

# Remote monitoring of sitting behavior of people with spinal cord injury

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**Abstract**—The clinical assessment of risk factors leading to pressure sores is normally undertaken in a hospital clinic. However, knowledge of the sitting behavior of the patient *outside* the clinic may more realistically and comprehensively identify these factors. Many patients, for example, are thought to sit habitually with more pressure on one buttock than the other, and this may significantly increase the risk. This sitting asymmetry may be due to the layout of a work area, the home, or a simple habit. Furthermore, busy wheelchair users may be too preoccupied to remember to reposition themselves regularly but may do so frequently at less hectic times. The applicants have developed a miniature remote pressure logger, which keeps a record of the sitting behavior of the wheelchair user. This study examines the feasibility of using the device for long-term monitoring of sitting pressure distributions during daylong wheelchair activities.

**Key words:** *pressure mapping, pressure ulcer, rehabilitation, remote monitoring, risk factors, wheelchair.*

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## INTRODUCTION

People who are paralyzed following spinal cord injury (SCI) spend much of their lives in a seated position. Incorrect long-term sitting leads to chronic postural problems, irreversible deformities, and progressive breakdown of tissue [1]. Able-bodied people sense physical discomfort associated with prolonged sitting and adjust their body positions, thereby protecting their tissues from ischaemic damage. People who have lost sensation in the gluteal region have no feedback to initiate the body movements important for protecting the tissues and frequently remain in the wheelchair for up to 16 hours a day.

Pressure sores continue to be the most prevalent secondary complication of SCI, with reported incidence ranging from 30 to 80 percent [2–4]. Other groups of people with disabilities are also at risk of developing pressure sores during wheelchair sitting, including people with spina bifida, multiple sclerosis, and other neurological conditions. A number of studies have been conducted that attempt to determine the duration of unrelieved loading that tissues can tolerate for difference levels of pressure [2,5,6].

The clinical assessment of risk factors leading to pressure sores is normally undertaken in a hospital clinic. However, knowledge of the sitting behavior of the patient *outside* the clinic may more realistically and comprehensively identify these factors. Many patients, for example,

are thought to sit habitually with more pressure on one buttock than the other, and this may significantly increase the risk of bedsores. This sitting asymmetry may be due to the layout of a work area, the position of a television in a room, or a simple habit. Furthermore, busy wheelchair users may be too preoccupied to remember to reposition themselves regularly but may do so frequently at less hectic times.

Therapists and doctors give patients with SCI simple guidelines to follow to help prevent pressure sores. They usually advise pressure relief every 15 minutes while the patients are sitting, with the duration of the relief approximately 15 seconds. They also advise the patients that when in bed, they should turn every 2 hours.

It has been reported that skin breakdown in SCI patients can be decreased with a patient education program [7]. Noble and Ferguson-Pell et al. both demonstrated approximately 50 percent reductions in pressure sore incidence following programs that included educational follow-up [8,9]. LaMantia et al. conducted a prospective study with patients with pressure ulcers presenting to an outpatient clinic [10]. Patients undertook a training program focused on information related to skin care, which was based on a test that was conducted at admission, discharge, and 3 months after discharge. The results indicated that there was a strong association between the test scores and the maintenance of intact skin at 3 months and 1 year. Other studies by Bandura and Krouskop et al. similarly demonstrate a dramatic reduction in readmissions for pressure sores following the instigation of a multifaceted program involving patient assessment, education, and follow-up [11,12]. One of the tools that has been recently introduced into seating programs that support people with spinal cord injuries is the pressure mapping system (**Figure 1**).

Pressure mapping can be helpful in the assessment of people when proving suitable cushions, for educating the patient about the effectiveness of pressure relief practices, and for helping provide seating for people with spinal deformities. Pressure mapping systems can indicate whether the cushion is effective in distributing pressure across a wide enough area of the seating surface. They can also determine the effectiveness of a pressure relief strategy used by the patient (e.g., push-ups, lateral leans, or forward leans) and show the position of the pelvis in the functional sitting position.

