Design a force platform for measuring center of pressure (COP) signal

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Introduction

- Falls are a major public health concern issue for the elderly people.
- The "**complexity**" was used to reflect adaptability and to determine balance stability from the center of pressure (COP) signals (Costa *et al.*, 2003).
- Application of subsensory noise to the feet has been demonstrated to improve postural stability in the elderly (Costa et al., 2007).
- It is assumed that elderly people can effectively enhance individual's postural balance stability through plantar vibratory stimulation.
- Main objective is to compare the complexities of COP signals before and after using vibratory insoles for elderly and young adults.

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Noise and poise: Enhancement of postural complexity in the elderly with a stochastic-resonance–based therapy

M. Costa[1], A. A. Priplata[2,3], L. A. Lipsitz[2], Z. Wu[4], N. E. Huang[5], A. L. Goldberger[1] and C.-K. Peng[1]

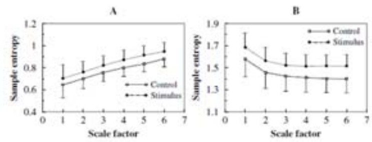

Fig. 2: MSE analysis of: A) anteroposterior and B) mediolateral postural displacement sway time series recorded under free-running (control) conditions and with subsensory noise stimulation (stimulus) from a healthy elderly subjects. Time series were detrended using the empirical mode decomposition method. The symbols represent mean values of sample entropy (SampEn) for all subjects and all trials and error bars represent standard errors. Parameters for the calculation of SampEn were: $m = 2$ and $r = 0.15$.

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Effect of step-synchronized vibration stimulation of soles on gait in Parkinson's disease: a pilot study

Peter Novak*[1] and Vera Novak[2]

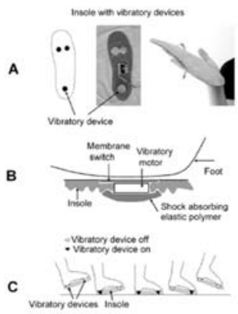

Figure 1

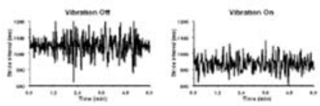

Figure 2
Stride intervals of the left leg from a 45-year-old Parkinson's disease subject obtained during 6-minute walking without (left) and with (right) the vibratory stimulation of soles. Vibratory stimulation reduced the coefficient of variation of stride interval from baseline value 11.49% (SD = 62.0 ms) to 9.43% (SD = 44.2 ms).

Nature in 1993, Crayfish

Noise enhancement of information transfer in crayfish mechanoreceptors by stochastic resonance

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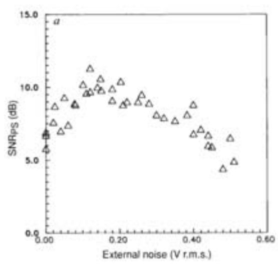
In linear information theory, electrical engineering and neurobiology, random noise has traditionally been viewed as a detriment to information transmission. Stochastic resonance (SR) is a nonlinear, statistical dynamics whereby information flow in a multistate system is enhanced by the presence of optimized, random noise[1-4]. A major consequence of SR for signal reception is that it makes possible substantial improvements in the detection of weak periodic signals. Although SR has recently been demonstrated in several artificial physical systems[5,6], it may also occur naturally, and an intriguing possibility is that biological systems have evolved the capability to exploit SR by optimizing endogenous sources of noise. Sensory systems are an obvious place to look for SR, as they excel at detecting weak signals in a noisy environment. Here we demonstrate SR using external noise applied to crayfish mechanoreceptor cells. Our results show that individual neurons can provide a physiological substrate for SR in sensory systems.



