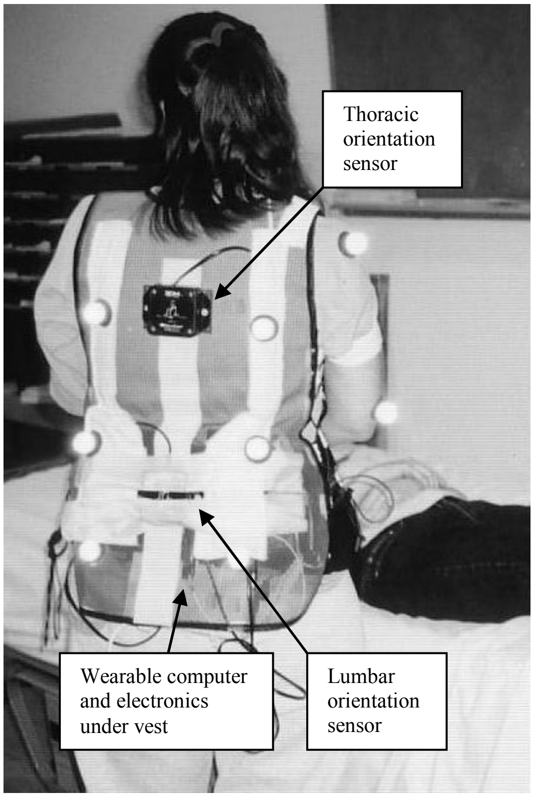
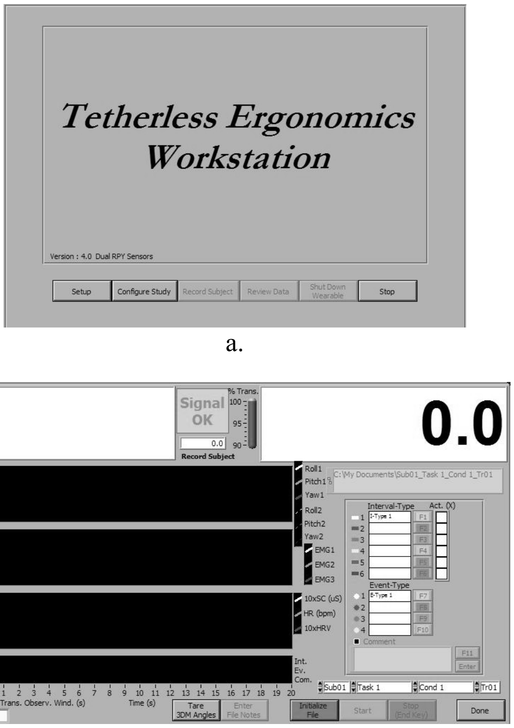


Fig. 1. Wearable part of the tetherless ergonomics workstation on a subject. The wearable computer and electronics are against the lower back beneath the vest. Orientation sensors are on the upper and lower back. Skin surface EMG electrodes are over the right lumbar, right trapezius, and right deltoid muscles. The bright dots are reflectors used in a video motion analysis laboratory to validate the wearable system.

The LabVIEW program on the base station laptop computer lets the user configure a study, make a recording, enter coded event markers and comments during recording, save the signals and user entries, and review, edit, and analyze recording files. Figure 2 shows the start-up (a) and record mode (b) front panels of the base station LabVIEW program.

The start-up front panel (Fig. 2a) first makes available a "Setup" button to let the user modify communication protocols if desired, a "Configure Study" button to let the user specify the study structure and names for study tasks and conditions, number of subjects, number of trials, and names for interval-type (having a beginning and ending) and event-type (at a point in time) markers that the user can enter during a recording, and a "Stop" button. After Configure Study is done, the front panel makes available the buttons "Record Subject" to make a recording, "Review Data" to review, edit, and analyze recorded files, and "Shut Down Wearable" to remotely turn off the wearable computer.



a.

b.

