Camntech Report on Actiwave Sleep Trial

Summary:
Twelve adults underwent overnight recording at Surrey Clinical Research Centre (SCRC), with three Actiwave devices and a number of channels recorded by the existing equipment. Data was recorded for comparison from two EEG channels, one ECG channel and one EMG channel. All 36 Actiwave recordings were downloaded successfully. A preliminary comparison of the recordings was conducted internally at Camntech, showing the Actiwaves recorded substantially the same signal as the SCRC equipment connected to adjacent electrodes for all the EEG and ECG signals. Loss of agreement was present where the electrode wires had become disconnected and during movement. Unfortunately the EMG signals could not be compared in detail because the Actiwaves were accidentally set to a low-resolution high-range recording mode for the trial, but the signals appear correct within that limitation.

Introduction:
The Actiwave devices are a range of miniature solid-state biosignal recorders which can be worn discreetly on the body without the need for a large belt mounted recorder or lengthy wires. This trial was set up to show that they work reliably and record the same thing as existing EEG/ECG/EMG capture equipment under normal sleep laboratory conditions.

Method:
Twelve adults, from both sexes and a range of ages, were recorded during one night at the SCRC. Reference recordings were made using Compumedics Siesta/ProFusion equipment to record EEG, ECG and EMG channels and these were used to annotate sleep stages. In addition, EEG signals for ‘C3-A2’ and ‘O1-A2’ were recorded using two channels of an Actiwave EEG/ECG 4 channel device, the chin EMG signal was recorded using an Actiwave EMG 2, and the ECG and chest acceleration/orientation was recorded using an Actiwave Cardio. The EEG and EMG electrodes for the Actiwaves and reference system were placed as close together as possible without connecting them together, as shown below.

| Wearer with Actiwaves attached (just inside T-shirt) | Adjacent C3 electrodes connected to reference and Actiwave recorders | Pairs of EMG electrodes for reference and Actiwave system |
Once captured and downloaded, the data from the Actiwave devices was hand-aligned with the reference data, because the reference recorders were not aligned to UTC as the Actiwaves were. However, this alignment only required a shift of between 20 and 30 seconds for all the recordings.

The spectral comparison of the EEG recordings was carried out using a custom script (using python with numpy and matplotlib libraries). This has not been validated, but was applied independently to both recordings and the results compared.

**Results:**
All of the Actiwave devices recorded and downloaded successfully. The different types of signals are compared separately below using appropriate criteria.

**EEG Results:**
Plots of the recorded EEG data from the Actiwaves and the reference system are shown below, categorised by sleep stage.

Comparison of EEGs from Actiwave with reference recording. In each graph, the Actiwave recorded the bottom two traces, while the Siesta/ProFusion system recorded the upper two from adjacent electrodes. The signals were ‘C3-A2’ and ‘O1-A2’.
Some data was lost as the Actiwave electrode wires were made slightly too short for their positioning, and so some pulled out of the Actiwave recording units later in the night. In total, out of 197 channel-hours of EEG data, around 22.5 were lost due to this.

The signals from the Actiwave remained substantially similar to the adjacent reference electrodes during the recording, but were observed to reach a ‘clipping’ limit more easily for the short periods when the wearer was moving around. This corresponds to the 400µV peak to peak limit of the recording hardware; the issue disappears immediately the wearer stops moving.

The EEG signals were also analysed for their spectral content in the Delta, Theta, Alpha and Beta bands during each sleep epoch. Scatter-plots for each of these during one recording are shown below. The red marks in these plots represent those epochs where movement occurred, resulting in the clipping described previously – hence the greater variability. The data is clustered around the line x=y, showing that the spectral content in the recordings is very similar across all these bands, as would be expected from adjacent electrodes. Analysis of the Gamma band showed significant differences, because the SCRC equipment was set to record up to only 35Hz (vs. the Actiwave’s 50Hz) as the Gamma band is not normally used for sleep staging.

ECG Results:
The ECG signals recorded clearly show an identical sequence of beats with respect to timing. There were some differences in precise morphology because the electrodes could not be placed very close to one another for comfort reasons. An example is shown below. The Actiwave Cardio devices also recorded acceleration during the trial, but no reference acceleration signal was available for direct comparison. However, the recorded waveforms for acceleration appear reasonable.

EMG Results:
Unfortunately, once the EMG units were downloaded it was discovered that an inappropriate recording mode had been used when setting up the devices. They were
configured for a large dynamic range, but poor resolution, resulting in large quantisation steps clearly visible in the example below. Obviously the EMG recording cannot be shown to be validated from this result. However, within the limits of the very poor quantisation, the EMG signal appears to be recorded, so there is no reason to suggest they will not work when set up in the correct mode. The error was made by Camntech, not the University of Surrey or the SCRC.

EMG recorded by Siesta/ProFusion system (above) and Actiwave (below). The Actiwave was set up in an incorrect mode resulting in the very poor quantisation visible.

Discussion:
All of the Actiwave units recorded reliably for the period of the trial. They were easily set up, attached to the electrodes, and downloaded without any problems.

EEG signals were correctly recorded and showed good agreement with adjacent Siesta/ProFusion equipment in both the time and frequency domains. Some more ‘clipping’ was observed in the Actiwave recording during movement artifacts, but this ceased immediately once the movement ended.

The position chosen for taping the EEG recorders – just below the collar bone – was shown to be not ideal, and the chosen leads were shown to be slightly too short. Subsequent testing has shown that the devices can be taped to the back of the neck or lower down between the wearer’s shoulder blades much more comfortably. These positions allow the device to be essentially ‘forgotten’. Even whilst sleeping on the back, the devices are small enough to simply push into the mattress or pillow with very little force.

The Actiwave Cardios recorded both an ECG and acceleration signal. The ECG signal showed good agreement with the reference recording despite some difference in electrode position.

Unfortunately, the EMG recording capability could not be verified due to an incorrectly chosen setup mode. However, the unit appears to have recorded correctly within that limitation.

The trial was conducted by Surrey Clinical Research Centre, part of the University of Surrey, but this comparison was performed internally within Camntech.