Nature in 1996, Noise-enhanced Tactile Sensation

Noise-enhanced tactile sensation

SIR — Stochastic resonance, a phenomenon in which noise enhances the response of a nonlinear system to a weak signal[1,2], has been demonstrated to be important functionally in various physiological systems[3-6]. Here we demonstrate improvements in human sensory perception mediated by stochastic resonance-type effects. We show that the ability of an individual to detect a subthreshold tactile

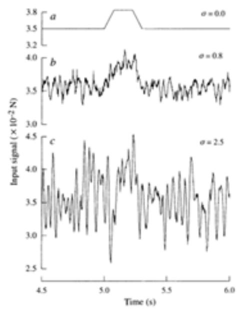


FIG. 1 Representative samples of the input signal for three experimental conditions: *a*, stimulus with no input noise; *b*, stimulus with input noise of moderate intensity; *c*, stimulus with input noise of high intensity. (Respective values for the

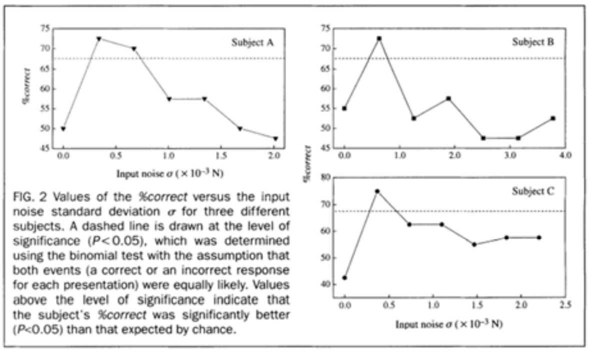


FIG. 2 Values of the %correct versus the input noise standard deviation σ for three different subjects. A dashed line is drawn at the level of significance ($P<0.05$), which was determined using the binomial test with the assumption that both events (a correct or an incorrect response for each presentation) were equally likely. Values above the level of significance indicate that the subject's %correct was significantly better ($P<0.05$) than that expected by chance.

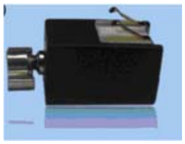
Part I
Design A Balance Stability Enhancement System

Vibratory insoles and shoes

Top view

Side view

Back view

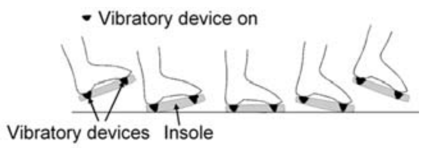


Micro motor

Variable resistor

vibratory insoles

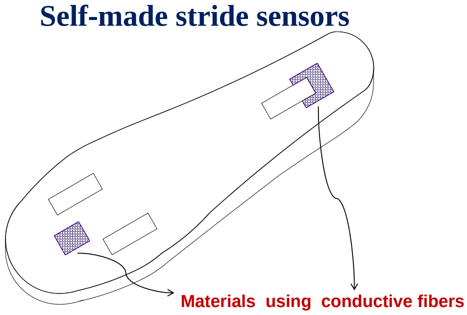
Variable resistor combine with the vibratory insoles