The distribution of pressure obtained can provide a great deal of information about the wheelchair user



**Figure 1.**  
Force Sensing Array pressure mapping system used in this study.

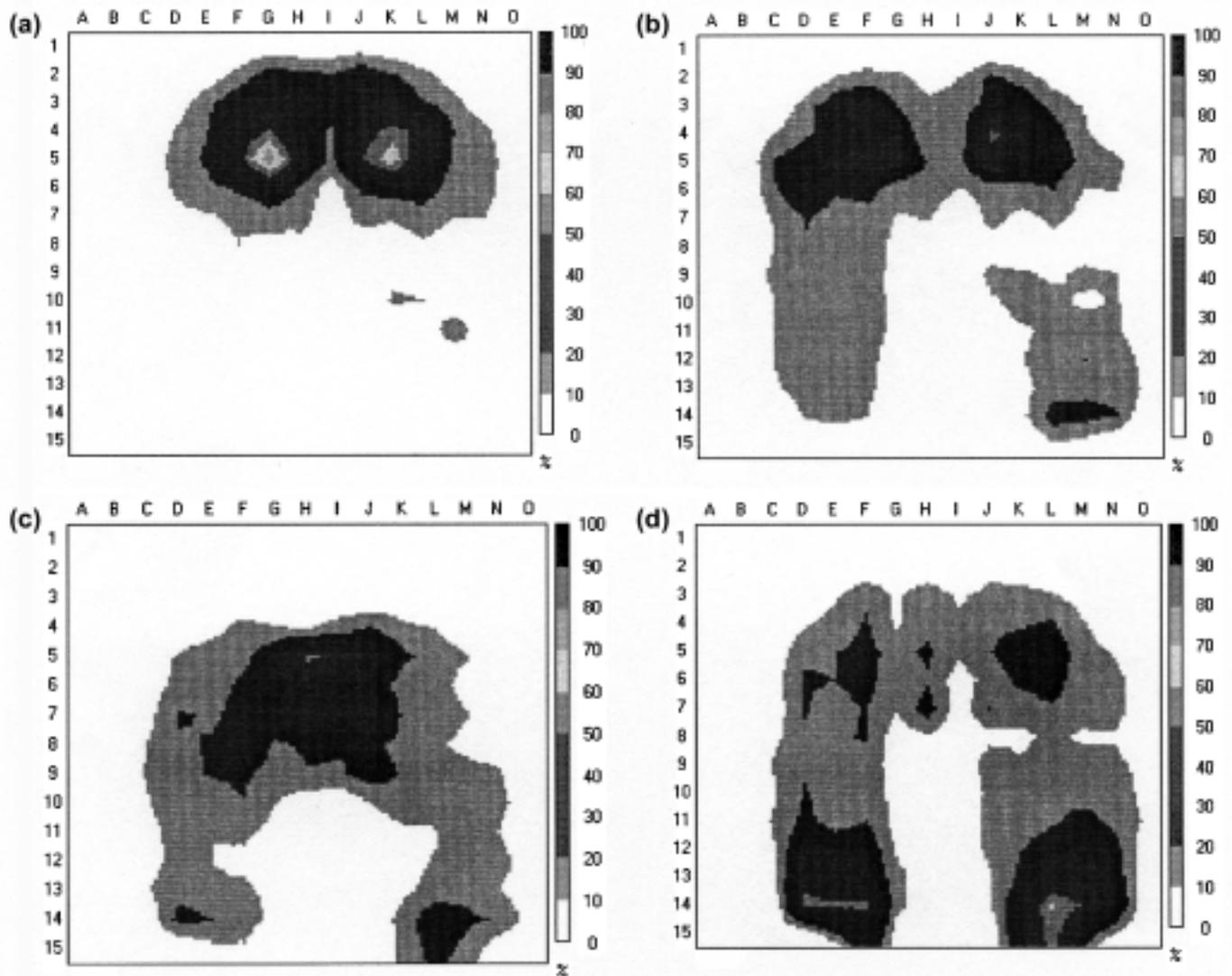
as illustrated in **Figure 2**. Different sitting postures can be clearly differentiated by examining the pressure distributions.

Although these clinical observations are of great value in selecting appropriate seating and reinforcing self-help strategies for pressure sore prevention, they are undertaken in the idealized setting of the outpatient clinic. It can be assumed that under such circumstances, the patient will be on his or her “best behavior.”

Merbitz et al. used a simple monitoring device to detect pressure relief activity in seven newly SCI patients in a hospital setting [13]. They demonstrated wide variations in deliberate pressure relief activity between patients and over time and suggest that there is no simple relationship between lift-off intervals and pressure sore formation. However, the size of the patient population was too small to support these conclusions statistically, and the incidence of pressure sores caused by prolonged sitting is usually very low because of the high level of professional supervision. Although Merbitz et al. allude to using their device to study the importance of measuring longitudinal behavioral compliance with training, no explicit evidence of any effects is offered.

