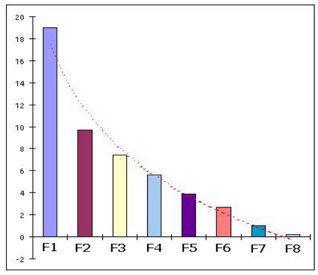
TETRAX: FOURIER TRANSFORMATION OF POSTURAL SWAY



The Fourier Transformation is a mathematical treatment of wave signals of any type and origin. The dimensions of a standard wave signal are frequency and intensity, with intensity plotted on the y-axis, while time in seconds is plotted on the x-axis of the wave graph. On Fourier Transformation graphs, the y-axis shows the level of intensity for frequency ranges in Hertz plotted on the x-axis, from low frequency at the left end of the graph to high frequency at the right end of the graph. It should be noted that postural sway waves are of low frequency, with the postural sway spectrum ranging from 0.01 to 3 Hz.

The Fourier Spectral Analysis of postural sway has been explored in several independent studies.[1] [2] [3] [4] [5] [6] These studies have shown that typical ranges of postural frequency (i.e. frequency bands) express the different levels of activity of postural subsystems – the systems that affect postural sway. Study of postural frequency can provide insights into the individual's use of these postural subsystems, which include the vestibular, somato-sensory, and other sub-systems, to maintain postural stability. Thus, spectral analysis of postural sway might be a valuable tool in clinical diagnosis.

The Tetrax system subdivides the Fourier Spectrum of postural sway as follows:

F1 = 0.01 - 0.1 HZ	F5 = 0.50 - 0.75 HZ
F2 = 0.1 - 0.25 HZ	F6 = 0.75 - 1.00 HZ
F3 = 0.25 - 0.35 HZ	F7 = 1.00 - 3.00 HZ
F4 = 0.35 - 0.50 HZ	F8 = 3.00 HZ and above

According to empirical research based on posturographic studies carried out with various posturographic systems, it appears that excessive sway in each of these frequency ranges reflects intensified activity within the relevant postural subsystem, either due to pathology or to compensatory efforts. On the other hand, weak or absent function of one of the postural control subsystems might be manifest in an abnormally low intensity within the relevant frequency range.

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[1] **DeWit, G**. *Optic versus vestibular and properoceptive impulses, measured by posturography*. Agressologie, 1972, 13-C, 79-82.

[2] **Taguchi, K.** *Spectral analysis of the movement of the center of gravity in vertiginous and ataxic patients*. Agessologie, 1978, 19-B,69-70

[3] **Gagey P.M et Toupet, M**. *L'amplitude des oscillations posturales dans la bande de frequence 0.2Hertz. Etude chez le sujet normal*. Paris, Publications de l'Institutde Posturologie, 1998

[4] **Patat A.** *Residual effects on the equilibrium of three hypnotics (loprazolam, flunitrazepam, triazolam) assessed by spectrum analysis of postural oscillations*. Therapie, 1986

[5] **Ferdjallah, M. Harris, G.F. Wertsch, J.J.** *Instantaneous spectral characteristics of postural stability, using time-frequency analysis*. Proceedings of the 19th Annual Conference of the IEEE Engineering in Medicine and Biology.1997, Vol. 19 pg. 1675-1678

[6] **Laughlin, P.J., Redfern M.S**. *Spectral analysis of visually induced postural sway in healthy elderly young subjects.* IEEE Transactions of Rehabilitation Engineering, 2001,9, (1), p.24-30

For pragmatic purposes the above-described 8 frequency ranges have been clustered into four (F1, F2-F4, F5-F6, F7-F8) ranges, tentatively denominated as Low, Low Medium, High Medium, and High, respectively. The clinical significance of these four frequency bands will be now described in greater detail.

1. The Low Frequency Band (F1)

Normal postural performance is characterized by the domination of the highest intensity at the lowest frequency range (0.1 Hz). This appears to indicate that posture for normal persons is controlled by an intact oculomotor vestibular-otolythic mechanism.[7] A graph of this type of postural system is illustrated in Figure 1-1.