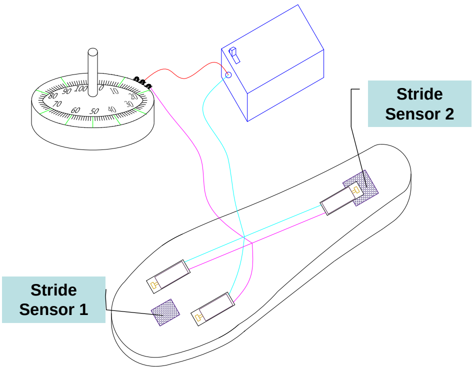
Vibration mechanism

Stride-interval measurement using conductive material

Self-made stride sensors

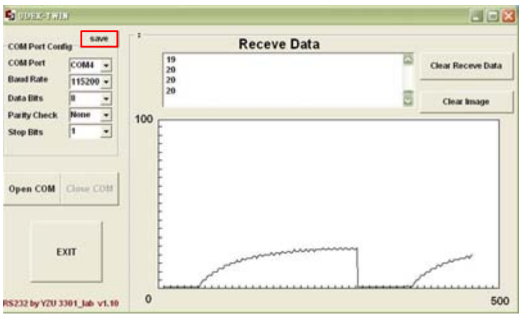


Self-Made Micromotors plus Stride sensors

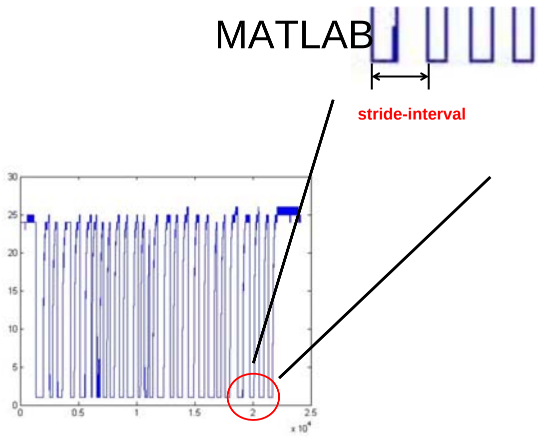


Self-Made Stride sensors in insole and shoes with ARM

ARM collecting data



MATLAB

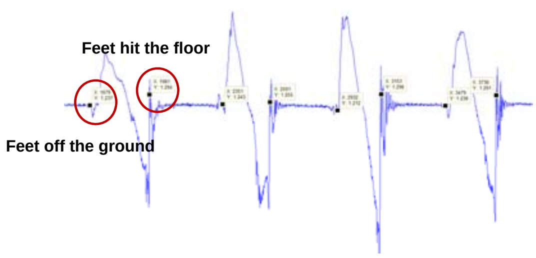


Stride-interval measurement using tri-axis accelerometer

Accelerometer

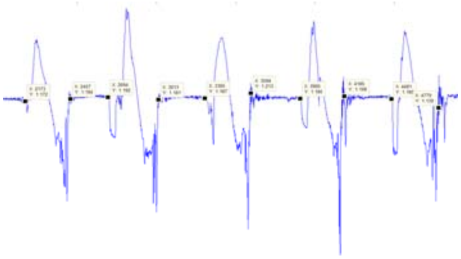
A/D card (500hz)

Step spacing - 30cm



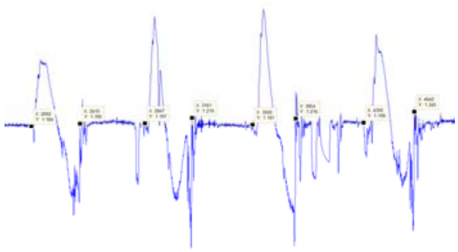
Average step time 0.56±0.076 (s)

Step spacing - 40cm



Average step time 0.58±0.054 (s)

Step spacing - 50cm



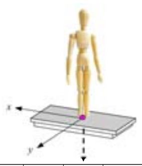
Average step time 0.63±0.04(s)

Part II
Multi-Scale Entropy Applied in Fall-Risk Evaluation via Measuring Non-invasive Physiologic Signals

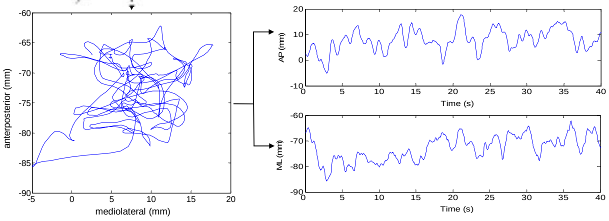
COP force plate

The COP signals were obtained from a force plate CATSYS 2000 (Danish Product Development Ltd., Snekkersten, Denmark) and its signal sampling frequency was about **40Hz**.

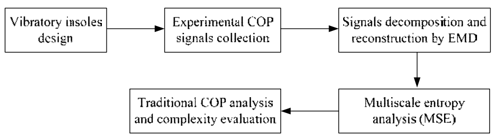
Postural stability and COP signal



- The **COP (center of pressure)**, which can be used as a measure of postural stability, is measured in the horizontal plane in both **anterposterior (AP)** and **mediolateral (ML) direction**.



