Second Course "Motion Analysis and clinics: why to set up a Motion Analysis Lab ?"

TRAMA Project

January 14 - 17th 2008

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Study of falling syndrome in elderly using movement analysis combined with stimulus-response techniques.

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Objective

To measure quantitative parameters to determine risk of falling in elderly using human movement analysis, by considering static and dynamic body stability, when they are submitted to hearing, vestibular, tactile, visual, and postural stimulation.

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Justification

- Fallings represent one of the most important geriatric syndromes with high impact on quality of life in elderly and in their families.
- A 30% of people 60 years old and over have suffered one fall per year at least.
- This percentage increases until 40% when people 75 years old are considered [Santillana, 2002].

Identification of people with disorders in corporal equilibrium and risk of falling is needed, as it has been recommended by several groups of research and clinics [Melzer, 2004; Furman, 1995; O'Neil, 1998; Shumway-Cook, 1986].

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Hypothesis

Risk of falling has been studied during years for several groups, focusing the efforts to clinical concepts. Recent research has been forward to study behavior and some movements as if the falling syndrome is present due to a disease or disorder. It has been reported that most of the fallings occur when people is performing common activities like walking or just being stood up. However, perturbing environmental conditions, which could be the causes of loosing the equilibrium because of the presence of some type of stimulus, have not been taken into account.

Complex control systems are used in biological structures for regulation of processes. In this sense, equilibrium is regulated with different balancing actions that include visual and vestibular sensors as inputs and specific movements as outputs.

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Hypothesis...

Therefore, our hypothesis is based on a study of movements as the response to stimuli related to environmental changes to determine how far or close are the regulation systems from stability, when spontaneous risky factors, like intensive light and infrasound generated by buses, trains, or trucks, are present. Then, we will study biological control systems of the human body using stimulus-response technique.

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Background

It has been reported that elderly have suffered fallings while they walk [*Cali 1995; Norton 1997*]. A common parameter related with a reduction of the gait speed has been determined. This reduction involves a shorter step, a longer double support phase, and a diminished dynamic supporting base [*Menz, 2003; Oberg 1993; Lord 1996*].

Recent studies have reported a relationship between displacements of the center of body pressure and the corporal balance [*Hahn, 2005; Raymakers, 2005*]. This relationship has been used to establish some criteria to determine the risk of falling. The body mass center is associated to the center of pressure, restricted to the base of support. This means that analyzing displacement, velocity, and acceleration of this anthropometric reference, the limits of corporal stability during gait could be obtained [*Detrembleur, 2005, 2005; Gard, 2004; Neptuno, 2004; Orendurff, 2004*]. However, because these signals are highly integrated, significant details have been lost.

The body equilibrium is the result of a balancing action of several corporal movements and specific control mechanisms. When this kind of system is studied to determine the correct performance, the stimulus-response technique (SRT) is commonly used. Our proposal is added to the traditional method of movement analysis of the center of mass. It is supported by the SRT and based on the concept that compensation mechanisms or reflexes in elderly are being deteriorated with ageing and they can not respond properly when are submitted to stimuli related with equilibrium.

In this sense, it has been reported that visual stimuli or lack of visual information (closed eyes) activate the balance processes because equilibrium may be lost. In this sense, subjective movements of corporal members are performed. On the other hand, it is known that hearing and infrasound stimuli may impact on human behavior and equilibrium respectively. Posture changes may also induce equilibrium lost and may produce balance actions.

Biological Concepts

- The lateral vestibular nucleous, the lateral vestibuospinal tract and the lower motor neurons in the spinal cord is a path that has a role in the muscular activities of the body and extremities associated with postural movements and balance.
- The impulses from the vestibular source stimulate the eye movements, and the visual impulses from the eyes; in turn create the conscious spinning sensation (vertigo).
- A larger postural sway was demonstrated in the elderly and attributed to visual declination. Absent vision sharpened the requirement of balance ability.
- Tests with single stance reduce limb support therefore increase the contribution of vision on the postural control.
- Contribution of vision to the postural stability increases with age.

Biological concepts…

In relation to the original direction of a spin, the post-rotational nystagmus is associated with the following features:

A fast component and the sensation of turning (vertigo or dizziness), are in the opposite direction.

A slow component, tendency to fall, past pointing, and direction of movement of endolymph, are in the same direction. Past pointing is the phenomenon of missing an object when reaching to touch it.

The plane in which the head is held during a spin will determine if nystagmus is horizontal, oblique, vertical, or rotational.