Gagey et al (1998) describes a "Fine Postural System" ("A Fine Tuned Postural System"), which is characterized by a dominant sway at 0.2 Hz. This frequency has also been shown to correspond to the rhythm of normal breath. This type of system is believed to maintain normal steady posture with minimal effort and stress and maximal persistence, not involving any activity of the semi-circular canals, which are insensitive to body displacements below 0.2 Hz.[8]

Figure 1-2 shows a postural system that has been affected by Multiple Sclerosis. Note the typical presentation of reversal of the intensity of sway in the F1 and F2 frequency bands.[9]

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[7] **Nashner, L. M.** *Organisation and programming in motor activity during postural control***. Progr.** Brain Research, 1979, 50, 177 – 184

[8] **Gagey P.M.,** op. cit.

[9] **Alpini, D., Caputo, D., Pellegatta, D., Fini, M.** *The evaluation of balance disorders in multiple sclerosis by means of Tetraxiometry.* Proceedings of the 10th Meeting of the European Neurological Society. Jerusalem, 2000

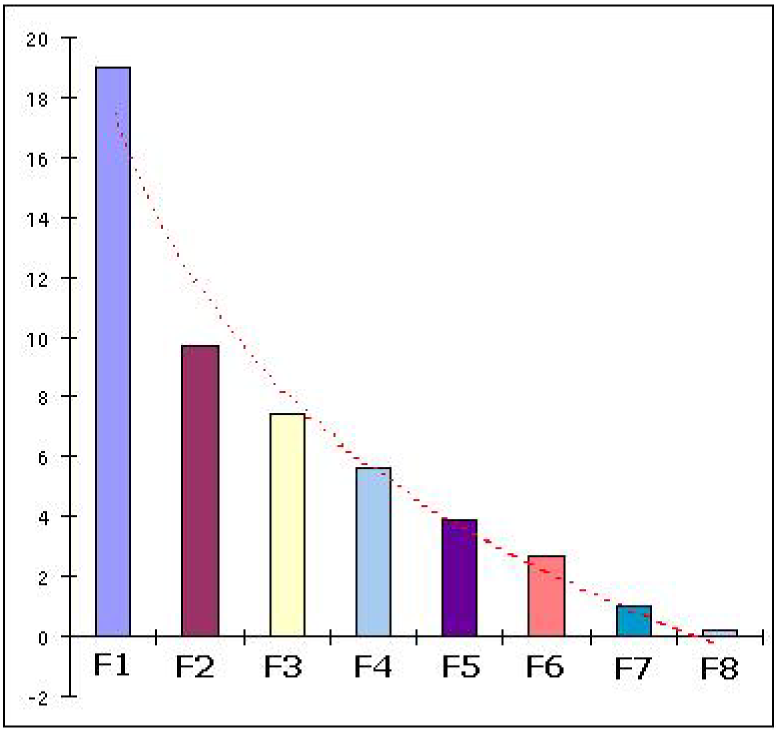

Figure 1-1 Fourier Spectrum of Normal subjects.
Note the dominant lowest frequencies (0.01-0.1Hertz).