A functional module flowchart for COP signal analysis



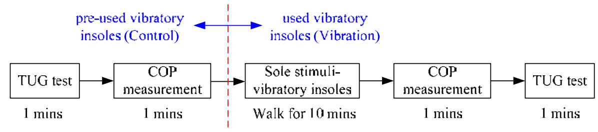
- EMD technique was adopted to decompose the COP signals.
- The reconstructed signals were analyzed by MSE.
- Complexity was evaluated and compared.

Vibratory insoles for elderly and young subjects

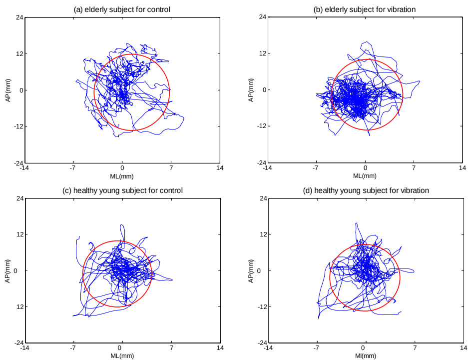
- **Subjects：**
- 26 elderly subjects (with fall experiences in one year; all males; age range: 65-95 years old).
- 16 healthy young subjects (fourteen males and two females; age range: 20-30 year old).

Time up and go and COP measure experiment

Time Up and go　　COP　　The sole of feet stimuli- vibratory insoles



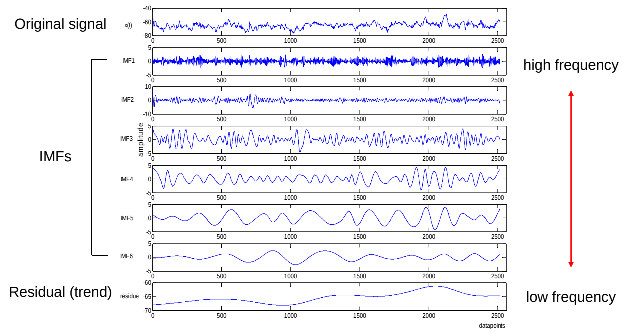
Traditional COP analysis-Area based



The AREA-CC (95%) can not effectively distinguish the differences in this experiment.

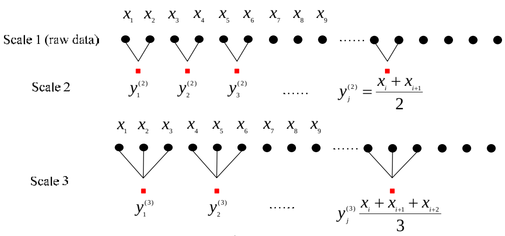
Empirical mode decomposition (EMD)

- Huang *et al.* (1998) developed EMD procedure.
- Signal is decomposed into **intrinsic mode functions** (IMFs) by EMD.



Multi-scale entropy (MSE)

Schematic illustration of the MSE for scale 2 and 3 (Costa *et al.* 2002)



$$y_j^{(2)} = \frac{x_i + x_{i+1}}{2}$$

$$y_j^{(3)} = \frac{x_i + x_{i+1} + x_{i+2}}{3}$$

$$y_j^{(\tau)} = \frac{1}{\tau}\sum_{i=(j-1)\tau+1}^{j\tau} x_i, \quad 1 \le j \le \frac{N}{\tau}$$

- The entropy is calculated by **sample entropy**.
- Match point (***m***) and tolerance ratio (***r***) → $m = 2$ and $r = 0.15$

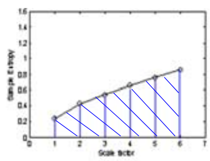
MSE

Complexity index (CI)

- Complexity index (CI) was defined as the area under the MSE curve as

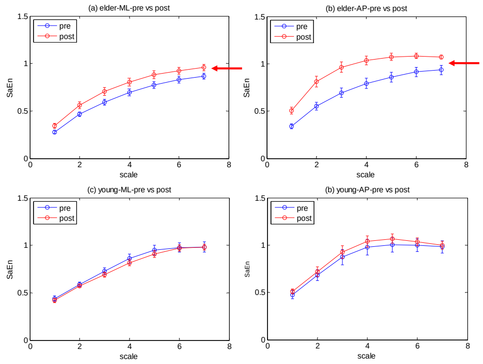
$$CI = \sum_{i=1}^{sn} SampEn\,(i)$$

where *sn* is presented scale numbers.