## AIMS

The purpose of this study was to develop and demonstrate a method for monitoring pressure distribution over a prolonged period in a real-life setting. Data obtained offer the opportunity to identify patterns of sitting behavior that increase pressure sore risk. These may include sitting asymmetry or infrequent pressure relief associated



**Figure 2.**  
Pressure maps for different postures.

with specific tasks or activities. It is envisaged that this will allow future enrichment of the existing training program for pressure sore prevention with information specific to individuals' daily sitting.

## METHODS

At the time of this writing, five commercially mapping systems were available:

1. Force Sensing Array (FSA) (Vision Engineering Group), Winnipeg, Canada.

2. Emed & Pliance System, Novel GmbH, Munich, Germany.
3. SEAT Tekscan, Inc., Cambridge, MA, United States.
4. Talley TPM3 Talley Medical, Romsey, United Kingdom.
5. Xsensor Crown Therapeutics, Bellville, IL, United States.

We selected the FSA system over the other systems for this study for several reasons. One reason was that the Tekscan and Talley systems require an electronics card to be inserted into the personal computer that is used to acquire and process raw data from the sensors. This

precludes the use of these systems as discrete and portable devices to be used onboard the wheelchair. Another reason was that the Emed and Xsensor systems are not packaged compactly enough for use remotely, and both systems require power via a mains transformer. The FSA on the other hand comprises a relatively small electronics package and is designed to operate remotely for short periods using a 9-V battery. Furthermore, the Vision Engineering Research Group provided extensive technical support in the development of the remote system and was willing to provide proprietary information needed in the development of the remote system reported here.

The system design of the FSA was based on the use of a TT8 microcontroller (Onset Computers, MA, USA), which is a very compact, low power, and versatile device. The investigators had substantial previous development experience with this device and a mature software "tool-kit." The TT8 requires at least 6 V to operate and consumes 60 mA to 80 mA when fully functioning. However, it can be programmed to stay in low power "sleep" mode (consuming  $\sim 200 \mu\text{A}$ ) until interrupted by either an external trigger voltage applied to an interrupt request (IRQ1) pin or by an internal clock causing the "wake up" to occur at prescribed intervals.

A simple circuit was constructed to interface to the TT8 so that when a wake-up occurred, a power transistor was switched on, providing necessary power to the FSA unit. With the FSA awake, it automatically tries to communicate through the RS232 serial interface. Using the TT8's RS232 port, the two units can acknowledge each other and the TT8 can send the necessary proprietary codes to set the gain and sensor array size for the FSA. Then pressure map values can be read to the TT8 for storage in hexadecimal.