Dizziness, headache, nausea, and vomiting are symptoms of motion sickness (seasickness, carsickness, airsickness). Motion sickness is primarily due to the stimulation of the utricle and saccule. The conflict of sensory cues from the labyrinth, the body and the eye may contribute.

Deaf-mutes, who lack labyrinthine receptors, do not experience motion sickness.

Biological concepts…

Man is so dependent on his vestibular system as on his visual and general proprioceptive systems. Injury to the labyrinths, the vestibular nuclei, or the vestibular pathways may result in nystagmus, tendency to fall to one side, past pointing, and some difficulty in maintaining erect posture. However, these symptoms may be attenuated and finally disappear as other proprioceptive cues are more fully utilized.

Loss of both labyrinths is not followed by vertigo or nystagmus. Normal locomotion and posture will then require the utilization of visual cues. The difficulties of walking and performing postural movements will lessen with time, but walking, for example, will always be accomplished with a broad base. A swimmer who has lost the use of his labyrinths may navigate down instead of up to reach the surface unless he receives adequate visual cues.

Biological concepts…

Although the visual, vestibular, and somatosensory systems are used to control locomotion, the nervous system does not integrate the inputs equally. It appears that the nervous system may give preferential weighting to the most reliable and relevant sources of sensory information during forward walking.

Protocol

The study will be defined for each subject and includes two phases:

Health history
Equilibrium and movement analysis

In general, the type of stimulation will be applied to evoke compensating movements not produced by chronic diseases o disorders, which could generate plastic responses.

We considered as important factors for the study in **phase 1** the following: Anthropometry, Muscle disorders, Vision disorders, Nistagmus, Reflexes, Hypoacusis, Arthritis, and Diabetes

Protocol…

Phase 2

Equilibrium and movement analysis
Static study

Standing posture.
Frontal and lateral study of movement paths of head and trunk is performed, including the center of mass and upper extremities. Subject is asked to hold an erected position supported on both feet, separated by a natural distance self-selected, during 20 seconds or until a risk of falling or fatigue appear. The test is performed over a flat and rigid floor alternating opened and closed eyes. The test is repeated three times.

Protocol….

Equilibrium and movement analysis
Static study

One-foot supported posture.
Frontal and lateral study of movement paths of head and trunk is performed, including the center of mass and upper extremities. Subject is asked to hold an erected position supported on one feet (if possible), during 20 seconds or until a risk of falling appears or the contralateral feet grounds. The test is performed over a flat and rigid floor alternating opened and closed eyes. The test is repeated three times.

Protocol…..

Equilibrium and movement analysis
Kinematic study

Passive-active combination (change of posture)
Frontal and lateral study of movement paths of head and trunk is performed, including the center of mass and upper and lower extremities. Subject is asked to hold an erected position supported on both feet during 20 seconds and start walking (three or four steps) when a visual signal is given. The test is repeated three times.

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Protocol…..

Normal gait.
Frontal and lateral study of movement paths of head and trunk is performed, including the center of mass and upper and lower extremities. Subject will be asked to walk along a frontal line under a self-selected speed over a flat floor. The test is repeated three times.

Sit-Stand up movement.
Frontal and lateral study of movement paths of head and trunk is performed. From a sit position, subject will be asked to stand up without the support upper extremities. The test is repeated three times.

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Protocol……

Sit-stand up-walk forward
Frontal and lateral study of movement paths of head and trunk is performed, including the center of mass and upper extremities. From sit position, subject will be asked to stand up and walk for at least three steps. The test is repeated three times.

Walking backward.
Frontal and lateral study of movement paths of head and trunk is performed, including the center of mass and upper extremities. Subject will be asked to walk backward for three or four steps. The test is repeated three times.

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Protocol….

Kinematic study with disturbing stimuli

Balance action under sonic and infrasonic disturbing stimuli.
Frontal and lateral study of movement paths of head and trunk is performed, including the center of mass and upper and lower extremities. With the subject in erected position, disturbing sonic and infrasonic stimuli are applied to the subject.

Gait under disturbing stimuli
Frontal and lateral study of movement paths of head and trunk is performed, including the center of mass and upper and lower extremities. The subject will be asked to walk forward at least three steps when submitted to sonic and infrasonic stimuli.

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Protocol….

Balance under visual stimuli
Frontal and lateral study of movement paths of head and trunk is performed, including the center of mass and upper and lower extremities. With the subject in erected position, disturbing visual stimuli are applied to the subject.

Gait under disturbing stimuli
Frontal and lateral study of movement paths of head and trunk is performed, including the center of mass and upper and lower extremities. The subject will be asked to walk forward at least three steps when submitted to disturbing lights or to a modified room illumination.