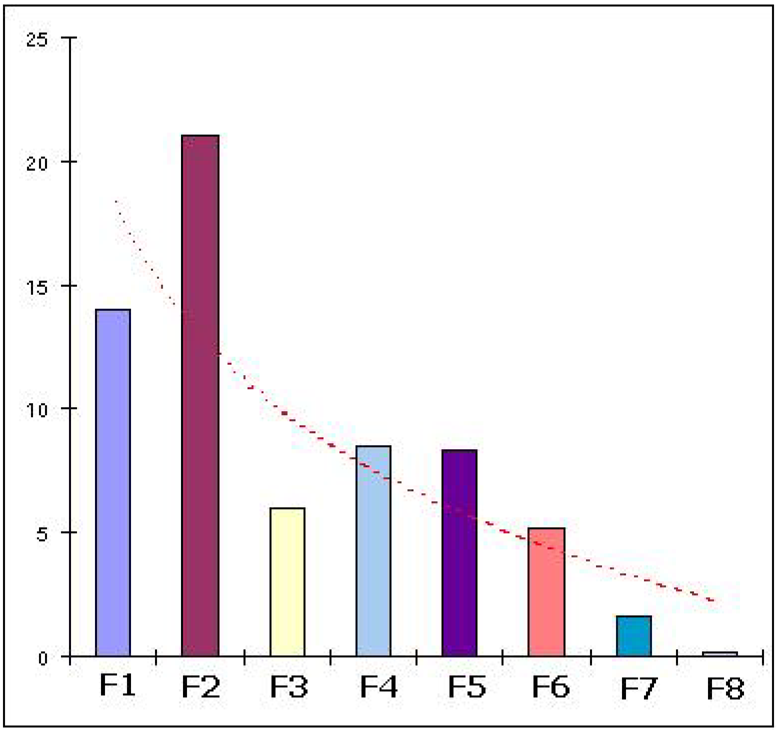

Figure 1-2 Fourier Spectrum of Multiple Sclerosis patients.
Note the disturbances in the low frequency range.

2. The Low Medium Frequency Band (F2-F4)

When the above-described Low Frequency Sway fails to maintain balance effectively, Medium Low Frequency sway is invoked, which centers around the frequency of 0.3 Hz. Such sway is physiologically manifest in drunkenness, but also in states of fatigue and physical exhaustion. In addition, clinical experience with Tetrax system has shown that patients with peripheral vestibular pathology typically sway at this range. It is interesting to note that a pendulum with the length that corresponds to the average height of a human body (i.e. 1.60 m) would swing at 0.3 - 0.4 Hz. Hence it might be - theoretically - assumed, that the human organism is equipped with some type of a postural "buffer system" which is "calibrated" to counterbalance medium frequency sway around 0.3 Hz, the most probable to occur in humans when balance is threatened and the Fine Postural System is no longer able to secure steadiness." The semi-circular part of the peripheral vestibular system appears to play an important role in this buffer mechanism.[10 11 12]

Please note the differences between the frequencies of postural sway in normal postural sway as described in Section 1 (Figure 2-1) and postural sway in a patient with a peripheral vestibular disturbance as described in Section 2 (Figure 2-2).

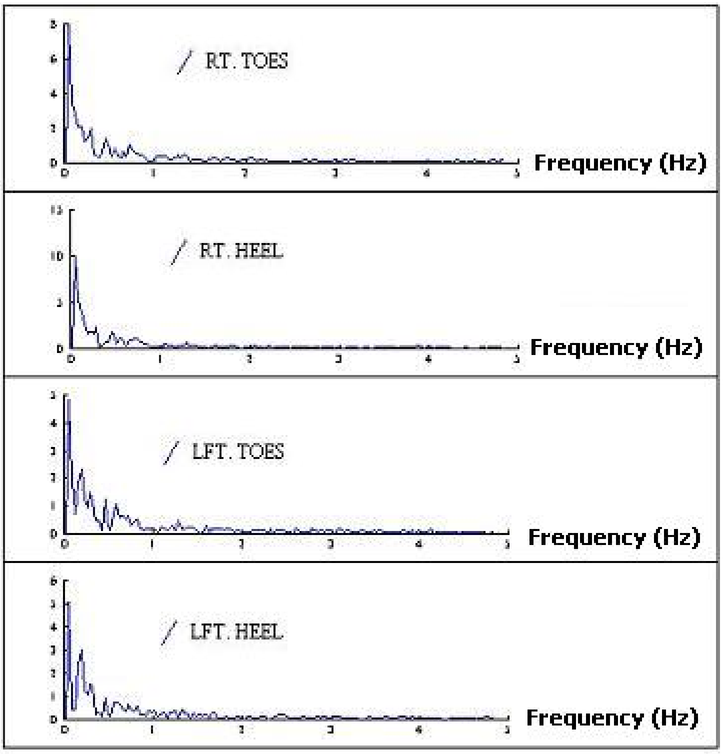

Figure 2-1 Normal postural sway.

