Proceedings of the 28th IEEE
EMBS Annual International Conference
New York City, USA, Aug 30-Sept 3, 2006

Practical Issues affecting the Measurement and Analysis of Physiological Data recorded remotely from Individuals with Spinal Cord Injury (SCI) during Normal Daily Activities

A Nunn [A1 A2], I. Brown [A2]
[A1] Victorian Spinal Cord Service, Austin Health, Heidelberg, Vic., Australia
[A2] Monash University Centre for Biomedical Engineering, Electrical and Computer Science Engineering, Clayton, Vic., Australia

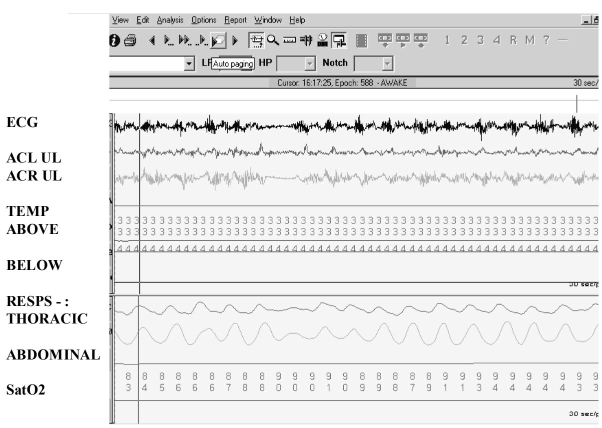
Background

Monitoring a range of physiological parameters in SCI patients during extended periods of daily activity and during therapy in rehabilitation raises a no of practical issues. A totally portable system can provide a clinically useful monitoring system for SCI to study the behaviour of physiological parameters during rehabilitation allows it to be prescribed and optimised to match the individual patient's needs. [1] Issues affecting our study will be illustrated by looking at results in the most compromised tetraplegic group.

Data logger

A"Siesta" digital recording device from Compumedics, Melbourne, Australia [2] was developed for sleep research studies[3] and comes with a range of sensors for that purpose. It is a lightweight, 32 channels, and 16 bit portable physiological monitoring system and viewing Profusion software (fig 1 no 5).Ideally any sensors or transducers can be interfaced with the "Siesta", recording of any desired signal is possible giving flexibility to evolve new sensors with generic export of data.

Fig 1 30 sec traces pushing a wheelchair
Demonstrate the cyclical movement of both upper limbs the R>L ACR+L, plus increase in abdominal breathing and HR on ECG and oximetry which remains stable.



Sensors

Any sensor system must be easily fitted and setup, comfortable, cause no damage (particularly if no sensation) and not interfere with daily activities.

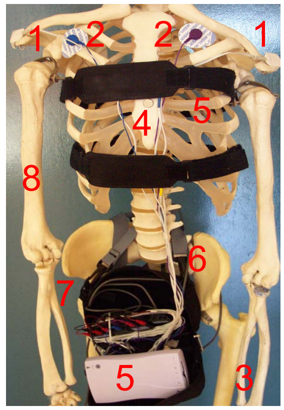


Fig. 2 Siesta Data logger and sensors schematic
Cf. nos in text and below

•no 5 temperature sensors above and below lesion

•no 8 = automatic arm BP on R arm measurement device with computer download capacity

•no 3 = Oximeter sensor on ear, hand or foot

1. Accelerometers measure limb movement
2. ECG – derive HR and beat-to-beat rate, change with breathing and HR variability.
3. Oximetry lack of information as HR only 1 Hz sampling. Position on finger difficult due to using wheelchair but perfusion of toes variable. Additional study designed new sensors getting more signals out of oximetry trace[4].
4. Respiratory band uses a piezo electric transducer to sense the change in circumference of the thorax or abdomen.

Their length-tension curve dictates they that must be well positioned/tensioned and may shift with any thoracic (accessory) respiratory muscles, abdominal, arm movement change in posture or motion in chair.Difficult to reproduce positions for each test.
Abdominal band moves as diaphragm actively drives breathing with passive reciprocal thoracic movement.(Fig 1- RESP movement ,2- position,3 -smoking)
Important to check baseline versus full breath to check full range is being measured.