Fig. 2. Front panels for (a) start-up and (b) record mode for the custom LabVIEW software on the tetherless ergonomics workstation base station laptop computer.

The record mode front panel (Fig. 2b) first presents a "Tare 3DM Angles" button, which lets the user zero out the triaxial values for each of the two orientation sensors once the subject is standing in the ready position, an "Initialize File" button, to store header information in a file named according to the selected subject, task, condition, and trial number, and "Done" button to return to the start-up front panel. Then, the front panel makes available the buttons "Enter File Notes" in case the user wants to include in the file some preliminary notes about the recording, "Start" to begin a recording, and "Stop" to terminate a recording. The front panel provides buttons for annotating the recording with previously-defined interval-type and event-type markers and also for entering free-format comments. During a recording, the front panel displays all of the orientation and EMG signals and user entries. The date and elapsed recording time in seconds are displayed in the top left and right areas on the front panel.

III. PILOT STUDY METHODOLOGY

The purpose of the tetherless ergonomics workstation is to study in the clinical setting the physical workload experienced by nurses during the common task of repositioning a bedridden patient. In preparation for these studies, the tetherless ergonomics workstation was used, with IRB approval, for a pilot study of student nurses on the California State University, Sacramento (CSUS) campus. The study was performed in the CSUS Biomechanics Laboratory in order to use its three-dimensional motion analysis system to validate the body posture and motion measurements obtained by the wearable system.

Six students from the CSUS Division of Nursing served as subjects. A seventh nursing student acted as a bedridden patient. Each subject repositioned the 57-kg patient on a standard electric-powered adjustable hospital bed. For the repositioning activity, the patient lay supine with knees raised so that the thighs formed approximately a 45-deg. angle from horizontal. The subject began a trial standing upright facing the right side of the bed. Then, by placing the left arm under the patient's shoulders and right arm under the patient's thighs, the subject moved the patient approximately 0.4 m to the subject's left, toward the head of the bed. The subject then returned to the upright stance. The repositioning activity was completed for two trials at each of three bed heights in randomized order. The first height ("Preferred") was individually selected by each subject (repeatability of this height was not determined). The other two bed heights were 0.1 m above and 0.1 m below the preferred height.

The subjects' physical workload was measured by the tetherless ergonomics workstation. With the aid of the vest, subject preparation could be done by one investigator. Spine orientation was monitored by a 3DM triaxial orientation sensor positioned over the subject's upper back (Thoracic) and another over the lower back (Lumbar) as shown in Fig. 1. To monitor the subject's muscle activity, pairs of skin surface EMG electrodes were placed over the lumbar region (right L4-L5), right trapezius, and right deltoid muscles. During the pilot study, high between-subject variations in muscle activity were noted, so, for the last two subjects, muscle activity was expressed as percent maximum voluntary contract (%MVC). This method of expressing muscle activity will be used for the actual clinical studies. To obtain 100 %MVC for the lumbar EMG channel, the subject lay prone on a table with legs held down and raised the trunk with maximal effort against an investigator's resistance. For the trapezius and deltoid EMG channels, 100 %MVC was obtained by having the standing subject respectively raise the shoulders and the horizontally outstretched right arm with maximal effort against an investigator's resistance. The final three subjects were asked to rate their assessment of level of difficulty of the task for each bed height on a visual analog scale from 0 (very easy) to 10 (very difficult). Similarly, they were asked to rate their assessment of level of discomfort on a scale from 0 (no discomfort) to 10 (high discomfort).

The three-dimensional video motion analysis system monitored musculoskeletal position and motion. The six video cameras were set at predetermined positions and the system calibrated prior to the patient repositioning activities. Reflective balls were attached to each subject's back and upper right arm as shown in Fig. 1 in order for the video system to track thoracic, lumbar, and right arm motion. Acquisition, processing, and analysis of the video data were performed by Vicon Motus software (Vicon, Centennial, Colorado).