Recordings of 3D displacement related to velocity and acceleration of the center of mass, head, trunk and upper and lower extremities will be performed for all the studies.

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STABILITY

We want to start studying the biological control systems as they were linear events, even we know they could not be, but we are considering this proposal as a first approximation. We are not interested on detailed models for the different control systems involved but rather in an integrated action. We want to find an objective indicator of the good performance of the integrated actions of the different control systems for equilibrium in the human body. Consequently, we are using a second order approximation of a mathematical model to study responses of head movements when it is submitted to visually disturbing stimuli.

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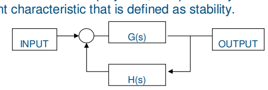
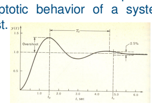
Stability…

The human body is composed by many open and closed-loop systems. In general, all the systems are very complex and they are integrated by many of units used in the analysis and design of control systems. A closed-loop system, independently of other specifications, must exhibit a very important characteristic that is defined as stability.



The concept of stability seeks for the exact and complete behavior due to a specific input for all time. Then, an asymptotic behavior of a system for all inputs as the time approaches infinity is of interest.



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Stability…

The study of stability of linear systems is related with two concepts: absolute-stability and relative stability. The former is qualitative in nature and seeks a simple"yes" or "no" statement concerning the system stability. The latter is quantitative in nature and is associated with the problem of determining how stable a system is.

The relative-stability information provides a bridge between minimal information of absolute-stability and the complete information provided by the total time response, falling somewhere between the two extremes. That is, the use of relative-stability concept is an attempt to characterize the behavior of a system by means of one or more relative-stability measures.

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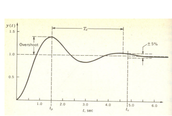
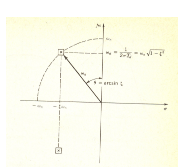
Stability….

A dual use of the concept of stability is referred as a complementary solution that decays to zero as time approaches infinity and as one in which all the poles are in the left half of the s plane. Results of this duality forward to consistency in the use of them.





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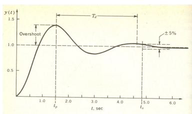
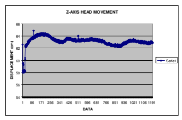
Given that the signals from motion of the head of static tests presented similar patterns of a step-function response in time domain of a second-order system (SRT), used for the design of control systems, we adopted this model for the analysis. Then, stability criteria established for this model will be used for those signals obtained from cases of study.
The absolute stability will be determined if the captured pattern are similar to the SRT and the analysis of the pattern, by using some parameters, will indicate how stable the system will be.





The model

The step-function response in time domain of a second-order system is presented as

$$y(t) = 1 - \frac{1}{\sqrt{1-\zeta^2}} \exp(-\zeta w_n t) \sin((w_n \sqrt{1-\zeta^2})t + \psi)$$

Here, ζ is the damping constant, w_n is the nature frequency of the oscillating response, and

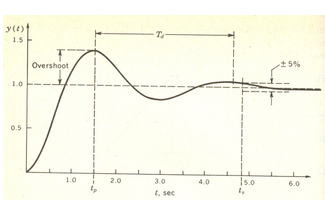
$$\psi = \arctan \frac{\sqrt{1-\zeta^2}}{\zeta}$$

The actual frequency of oscillation in radians per second is,

$$w_n \sqrt{1-\zeta^2}$$

which is known as the damped frequency w_d. A typical oscillatory response is shown in the following figure

The model…



Step-response of a second order system

The model….

In general, this kind of behavior is considered stable and this condition has been established around the parameters ζ and w_n.

To represent graphically the step response ***y(t)*** for different values of ξ and w_n would require a four-dimensional figure. The dimensionality may be reduced to two if we do not plot ***y(t)*** versus ***t*** but rather plot some characteristic of ***y(t)***, which could be the rise time or percent overshoot.

Normalizing respect to w_n, the new expression for the step-function response is

$$y(t') = 1 - \frac{1}{\sqrt{1-\zeta^2}} \exp(-\zeta t') \sin((\sqrt{1-\zeta^2})t' + \psi)$$

The specifications of relative stability in the time domain is the percent overshoot (PO), which is measured at the time ***t*** equal to peak time t_p or

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The model….

$$t_p = \frac{\pi}{w_n\sqrt{1-\zeta^2}}$$

This peak time becomes t'_p when is normalized

$$t'_p = \frac{\pi}{\sqrt{1-\zeta^2}}$$

If this time is substituted in the expression for $y(t')$

$$y(t')_{\max} = 1 + \exp(-\frac{\zeta\pi}{\sqrt{1-\zeta^2}}$$

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The model….