5. Temperature – thermistors were placed on the patients' skin to monitor their body surface temperatures above and below the SCI lesion
6. short organised wiring harness leading into no7
7. connection bridge and case for "Siesta" logger
8. Blood Pressure - Unfortunately whilst automated BP measurements were taken these use an inflatable cuff with frequency of readings at 1 minute. Continuous non-invasive systems would facilitate study of more rapid changes whilst mobile.

Sources of noise and signal corruption

Given small magnitude is (10µV – 50mV) and they are in the low frequency range (0.05Hz – 1Hz) bioelectric signals are particularly susceptible to noise. Patient movement causes Electrode motion artefact as the skin stretches and disrupts the ionic reaction between the skin and the gel solution. Skin preparation and a stick on electrode minimise this. Also weight of the leads will result in movement artefact and the electrodes must be firmly attached. Cable motion artefact can be reduced by restraining the leads from movement and by minimising the electrode impedance.50Hz Power mains interference can be reduced by minimising skin/electrode impedance, using amplifiers with high common mode rejection ratio, keeping the leads close to the body and twisting pairs of leads (eg. ECG leads) to minimise the size of an induction loop. There is a 50Hz notch filter built into the proprietary software. Electromagnetic interference artefacts minimal with intelligent design of the device and decoupling of the leads. Artefact from within the body such as the EMG trace having the ECG trace coupled to it are reduced by taking differential recordings to most of the common mode signal. Artefact management and signal processing Good organisation, shortening and decoupling of leads to minimise cross talk between signals and other capacitive effects. (setup see fig 2 no 6 short organised wiring harness leading into no7 connection bridge and case for “Siesta” logger) For instance, twisting of a pair of leads to reduce the size of the induction loop to minimise the pick up of interference signals. Individual channel signal improvement and artefact management. Signal specific signal processing will need to be done for the different types of physiological signals to remove the artefacts or interference. For example, precision peak detection for the respiratory signals, and full-wave rectification and amplitude modulation for the EMG waveforms.

Medical Issues

- age, health before and after injury.
- SCI level of injury determines function

“Complete” Tetraplegics have more abnormal physiology with marked cardio-respiratory stress an activity limit to reached readily.(figs 1,4,5,6,)

Presumably lower neurological levels eg. Paraplegics or incomplete SCI can perform with less cardiorespiratory stress for a given activity and at higher activity levels although this increases measurement range and interference to measurement system.

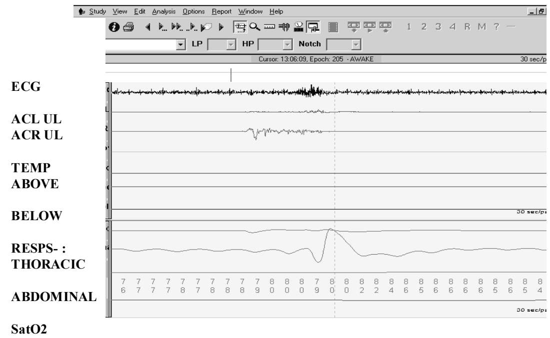
- Time after injury eg chest wall compliance decreases post injury with more effective abdominal breathing
- Completeness of Injury

If “Incomplete pattern of injury” may have greater change overtime and less predictable recovery pattern.

- Asymmetry of trunk and limb function is not unusual and can be due to neurology or damage .(see fig 1 R>injured L upper limb)
- Medication – such as asthma treatment or drugs to raise BP can have significant effects

Smoking profoundly affects results and fitness. Also need to note caffeine, food, anxiety etc not controlled and may affect and baseline response.

Fig3 Smoking is shown by R dominant upper limb (ACR) holding cigarette and L UL (ACL) lighting followed by a deep inspiration ABDOMINAL and increase in (ECG)HR



It is also vital to document intercurrent illness which may dramatically change performance.