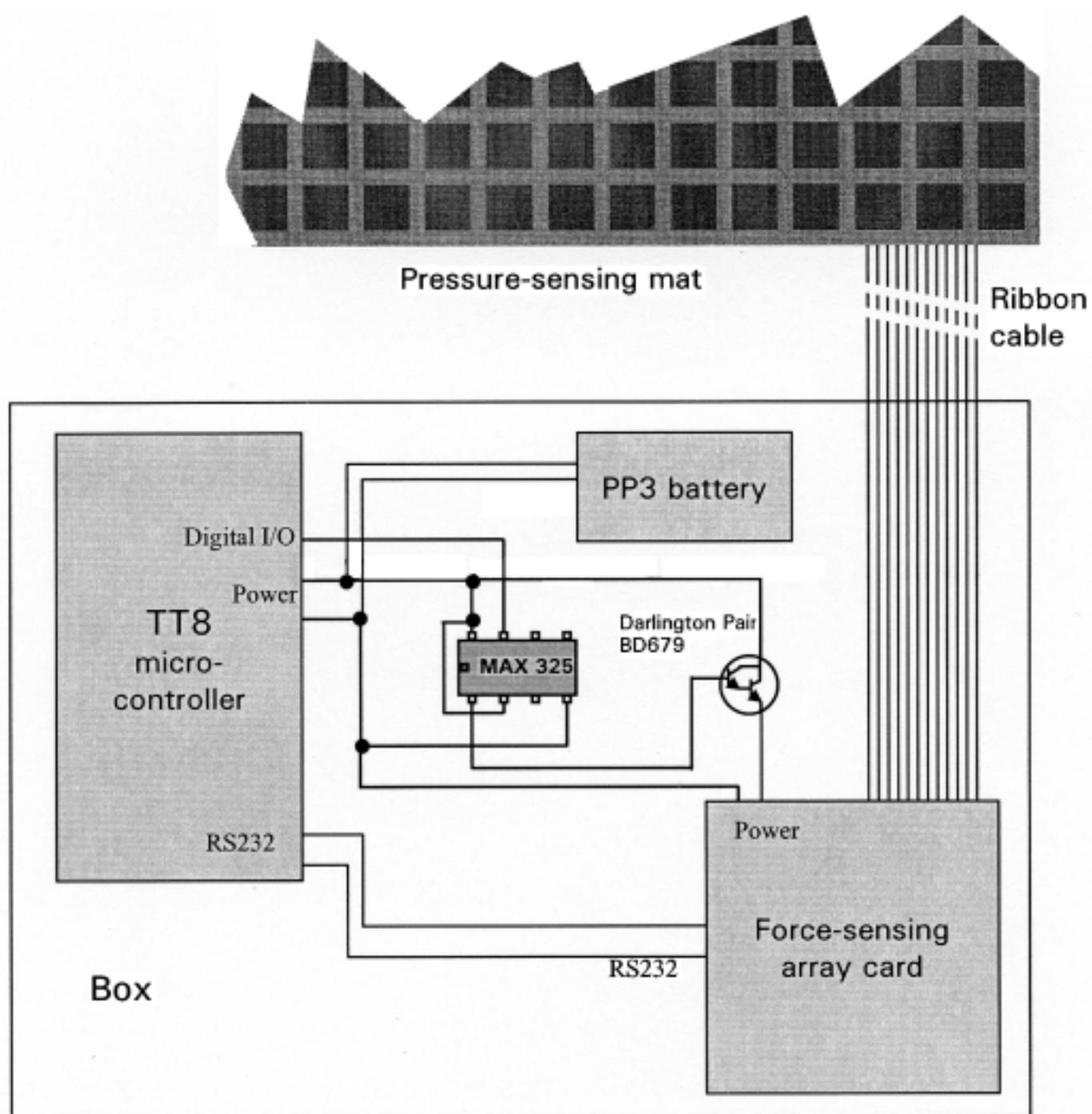
The original design of the remote monitoring device called for a group of FSA sensors to be continuously monitored by a simple threshold circuit. With any significant change in the pressure values on these selected sensors, a level change would be initiated on a trigger connected to the IRQ1 pin, which would wake up the TT8 and then the FSA. In practice, this was found unreliable. Problems with a software utility provided by Onset Computers resulted in intermitted failure of the program and total data loss. We also found that because of wide variations in sitting habits, we had difficulty selecting a group of sensors that would be consistent and sensitive to small movements. Sometimes a small movement would trigger a wake-up if the subject was located in the antici-

pated sitting position. However, if the subject were slightly displaced from the anticipated position, a much larger movement would be needed to trigger the system.

Upon careful analysis of the system, we decided that the limiting factor in the system was not the electrical power, but the amount of available memory. Each reading took approximately 1 kB of memory, and after program space had been accounted for, there was sufficient memory space to accept 700 full pressure maps before data needed to be downloaded. Assuming one significant pressure relief event every 10 minutes and a maximum sitting time of 14 hours a day, the system would operate for well over the 4 days planned (up to 8 days). We therefore decided to wake the system up every 5 seconds to obtain one pressure map. The microprocessor then compared the data set with the previous frame and counted the number of sensors in the array, which had changed in reading by more than 10 percent. If this number was less than 5 out of 256, we deemed that there was no significant change; the data was not stored and the system went back to sleep. If on the other hand, we deemed there to be a significant change, then the system stored the new map and used this to test for the next significant event. If the patient had left the wheelchair, represented by a very small sum pressure for 15 minutes on the mapper, then the system was set to wake up every 15 minutes until the patient returned. This provided an additional power conservation strategy. A schematic of the remote pressure mapping data logger is shown in **Figure 3**.

## CLINICAL CONSIDERATIONS

The study protocol was approved by the University College London—Royal National Orthopaedic Hospital (UCL-RNOH) Ethical Committee, and informed consent was elicited from participants. One concern of the participants was that the pressure mapping system would interfere with the pressure relieving properties of their cushion and could increase their risk of developing a pressure sore during the study. A short duration trial was undertaken with each subject who volunteered. After 1 to 2 hours of sitting on the pressure mapping system placed on his or her wheelchair, each subject checked the skin for marking attributable to the pressure mapping system. None was noted by any of the subjects, but this did continue to concern the investigators, and a change in protocol was decided. For the sake of this initial pilot study, we decided that all subjects would be inpatients who could be closely supervised, and they



**Figure 3.**  
Schematic layout of system.

would only use the system for 1 day before their skin was checked for marking.