[10] **DeWit, G.**, op. cit.
[11] **Taguchi, K.** op. cit.
[12] **Kollmitzer, J., Ebenbichler, G.R., Sabo, A. Kerschan. K., Bochdansky**, *Th. Effects of back extensor training versus balance training on postural control*. Medicine & Science in Sports & exercise, 2000, 1770-1776

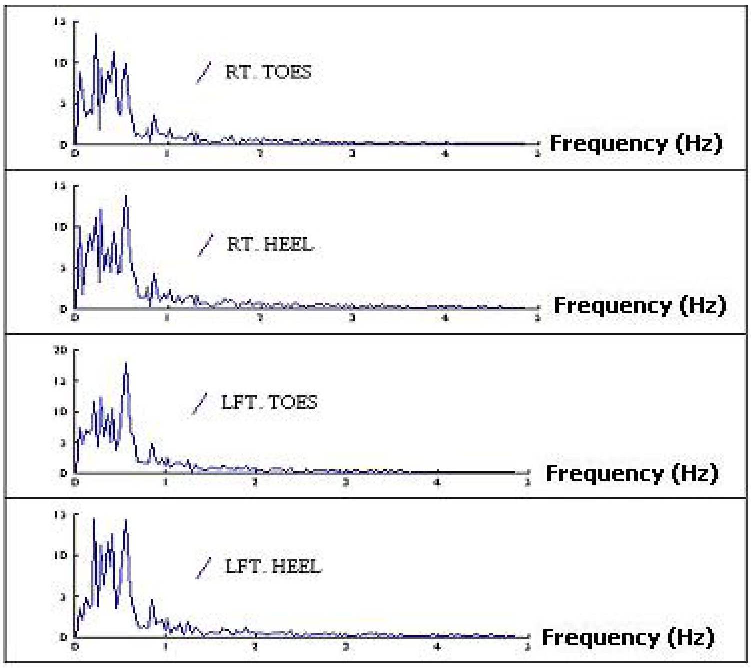

Figure 2-2 Patient with peripheral vestibular disturbance

3. The High Medium Frequency Band (F5-F6)

Intensified sway at High Medium Range reflects the mobilization of somato-sensory reactions mediated by the motor apparatus of the lower extremities, the spine and lower back. Fourier spectra with elevated medium-high frequency often appear after injuries to the lower extremities, but have also been found in patients with diabetic neuropathy, as shown on Figure 3-1. [13]

[13] **Oppenheim, U, Kohen-Raz R., Daitz, A, Kohen-Raz A. Azarya, M.** *Postural characteristics of diabetic neuropathy***.** Diabetes Care, 1999, 22, 328-332

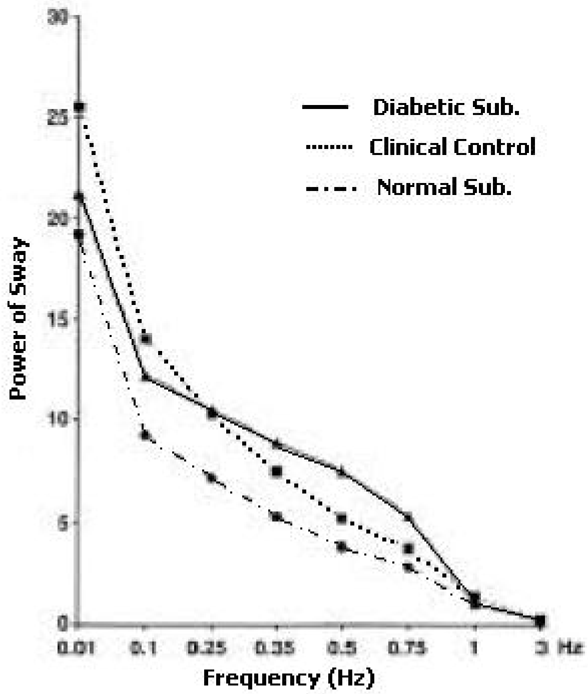

Figure 3-1 Fourier Spectral pattern of postural sway in norm, clinical control and Diabetic Subjects (Oppenheim et al, 2000)