- CI is compare to determine the complex degree of the signal.
- **If the CI value of the subject is greater , the Complexity of the subject is higher.**

The MSE analysis of reconstructed COP signal (IMF2+IMF3)-EMD



The comparisons of Area-based and MSE for elderly and young subjects under pre-test and post-test conditions

Stabilometric parameters	Elderly fallers		Healthy young		P_a	P_b
	pre	post	pre	post		
Area-based						
AREA-CC (95%) (mm^2)	31.55 ± 14.57	25.11 ± 16.90	25.81 ± 17.53	23.52 ± 13.41	0.104	0.611
AREA-SW (mm^2/s)	58.15 ± 28.13	46.12 ± 22.37	27.7 ± 14.8	23.6 ± 14.31	0.102	0.335
MSE-ML (complexity)	5.205 ± 1.085	5.829 ± 1.353	5.517 ± 0.728	5.349 ± 0.646	**0.030**	0.427
MSE-AP (complexity)	5.611 ± 0.734	7.263 ± 1.355	5.926 ± 1.266	6.299 ± 0.599	**0.001**	0.321

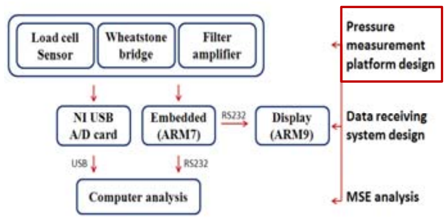
- P_a: *p*-value for elderly subjects between pre-test and post-test.
  P_b: *p*-value for healthy young subjects between pre-test and post-test.

The statistical significance of MSE-ML and MSE-AP is higher, especially for MSE-AP. (P_a <0.001)

Part III
Developing a Fall-Risk Evaluation System

Balance Measurement Device

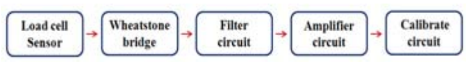
- There are many commercial COP measurement systems (such as Kistler, CATSYS2000) in the market. However, their prices are usually too high to be affordable.



The balance measurement system design flow chart

Balance Measurement Device

Pressure measurement platform design

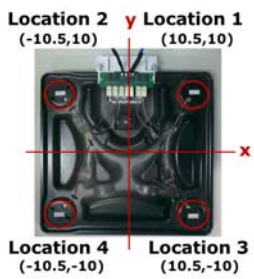


Pressure measurement platform

Reproducibility tests

Static state COP test

The location of four static test points



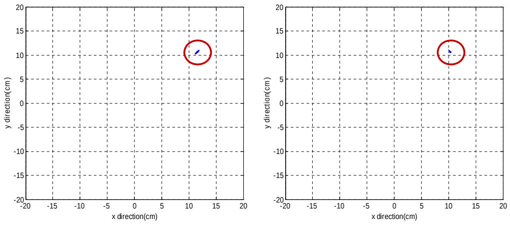
Static test at location 1

Reproducibility tests

Static state COP test

The location of four static test points

Static test at location 1



(a) High resolution balance measurement system

(b) Embedded balance measurement system

Reproducibility tests

Static state COP test

Result

Table 1. The mean and standard deviation value of four locations which measured by **high resolution balance measurement system**