A resolution to this problem has now been found. The FSA has produced a new pressure sensor map, com-

patible with our existing electronics, but is more flexible and much flatter than the older style map. In future studies, the new “Super-Flex” 12- × 12-sensor array should be used.

For the purposes of the highly supervised sessions, the electronics package was attached to a convenient part of the framework of the wheelchair. We noted that although weighing only 0.8 kg, the electronic package could be inconvenient for patients when their wheelchair was not occupied because it would have a tendency to tip over. In future studies, the location of the electronics package and the use of a temporary counter weight will need to be considered. A photograph of the system in operation is presented in **Figure 4**.

Five SCI patients were fitted with the pressure mapping device and electronics. All tolerated the device well and showed no signs of adverse tissue response.

## DISCUSSION

The data once collected from each subject were downloaded from the TT8 to a personal computer for analysis. The raw data on the TT8 required decoding and formatting, and a program was written to create a data file that could be read by most software analysis packages (e.g., Mathcad and Excel).

Once a complete data file had been created, the data had to be prepared for visualization, summarization, and interpretation. We decided to consider each map reading to be a frame. Associated with each frame was information about the time and date of the measurement and a "flag" indicating whether the reading was obtained as a



**Figure 4.**  
FSA—TT8 monitoring system in operation.

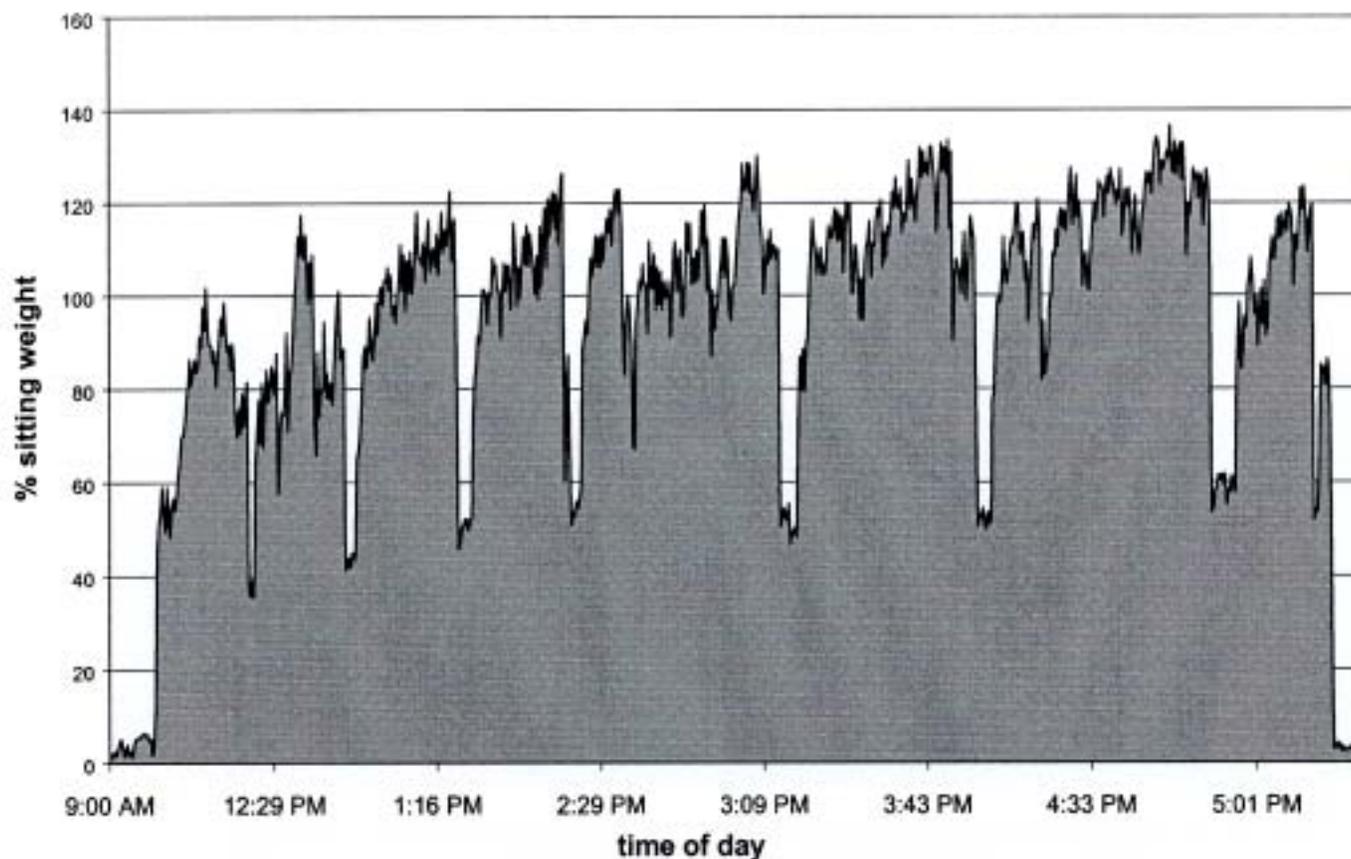
15-minute sample or was stored because it represented a significant change in the pressure distribution. The processed data could be presented dynamically, as a video saved as an .avi file.