The contrast between vestibular disturbance (low medium sway dominates) and spinal pathology (high medium sway dominates) can be also seen in Taguchi's paper (Figure 3-2).[14]

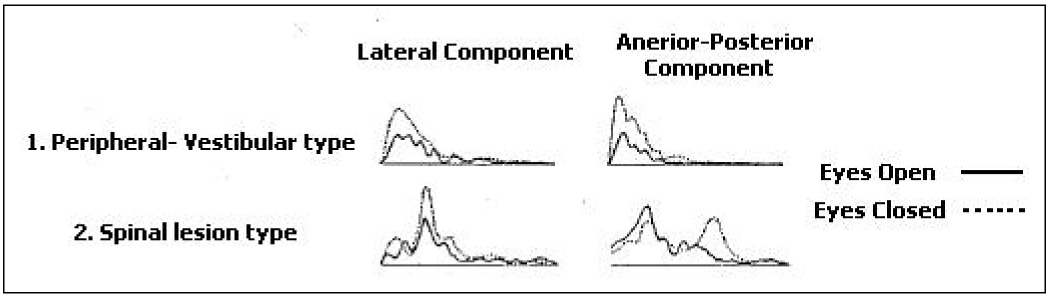

Figure 3-2 Vestibular versus spinal disturbances

Another example (Fig 3-3) of validating the difference between low medium and high medium frequency sway can be found in the classic work of Dewit[15], who has shown the following: In patients after removal of the labyrinths (labyrinthectomy) the low medium frequency is missing, while in patients after intake of Valium, which suppresses somatosensory sensation, the high medium frequency disappears and only low medium frequencies dominate.

[14] **Taguchi, K.** op. cit.
[15] **DeWit, G. ,** op. cit.

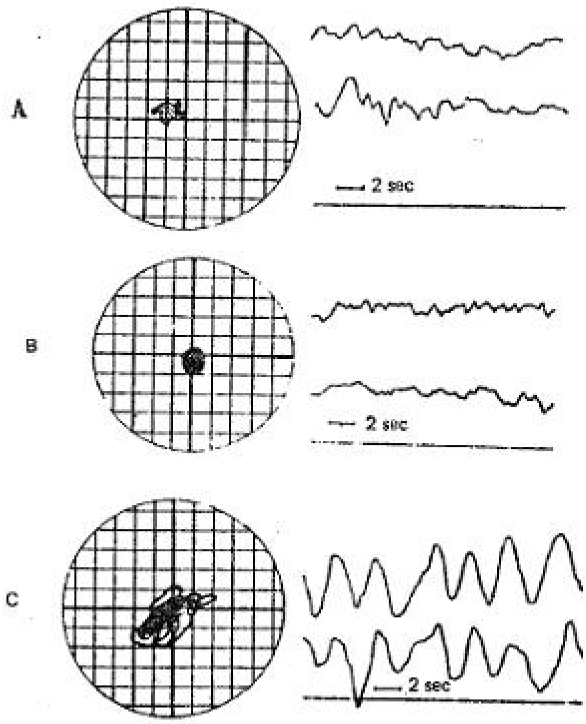

Figure 3-3 A- Normal person, B- person without labyrinthine function, C- person under influence of Diazepam (Valium)

Finally it has been shown in the work of Kollmitzer et al, (2000) that vestibular training lead to a change in postural sway frequencies, i.e. a decrease in the frequencies range F2-F4.[16] When the patients underwent back muscles training, which irritated their somatosensory system, a significant intensification in the frequencies F5-F6 was observed.

4. The High Frequency Band (F7-F8)

High frequency oscillations are a sign of central nervous involvement, often involving tremor. See Fig 4-1 for an example of a patient with brain damage, who shows postural sway in high frequencies.