The settling time t_s is normally defined as the time required for the response to remain within 5 percent of its final value. Since the magnitude of the sinusoidal portion of the model for *y(t)* is always less than or equal to 1, for convenience the settling time is often approximated as the time beyond which the overshoot is less than 0.05 or,

$$\frac{\zeta n\pi}{\sqrt{1-\zeta^2}}$$

Or, in other terms

$$\zeta \rangle 0.69$$

to fulfill one requirement of relative stability.

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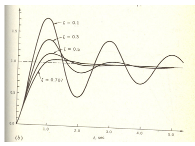
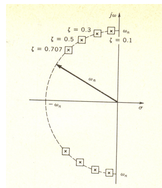
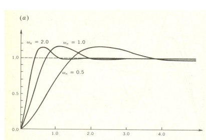
Some examples showing how the damping factor is related to the response and the stability criteria is presented in the following figure.

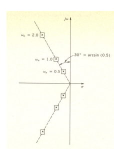




$W_n=1$

We can also observe how the natural oscillating frequency changes for each case.





$\zeta=0.5$

It appears that the nervous system may give preferential weighting to the most reliable and relevant sources of sensory information during forward walking or under unbalancing stimuli where compensation actions are needed.

Example: Case of study of 3D head movements from a male subject 54 years old.

No apparent diseases or disorders were present. However, it does not mean that any compensating process could be in progress due to ageing.

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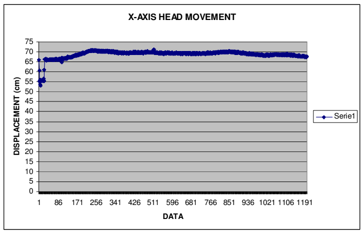

MALE, 54 YEARS OLD, NO APPARENT DISORDERS IN MOTION
NEITHER CHRONIC DISEASES REPORTED

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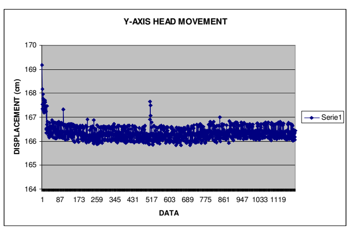

MALE, 54 YEARS OLD, NO APPARENT DISORDERS

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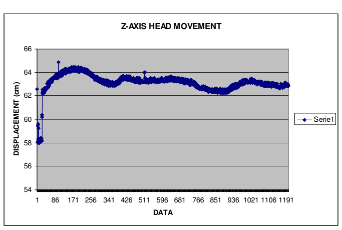

MALE, 54 YEARS OLD, NO APPARENT DISORDERS

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Damping factor, natural frequency determination and the mathematical model for the case of study.

From the figure,

$$Td = 4.1$$

Then

$$w_n = \frac{2\pi}{Td} = 1.53(rad)$$

From t_p equation, ζ can be obtained,

$$\zeta = \sqrt{1 - \frac{\pi}{w_d t_p}}$$

Substituting values,

$$\zeta = 0.742$$

and ψ=42.23°

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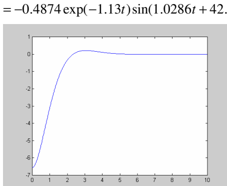
The math model of the step-response (x-axis) for the case of study taken as example is,

$$y(t) = -0.4874\exp(-1.13t)\sin(1.0286t + 42.23^{o})$$



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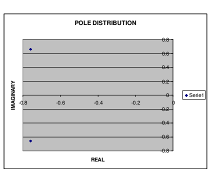
To represent the model in the s-plane, w_d and θ must determined according with

$$w_d = \frac{1}{2\pi T_d} = w_n\sqrt{1-\zeta^2} = 1.0286 \quad \text{and} \quad \theta = \arcsin\zeta = 49.5862^{o}$$



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Conclusions

We are starting an interesting study to obtain objective indicators to determine the capacity of regulation of natural systems to maintain the equilibrium under the assessment with stability criteria when step-type stimuli are applied.

Elderly were only submitted to one procedure because of cognitive problems to follow instructions during the study.

Even the title of the study is referred to elderly, we are submitting subjects with ages covering decades in order to reference changes in balance mechanisms due to plastic processes occurring along the life.

Our proposal of protocol includes procedures that must be defined according to the subjects under study. Each case will probably need more than one procedure.

According with the signals recorded from the head movements and the good relationship observed with the step-response of a second order control systems, we are encouraged to follow our hypothesis that biological control systems can be studied using concepts of stimulus-response to determine stability disorders.