- Motivation vital for rehabilitation or any trial.
- Autonomic dysfunction particularly variations in pulse and blood pressure (postural hypotension or hypertension with autonomic dysreflexia) are a major feature

Fig. 4 Progressive tilt is a reproducible stress with significant changes from baseline (BL) ,a fall in systolic (SYS)120 - 60 a diastolic (DIO) to 75 -40 MmHg. BP and pulse pressure (PUL) with a rise in pulse 50 – 110 beats per min. A limit is reached in this test at 60 degrees tilt when inability to compensate and symptoms of hypotension stop the test and return to recumbency is followed by an overshoot and return to baseline.

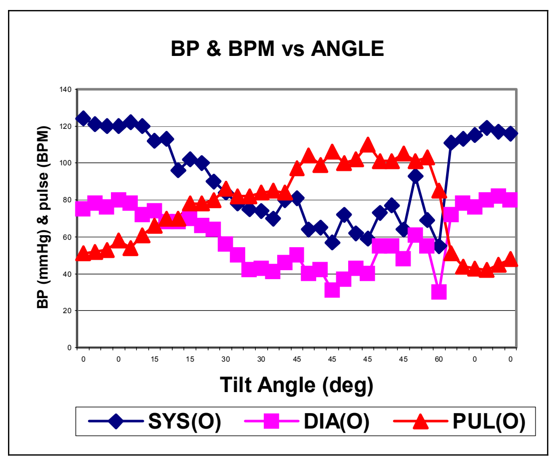


Fig.5 % change from Base Line with Tilt significant change of 100 % increase for pulse and 50% decrease for BP measurements.

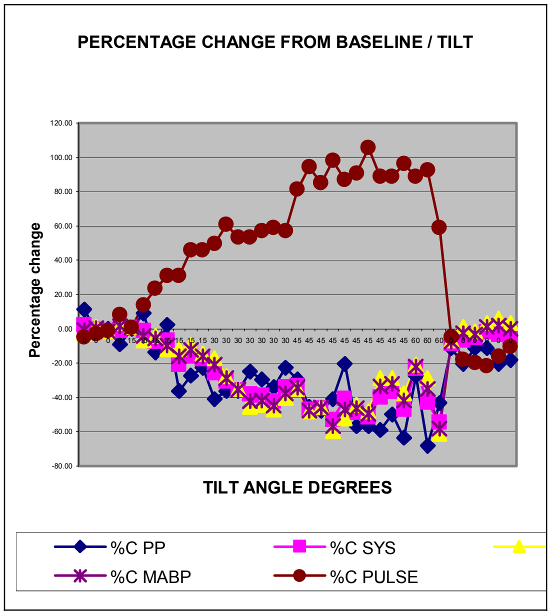
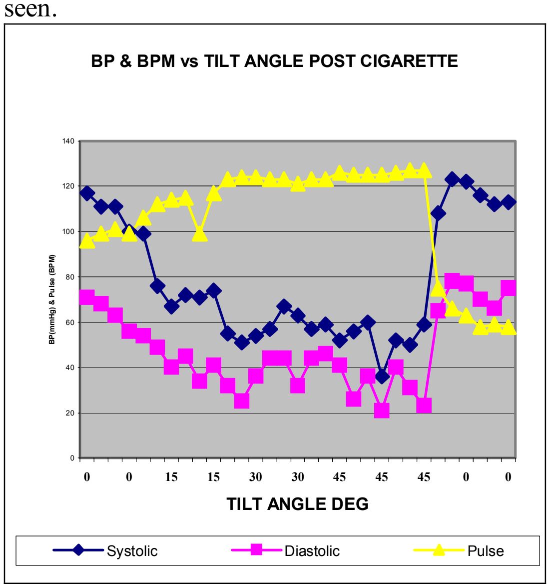


Fig. 6 The same individual had a cigarette prior to tilt test .Baseline Pulse was raised from normal of 50 to 80 beats/min but the maximum threshold remained as in fig 3 100 beats per minutes reflecting inability to elevate sympathetic nervous system activity. Again decompensation ,stopping of the test and an overshoot is seen.