[16] **Kollmitzer, J., Ebenbichler, G.R., Sabo, A. Kerschan. K., Bochdansky**, op. cit.

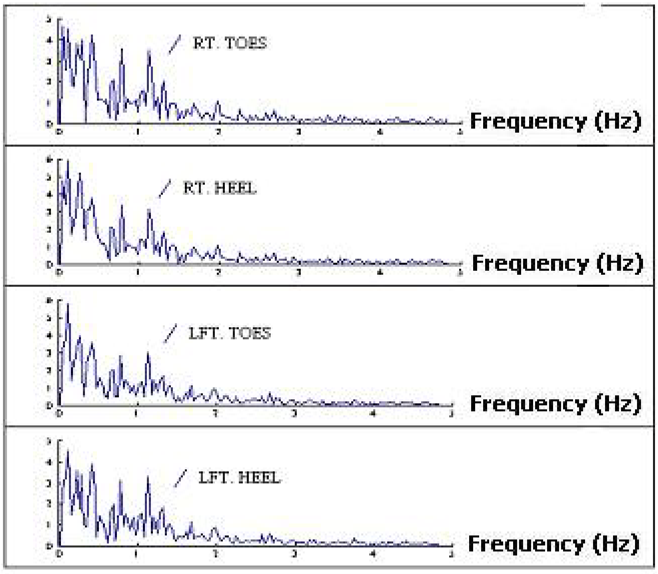

Figure 4-1 Patient with Brain Damage

A similar example can be found in Taguchi's paper.[17]

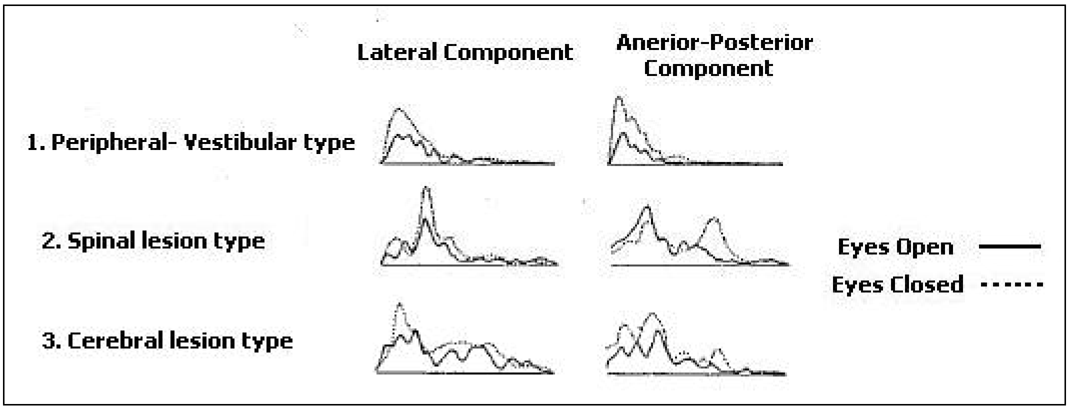

Figure 4-2 Cerebral lesion type (see example 3)

5. Circadian Rhythms

It is interesting to note that the different subsystems as reflected by the Fourier spectrum appeared to have a different circadian rhythm.

It has been shown by Shub et al,[18] who retested 8 normal subjects 16 times during a sleepless period of 36 hours, that different frequency ranges show a different circadian

[17] **Taguchi, K.** , op. cit.
[18] **Shub, Y., Kohen-Raz, A. Kohen-Raz, R. Ashkenazi I.E.** *Combination effect of circadian variations and fatigue assessment by Flight Simulator and Multiple Posturography*. Proceedings of the

rhythm (Figure 4-3 and Figure 4-4). This data suggests that these systems are differentially affected by fatigue. It seems that the vestibular system represented by low medium sway has a rhythm of 8 hours, while more central mechanisms are quite resistant and have a rhythm of 24 hours. (This may explain the phenomena of jetlag).