For further summarization of the data, certain key parameters were defined and plotted against time. By adding together all the force values, we have a measure of the total force applied by the subject to the pressure mat. If the subject performed a pressure relief by pushing up on the armrests of the wheelchair or if he or she vacated the wheelchair, then the sum was close to zero. By plotting the sum of the pressures against time, we could readily see when the subject performed an effective pressure relief. A chart was generated for each subject, representing the total force as a percentage of sitting weight. A sample result is reproduced in **Figure 5**.

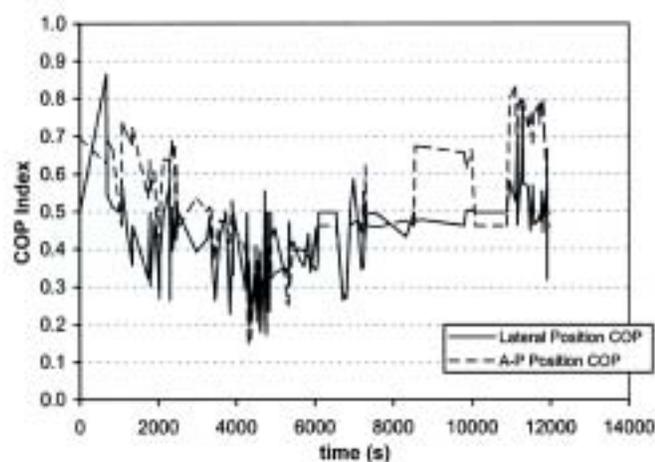
Similarly, it is possible to monitor the lateral and forward-backward movement of the subject. This capability provides information on the sitting symmetry of the subject against time and identifies events such as lateral leans or forward leans used by tetraplegic subjects to weight shift if they cannot push up on the armrests. To represent these parameters, we summed moments of each pressure element and divided them by the total pressure on the mat at that moment. This quantity is referred to as the Center of Pressure (COP) index and is related to the position of the subject's center of gravity as a proportion of the length and breadth of the mat. Thus, a subject positioned centrally would have a lateral COP index of 0.5, and an anterior-posterior (A-P) COP index of 0.5. An example graph is shown in **Figure 6**.

## CONCLUSIONS

The goal of this study was to demonstrate the feasibility of monitoring wheelchair users for up to 4 days in the community, without intervention from the clinical or research team. We are pleased to report that this goal was met with the one reservation that at the time of the study, the pressure mats were not flexible or smooth enough to allow patients to use them unsupervised. However, a new mat design, which is more acceptable for long-term use, has recently been launched by Vision Engineering Group and has been tested as part of this study. There is no doubt that future work could be safely conducted, remotely, with this new instrumentation.



**Figure 5.**  
Example of sum of force values versus time.



**Figure 6.**  
Position of center of pressure with time.

The data collected in this study show a wide range of sitting behaviors. Several subjects exhibit “textbook” pressure relief behavior, while others sit for very prolonged periods without relief. Also interesting to note is that several of the subjects appear to make many small body movements, which are however successful in producing brief reductions in pressure. Several of the subjects favor one side, having asymmetric distributions of their center of pressure over time.

It was not a goal of this study to use the tool to provide treatment for individual subjects nor was the study expected to study enough subjects to shed light on pressure sore aetiology. However, the data obtained are very intuitive and easy to produce. The instrumentation has proved very reliable in the field. We are therefore confident in suggesting that this work should now be continued using the tool to answer some of the questions raised in the introduction to this paper.

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