After the subject trials, the tetherless ergonomics workstation's orientation and EMG data and the video motion analysis system data were transferred to Excel (Microsoft, Redmond, Washington) spreadsheets for further analysis and comparisons.

IV. PILOT STUDY RESULTS

Subjects selected preferred bed heights ranging from 0.77 to 0.91 m. There was no correlation between preferred bed height and subject height, which ranged from 1.57 to 1.73 m.

The tetherless ergonomics workstation successfully recorded all nine signals: three-axis thoracic and lumbar orientations and lumbar, trapezius, and deltoid EMG. Figure 3 shows the results obtained for one trial at the preferred bed height. The thick lines show thoracic flexion (solid), right lean (dashed), and right rotation (dotted), and the thin lines show right lumbar (solid), trapezius (dashed), and deltoid (dotted) EMG %MVC values. Thoracic flexion increased to a rough plateau and then decreased again as the subject bent forward, repositioned the patient, and stood upright again. Right lean and rotation deviations remained smaller. Lumbar EMG activity was the most prolonged, with peaks at 4.6 and 7.3 s. Deltoid activity peaked at 4.8 and 7.5 s, while trapezius activity was relatively low for this trial.

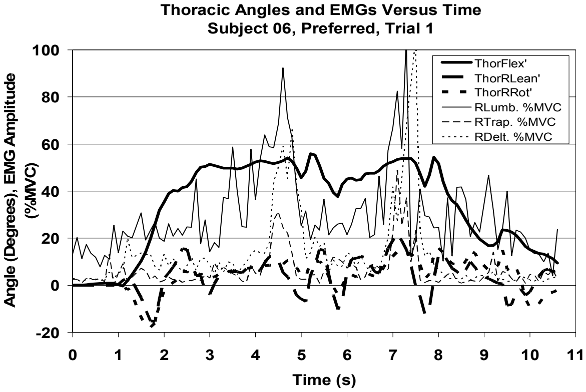


Fig. 3. Thoracic orientation (thick lines) and EMG %MVC recordings (thin lines) from the tetherless ergonomics workstation for one trial with the bed in the preferred position. Thoracic flexion (solid) increased from zero to a rough plateau and then decreased again while lean (dashed) and rotation (dotted) had smaller values as the subject bent forward, repositioned the patient, and then stood upright again. Lumbar (solid) EMG activity was the most pronounced and peaked twice. Deltoid (dotted) activity also peaked twice, and trapezius (dashed) activity remained relatively low.

Figure 4 shows average thoracic flexions obtained by the tetherless ergonomics workstation for the six subjects at the three bed heights. The figure shows that, for all subjects, flexion decreased as the bed was raised. A similar pattern

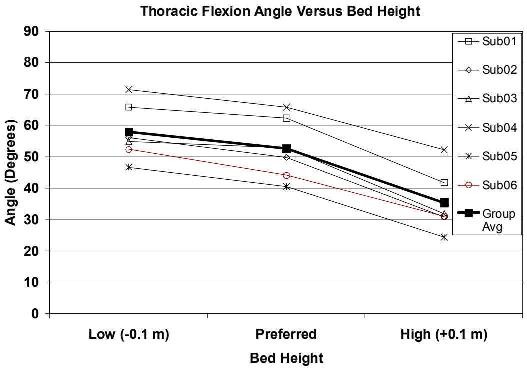


Fig. 4. Average thoracic flexion angles for six subjects for the three bed heights. Flexion decreased as the bed was raised.

was obtained for lumbar flexion.