	Location 1		Location 2		Location 3		Location 4	
	X	Y	X	Y	X	Y	X	Y
1	11.325	10.403	-10.428	9.9516	12.219	-11.020	-11.249	-10.618
2	11.292	10.35	-11.087	10.363	12.373	-11.188	-11.747	-11.084
3	11.277	10.326	-11.051	10.412	12.440	-11.263	-11.124	-10.548
4	11.335	10.373	-11.105	10.521	12.104	-10.925	-11.402	-10.799
5	11.272	10.306	-10.925	10.371	12.125	-10.944	-11.257	-10.667
6	11.495	10.516	-10.739	10.233	12.111	-10.936	-10.856	-10.301
7	11.428	10.459	-10.926	10.384	12.108	-10.935	-11.082	-10.515
8	11.433	10.46	-10.688	10.183	12.036	-10.881	-11.253	-10.667
9	11.467	10.557	-10.475	9.9963	12.177	-11.000	-11.223	-10.627
10	11.48	10.562	-10.39	9.9053	12.151	-10.975	-11.241	-10.646
Mean	11.38	10.431	-10.781	10.232	12.184	-11.007	-11.244	-10.647
SD	0.0889	0.0938	0.2779	0.2157	0.128	0.123	0.22842	0.2009

Standard deviations are between 0.09 and 0.28 (cm)

Reproducibility tests

Static state COP test

Result

Table 2. The mean and standard deviation value of four locations which measured by **embedded balance measurement system**

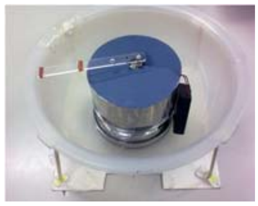
	Location1		Location2		Location3		Location4	
	X	Y	X	Y	X	Y	X	Y
1	9.919	10.082	9.941	-10.118	-9.768	10.440	-10.063	-10.250
2	9.976	10.087	10.117	-10.341	-10.404	10.623	-9.976	-10.183
3	10.063	10.250	9.936	-10.180	-10.250	10.455	-9.775	-10.105
4	10.031	10.306	10.105	-10.328	-10.201	10.401	-9.822	-10.005
5	10.061	10.249	10.101	-10.293	-10.177	10.437	-9.817	-10.025
6	10.044	10.233	9.971	-10.284	-10.196	10.407	-9.828	-10.012
7	10.056	10.258	9.907	-10.238	-10.192	10.413	-9.827	-10.010
8	10.173	10.336	10.141	-10.349	-10.169	10.451	-9.810	-10.059
9	10.259	10.387	10.128	-10.327	-10.160	10.466	-9.779	-10.114
10	10.067	10.262	9.729	-10.227	-10.194	10.410	-9.788	-10.144
Mean	10.065	10.245	10.008	-10.269	-10.171	10.450	-9.848	-10.091
SD	0.0945	0.0967	0.1337	0.0765	0.1584	0.0647	0.0945	0.0836

Standard deviations are between 0.06 and 0.16 (cm)

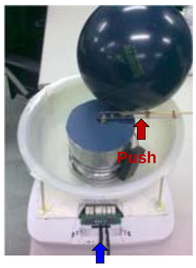
Reproducibility tests

Dynamic state COP test

The dynamic simulation device



Dynamic simulation device

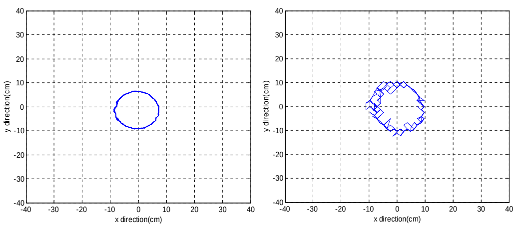


Simulation device with a ball

Reproducibility tests

Dynamic state COP test

The regular displacement figure



(a) High resolution balance measurement system

(b) Embedded balance measurement system

Reproducibility tests

Dynamic state COP test

Result

Table 3. The mean and standard deviation values of radius:

R1 : Measured by the high resolution balance measurement system

R2 : Measure by the embedded balance measurement system

	R1 (cm)	R2 (cm)
1	9.20	9.82
2	9.18	9.56
3	9.80	9.96
4	9.73	10.76
5	9.55	10.37
6	9.66	10.69
7	9.33	10.65
8	10.01	10.78
9	10.19	10.85
10	10.02	10.59
Mean	9.667	10.403
SD	0.353	0.459

Balance Measure System
Human balance test

AMTI BIOMECHANICS PLATFORM

PLATFORM

Signal Processor

Balance Measure System
Human balance test

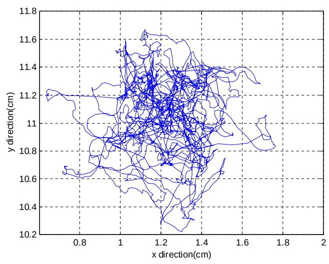
AMTI BIOMECHANICS PLATFORM

High resolution balance measure system on the AMTI system

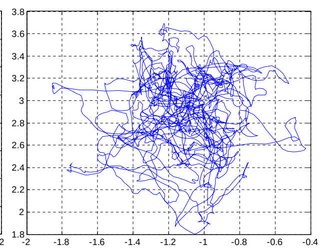
Balance Measure System
Human balance test

Subject standing on the AMTI system and our CPCMS

Balance Measure System
Human balance test



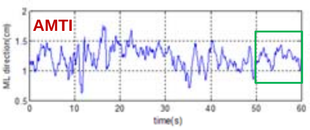
AMTI

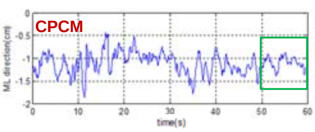


CPCMS system

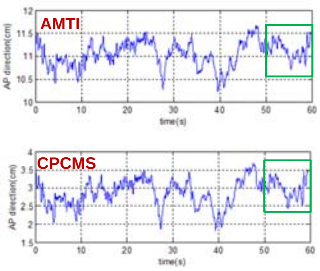
Balance Measure System
Human balance test

ML direction(cm)

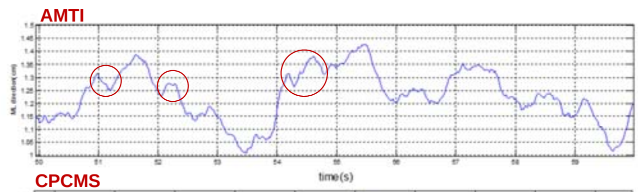


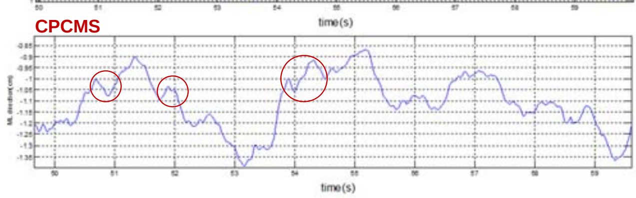


AP direction(cm)



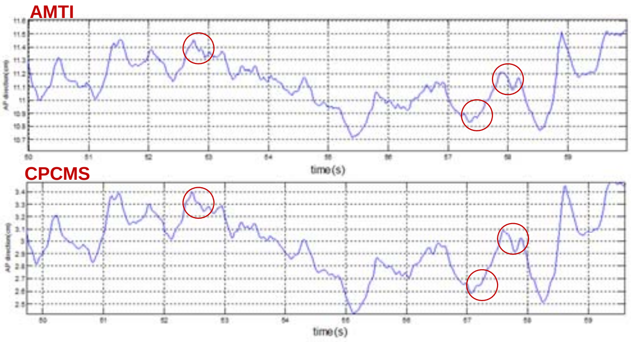
Balance Measure System
Human balance test





Balance Measure System

Human balance test



Balance Measure System

Human balance test

Experiment:

(1) Standing directly on the platform:

-Eyes open (Sway1)

-Eyes closed (Sway2)

(2) Standing on the platform with a soft foam (Water cushion) under their feet:

-Eyes open (Sway3)