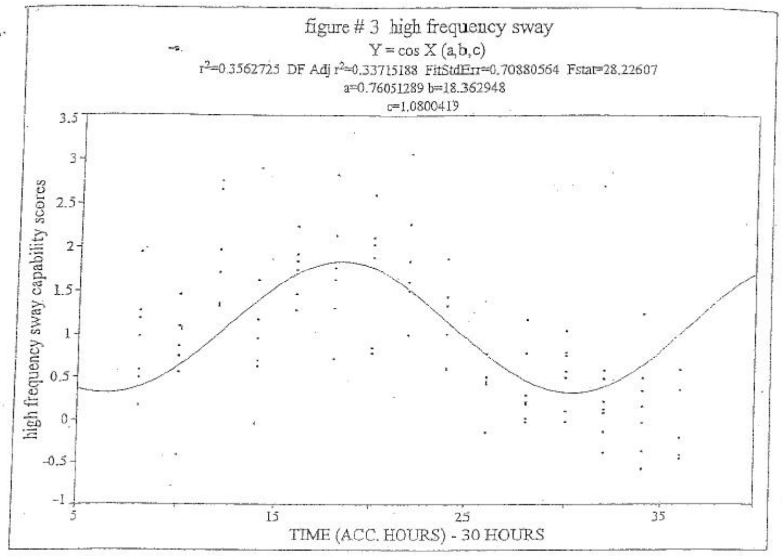

Figure 5-1 The rhythm of high frequency sway (F7-F8) has 24 hours periodicity

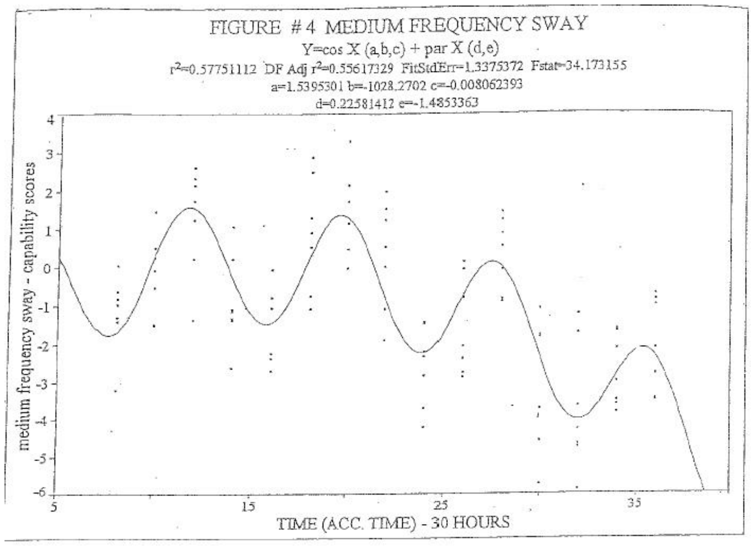

Figure 5-2 The intensity of medium frequency (F2-F4 shows an entirely different rhythm – a rhythm of 8 hours periodicity)

In another recent not yet published study[19] it has been demonstrated that sway at the medium low frequency range, which is sensitive to vestibular functions, is the most susceptible to fatigue in comparison to the other postural subsystems.

Tenth International Symposium on Aviation Pyschology. The Ohio State Department of Aviation Psychology. Columbus, Ohio, 1999

[19] **Noa Avni, Isaac Avni, MD, Erez Barenboim, MD, Bella Azaria, MD, David Zadok, MD, Reuven Kohen-Raz, PhD, Yair Morad, MD**, *A brief posturographic test as an indicator of fatigue*. Psychiatry and Clinical Neurosciences (Volume 60, No.3 June 2006)

6. Conclusion

In conclusion, we note that each postural sway frequency range represents the use of a different postural subsystem. Thus, deviance from the norm in each frequency range has different clinical relevance. By using this information, physicians and other health care experts can use Fourier transformation of postural sway to guide diagnosis and help plan therapy for instability.