Activity type, timing and level

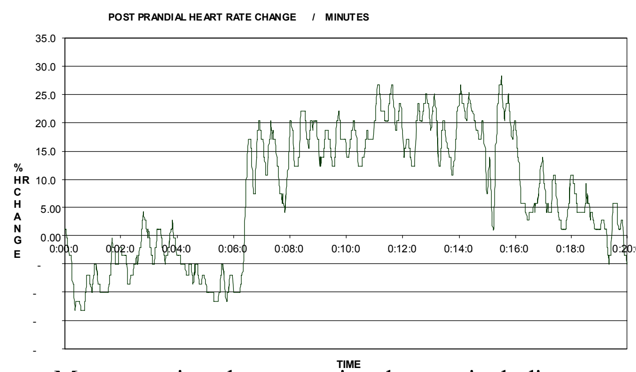
Accurate logging of Activity is essential

Need to document each epoch and identify stressors.

Normal activities reflect real performance, fitness and function but are affected by - :

- Test day and timing of test in daily routine Fatigability is common.
- Baseline Critical before/ after any activity.
- Posture and Position in bed chair, standing, with uptime and down time in wheel chair.[5]
- Mobilisation /Showering and dressing result in autonomic instability with slow recovery.
- Wheelchair Use has less movement artefact in general specifically uses upper limbs for cyclical propulsion[1] with artefact.(fig 1)
- Type of transfers involving static load.
- Prescribed activity eg. Physiotherapy marked change in HR with leg stretch[1].
- Reproducible challenge such as Tilt or wheelchair overtimed distance.[1]
- Upper limb work eg cranking ergometer or weights.[1]
- Rate of physiological change Time over which activity occurs -rapid change with Valsalva Manoeuvre versus slower change like recovery after exercise. [1]
- Meals are a challenge[1] see 20 minute trace

Fig.7 11 minutes *fter a meal* at the pulse rises to 30 % > baseline with the exercise of digestion and associated autonomic/vascular changes.



- Movement is voluntary or involuntary including spasticity or secondary overall body movement effects, all which affect measurements.(fig 1) outlined in paper[1]
- Oedema is measurable particularly in the lower limb and can limit sensor fitting.
- Upper limb work greater is a very major exercise stress and produces artefacts

Environment

- Temperature environmental determinant as ambient temperature determines body core temperature with higher spinal cord injuries given patients are poikilothermic Temperature indicates if outside with > stress
- Wheelchair many types, good platform ,less overall artefact but makes measurement of wheelchair parameters was difficult.A self contained (prototype) data-logger wheel chair Ergometer [5] was designed to measure rotated wheel distance and acceleration plus a seat sensor showing time in chair, lifts for pressure relief and other movements with transferring. Pushing on inclined and variable surfaces present a challenge.
- Seating pressures need assessment

Data Review

- Aim to study real / normal activity data but this increases uncontrolled variables and difficulty of measurement.(fig 1)
- Rigid protocol to ensure reproducibility was vital as was logging activities .It is vital to look at the whole time line and activities logged at each epoch/s and to focus in on the appropriate baseline and period of change for that activity. For example change occurs variably with tilt = 30 sec. (fig 4), smoking 2-3 min. (fig 3), lunch = 10min. (fig 7).
- Artefact often indicates but obscures signals and filtering helpful.(fig 1 UL effect on ECG)
- Standard Baseline Trace important at setup at each posture test done in to provide comparison and baseline must be reached before and after each activity measured.
- Given variables use individual as own control and look at change with stressors from baseline and then compare tests over time. There appears to be consistent response patterns in each individual with functional change over time tested[1].(see figs 5+7)
- Percentage change from baseline is most useful. [1] (fig 6)
- Risk of averaging data over time given increase and decrease in most parameters measured.