-Eyes closed (Sway4)

Balance Measure System

Human balance test

Water cushion on the balance measure system

Balance Measure System

Human balance test

Standing directly on the platform

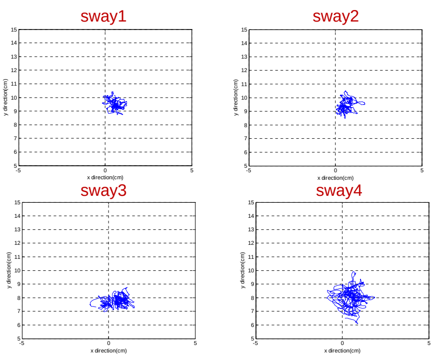
Eyes open (Sway1)
Eyes closed (Sway2)

Standing on the platform with a soft foam (Water cushion)

Eyes open (Sway3)
Eyes closed (Sway4)

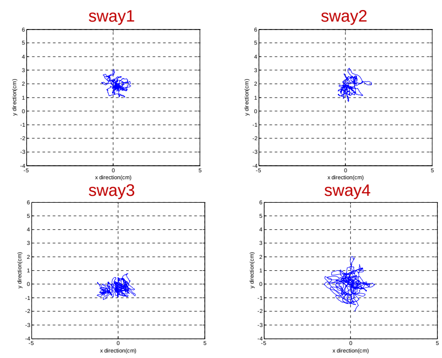
Balance Measure System

Human balance test (AMTI)



Balance Measure System

Human balance test (Our system)



Balance Measure System

Human balance test

Tradition Analysis method

Table1. Definition of the specific parameters examined for the **postural sway**

Parameters	Definition
Mean Sway (MS)	Simple mean of the distance from the mean force centre position (FCP) to all recorded force centre positions during the test.
Transversal Sway (TS)	Simple mean of the recorded x-direction values of the force centre in a coordinate system.
Sagittal Sway (SS)	Simple mean of the recorded y-direction values of the force centre in a coordinate system.
Sway Index (SI)	Relates the sway test result to human normal sway established by the manufacturer.
Sway Area (SA)	Area of the smallest polygon, which includes the total trajectory of the force centre in the horizontal plate plane.
Sway Velocity (SV)	Average travel speed of the force centre in the horizontal sway plate plane calculated by dividing the total length of the force centre trajectory (in mm) by the recording period length (in sec.).

	Standing directly on the platform		Standing on the water cushion		P_a	P_b
AMTI	**Eyes open**	**Eyes closed**	**Eyes open**	**Eyes closed**		
MS	0.39±0.12	0.36±0.08	0.43±0.12	0.77±0.22	0.358	<0.001
TS	0.18±0.07	0.19±0.06	0.24±0.08	0.44±0.15	0.630	<0.001
SS	0.31±0.1	0.27±0.06	0.30±0.10	0.53±0.16	0.133	<0.001
MSE(X)	3.19±0.86	3.21±0.90	3.87±0.63	3.92±0.96	0.943	0.847
MSE(Y)	2.79±0.99	3.62±1.01	3.63±0.98	4.14±1.30	0.012	0.169
CPCMS						
MS	0.47±0.13	0.44±0.12	0.50±0.12	0.93±0.31	0.453	<0.001
TS	0.21±0.09	0.22±0.08	0.28±0.09	0.52±0.20	0.712	<0.001
SS	0.38±0.12	0.34±0.09	0.35±0.10	0.66±0.23	0.240	<0.001
MSE(X)	3.94±1.06	4.02±1.01	4.67±0.87	4.85±1.02	0.808	0.552
MSE(Y)	3.41±1.22	4.48±1.16	4.41±1.25	5.09±1.50	0.007	0.128

- P_a: *p*-value for Standing directly on the platform between EO-test and EC-test.
  P_b: *p*-value for Stand on the water cushion between EO-test and EC-test.

Balance Measure System

Human balance test

Volunteer Standing on the Force Platform Protected by Plastic Mats

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