Visualization of a Stationary CPG-Revealing Spinal Wave

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Abstract: Central Pattern Generator (CPG) is still an elusive concept that has a visual manifestation as a rhythmic oscillation commanded from the spine, but that also has another manifestation as a train of bursts in the surface electromyographic (sEMG) signals recorded on the para-spinal muscles. This leads to the challenging problem of correlating the visually observed spinal wave with the sEMG signals recorded during the session. This paper develops a mathematical model of the spinal wave phenomenon, which, when driven by the sEMG data, yields such visually observable features as wave nodes.

Keywords: Central Pattern Generator, surface electromyography.

1. Background/Problem:

Network Spinal Analysis (NSA) is a technique through which the practitioner sensitizes two specific points along the spine by applying light pressure: i) the cervical region where the dura is attached to the vertebra [1] and ii) the sacral area where the *filum terminale* attaches to the coccyx. These attachments indeed provide feedback mechanisms [6,7] which, when the areas are sensitized enough by the pressure contacts, create spontaneous oscillations. The early sequence of events is, first, an oscillation localized in the sacral area, then an upward propagation of the oscillation towards the cervical area, and finally a cervical oscillation elicited by the upward propagation phenomenon. During the initial phase, the oscillators are out of synchronization, traveling waves are moving in opposite directions, and the spine is in a non-periodic motion. However, after a few seconds, the sacral and cervical oscillators become synchronized, at which time the spine goes into a stationary wave pattern. Next to the above paradigm of two oscillators at the distal ends of a propagation medium, there are other more elusive wave patterns, like the wave pattern lumped in the sacro-lumbar area [3]. These wave patterns already point towards a CPG hypothesis [4] of these spinal oscillations.

The goals are i) to positively establish the wave phenomenon by correlation analysis of the sEMG signals recorded at various points along the para-spinal muscles and 2) to correlate the mathematically established wave phenomenon with the actual wave pattern as seen from a video clip.

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2. Tools and Methods:

The data collection protocol is the same as that of [3]. All research subjects had signed the informed consent form approved by the Institutional Review Board of the University of Southern California (case USC UPIRB #01-01-009).

3. Results:

Let $x_i(t), i = 1,2,3,4$ be the signals recorded at the cervical, thoracic, lumbar, and sacral levels, resp. Let $y_i(t)$ be the D8 subband of the DB3 wavelet decomposition of the signal $x_i(t)$. The purpose of this filtering is to compensate for some analog problems and, more importantly, to capture a single fiber signal [9]. The canonical correlations $\sum_t y_i(t) y_j(t+s) / (\| y_i \| . \| y_j \|)$ exhibit consistent zero crossings for some time shifts s as shown in Fig. 1. This is indicative of a stationary wave pattern [7]. Multimedia video footages integrated with sEMG display will be made available on http://eudoxus.usc.edu/CHAOS/nsa.html and will provide visual confirmation of the standing wave. A bank of Auto Regressive Integrated Moving Average (ARIMA) models were developed and the model best matching the data in a window around the specific time was found and plotted versus the time as shown in Fig. 2. This latter is a rather unique finding, as it shows a clear switching among ARIMA models, hence a bifurcation, occurring in the sacro-lumbar area.

4. Discussion/Conclusion:

The neurosurgical foundation of the sensitization of the cervical area is Breig's theory of dural vertebral attachments [1], which are conjectured to create sensory motor instabilities [7]. The neural pathways are hypothesized to be confined to the spine without higher cerebral function involvement, as demonstrated on a quadriplegic subject who was able to sustain the wave despite a C4-C5 injury [6,7]. This rhythmic motion sustained without external stimuli, with nervous pathways localized in the spine, and in a stationary wave pattern are indicative of a Central Pattern Generator (CPG) [2]. A recent paper [3] showed that patterned locomotor activity (stepping knee movement) of the lower limbs can be induced in paraplegic subjects by applying non-patterned epidural electrical stimulation on the sacro-lumbar area of the spine (in particular, L2). It provides another confirmation of the conjecture that the sacro-lumbar oscillator of the human gait can be elicited (see also [2]). Whether the sacro-lumbar phenomenon shown in Fig. 2 is related to the gait CPG is currently being investigated. Further investigation is underway aiming to understand the neuronal level organization of the human spine CPG oscillators (similar results have been reported on the mice population [8]).

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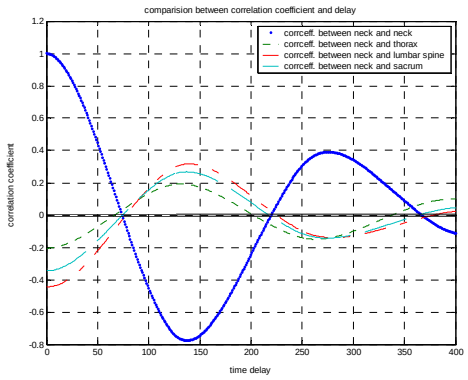

Fig 1

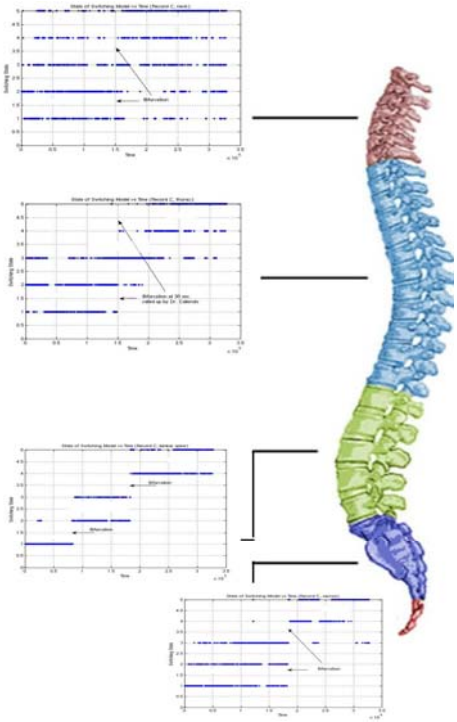

Fig 2