Fig.8 More sophisticated analysis by exporting data (text files) to MATLAB and processing in this case to look at HR variability.[1] Whilst there is no apparent difference noted at baseline rest state an inability to respond to stress and maintain BP with each tilt at 15 and 30 degrees .Consistently the parasympathetic NS response (Hi frequency) shows some response with a lesser sympathetic nervous system NS response (Lo frequency)

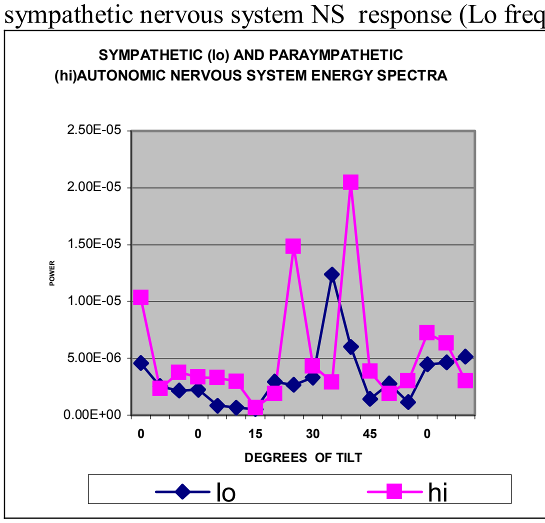


Fig. 9 % Group data useful to confirm individual changes. Eg.% HR change from baseline during tilt which is greatest in the tetraplegic group 100% compared to paraplegics 70% and normal (controls) 10%.

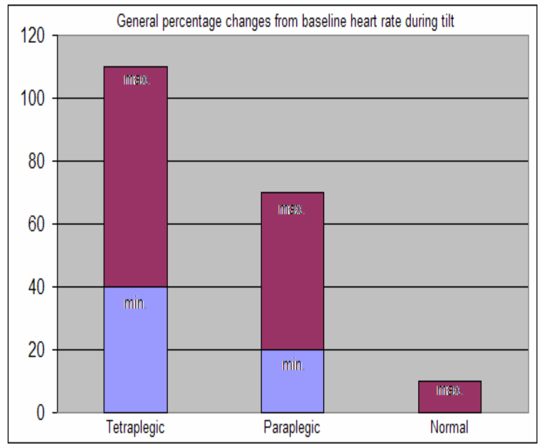
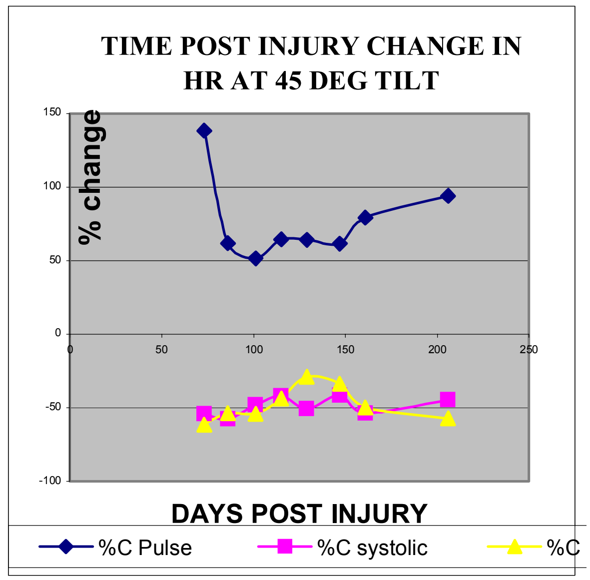


Fig 10 parameters with time post injury the complete C5 tetraplegic patient in the below examples a > ability to tolerate tilt with time.



Conclusion

As described ; accurate setup ,protocols , logging of activity, reproducible measurements in addition to normal activity and careful interpretation affect the design and use of these sensor systems.

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Keywords Spinal Cord injury, data logger, remote monitoring, physiology, activity, heart rate, blood pressure, rehabilitation, human, pilot study

Contact author andrew.nunn@eng.monash.edu.au