The pilot study showed that the thoracic and lumbar flexions recorded by the tetherless ergonomics workstation closely tracked those obtained by the video motion analysis system, therefore validating use of the wearable system for tracking back flexion in the clinical setting. Linear regressions of sensor versus video thoracic flexion recordings resulted in group average values of $r^2 = 0.98$, slope = 1.10, and intercept = -0.9 degrees. The corresponding lumbar values were $r^2 = 0.96$, slope = 1.16, and intercept = 2.2 degrees. The thoracic and lumbar recordings for trunk lean and rotation angles differed more between the wearable system and the video motion analysis system. A contributing factor to the lean and rotation results may be that the video analysis system provided projection angles, whereas the orientation sensors provided Euler angles (see [6] for angle definitions). Another factor may be the sensitivity of the orientation sensors to motion and magnetic field perturbations. More appropriate angle definitions [7] now are being considered for presenting body orientation, and additional work is proceeding on the use of the orientation sensors, including custom-processing direct triaxial accelerometer and magnetometer outputs instead of using the pre-processed and filtered roll, pitch, and yaw outputs.

The pilot study group data revealed the following trends:

1) Thoracic and lumbar flexion decreased as the bed was raised.
2) Thoracic lean to the left, thoracic rotation to the right, and lumbar rotation to the left decreased as the bed was raised.
3) Back curvature (hunching) was greatest for the preferred bed height.
4) Thoracic relative to lumbar left lean and right rotation decreased as the bed was raised.
5) Lumbar EMG activity decreased as the bed was raised.
6) Average right trapezius and right deltoid EMG activities were smallest for the low bed height.
7) There was a transfer of EMG activity from lumbar to trapezius and deltoid muscles as the bed was raised.
8) Subject self-assessed difficulty and discomfort were minimum at the preferred bed height.

V. CONCLUSIONS

A tetherless ergonomics workstation was developed to enable studies of nurses' physical workload in the clinical setting. To validate the workstation and as a test run of experimental protocol, a pilot study of the effect of bed height on the workload involved in the common task of repositioning bedridden patients was performed with student nurses in a laboratory equipped with a three-dimensional video motion analysis system. The pilot study confirmed that all six channels of orientation signals and three channels of EMG signals were successfully recorded by the tetherless ergonomics workstation and that thoracic and lumbar flexion recordings by the wearable system faithfully tracked those by the video motion analysis. Trends observed in the pilot study regarding the effects of bed height on the workload of repositioning bedridden patients will be evaluated in studies of practicing nurses in the clinical setting. The pilot study showed the value of collecting subjects' self-assessments of discomfort and difficulty, as well as recordings of their body posture and movements and EMG activity levels.

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REFERENCES

[1] L. Hui, G. Y. Ng, S. S. Yeung, and C. W. Hui-Chan, "Evaluation of physiological work demands and low back neuromuscular fatigue on nurses working in geriatric wards," *Appl. Ergon.*, vol. 32, pp. 479–483, 2001.

[2] W. S. Marras, K. G. Davis, B. C. Kirking, and P. K. Bertsche, "A comprehensive analysis of low-back disorder risk and spinal loading during the transferring and repositioning of patients using different techniques," *Ergonomics*, vol. 42, pp. 904–926, 1999.

[3] B. Bernard (ed.), "Musculoskeletal disorder and workplace factors: a critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back," *DHSS (NIOSH) Publication No. 97-141*, U.S. Government Printing Office, Washington, D.C., 1997.

[4] G. Li and P. Buckle, "Current techniques for assessing physical exposure to work-related musculoskeletal risks, with emphasis on posture-based methods," *Ergonomics*, vol. 42, pp. 674-695, 1999.

[5] W. D. Smith, R. Berguer, and J. C. Rosser, "Wireless virtual instrument measurement of surgeons' physical and mental workloads for robotic versus manual minimally invasive surgery," *Studies in Health Technology and Informatics*, vol. 94, pp. 318–324, 2003.

[6] J. J. Craig, *Introduction to Robotics: Mechanics and Control*, 2nd ed. Reading, MA: Addison-Wesley, 1989.

[7] P. L. Cheng, "A spherical rotation coordinate system for the description of three-dimensional joint rotations, *Annals of Biomedical Engineering*, vol. 28, pp. 1381-1392, 2000.