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Monitoring human emotions during earthquakes

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Abstract

In this research work, the human behaviour during strong seismic events is studied. This aspect is of paramount importance in emergency for being able to develop effective evacuation strategy and increasing the safety level of emergency response personnel and people operating critical facilities. In particular, the quantification of the evacuation and control ability to maintain their stable position of normal people has been initially assessed through shaking table tests. The experimental tests have been performed with the support of virtual reality by replicating indoor and outdoor environments. Vital parameters have been collected through sensors. This work involves at this stage two research groups in Italy and Chile with the aim of evaluating strategies and methods on this topic that is rather new in earthquake engineering. This is supposed to be the first step of further investigations on larger campaigns, and number of individuals as well, in order to achieve a comprehensive statistic.

1. Introduction

The number of casualties caused by an earthquake is usually linked to the collapse of structures in which people cannot properly exit during the event. While the human losses are positively correlated to the structural damage, injuries have also been found to occur even when no damage was present in the structure. Such injuries are the result of the individuals being struck by objects or falling off the staircase while trying to escape from the building. Therefore, the shaking itself is deemed to be a significant cause for injuries and death during earthquakes. In addition some people are required to perform activities during the earthquakes as example critical facility operators that should in some case monitor and actuate certain shutdown procedures, controllers of transport systems that should safely park the vehicles, doctors that should control the patient at the operating room, etc. This preliminary work aims at understanding the ability of normal people to maintain their position during ground shaking. This subject has not been extensively study but some pioneer work has been done by (Takahashi et al. 2004, 2011).

Test on humans due to vibration has been performed in other areas of knowledge, (Griffin 1990, 1998, among many others). The main idea is to evaluate the ability to perform control evacuation or controlled pre-determined tasks. The literature review indicate that this conditions are influence by stability of the individual in standing positions, the motion of individual in siting position, the level and frequency of the vibration at the points of entry to the individual, state of health, gender, age and most importantly previous experience or practice. Due to the large number of variable and their variability between humans, testing is difficult to capture overall tendencies.

Additionally the monitoring ability to detect the capacity of individuals is difficult due to the spatial motion of the individuals. To understand and initially quantification and evaluate different variables tests were performed on different individuals and human characteristics consider gender, age, height, complexity and state of health. Each person is equipped with sensors to analyze the person's stability and capability to maintain the initial position, heart rate and breathing in order to measure the main vital parameters and anxiety of the person during the shaking.

A six degrees of freedom (3 translations and 3 rotations) shaking table and a one direction shaking table are used to generate artificial earthquakes. In addition, a virtual reality setting is used in order to recreate a more realistic environment. During the experiment, special attention is given to the factor of "surprise" which is necessary to ensure a natural reaction of the individuals.

2. Laboratory facilities

The research groups at Politecnico di Torino and University of Chile perform complementary test. The laboratory facilities and sensors are described below.

2.1 Research at Politecnico di Torino

Virtual Reality Earthquake Simulator

The growing investment by Google, Facebook, Microsoft, Htc and Sony in the Virtual Reality shows that this technology is a reliable solution for many problems such as training, testing and researches. Virtual Reality has been used for years in medicine as surgery training, for motor rehabilitation and psychological treatments (Figure 1). Professional and free of charge developing environment such as Unity 3D, open source modelling software as Blender, cheap virtual reality head mounted display like Google Cardboard or Samsung Gear VR and user tracking/natural interaction sensor like Microsoft Kinect allows the uses of synthetic environment a research opportunity within the reach of any university (Figure 2).

The virtual reality system that has been developed in this research is a client-server application that uses the following hardware equipment:

- Samsung Gear VR 2016
- Samsung Galaxy S8
- Microsoft Kinect V2 Sensor
- A Notebook with Windows 10 and one usb 3.0 port

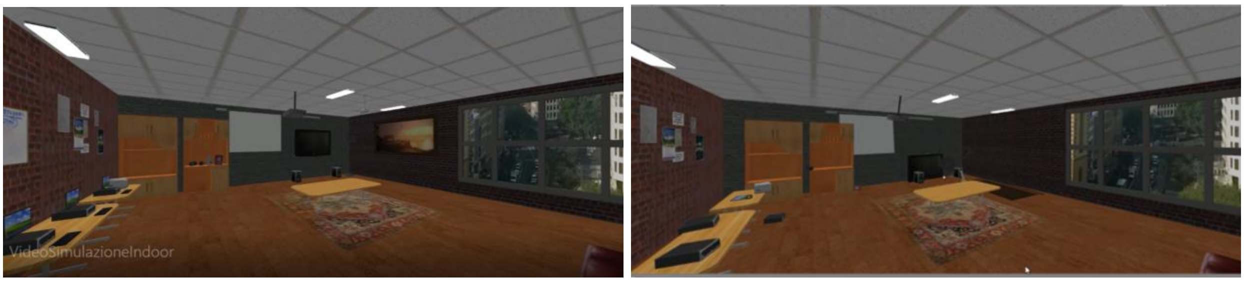
The software has been developed using Unity3D for the client side, and C# with Kinect V2 SDK for the server side.

The simulation system has to achieve three goals:

- quick development time;
- cost-efficient software/hardware architecture;
- connection between one's movements in real world and those perceived into the virtual environment.

A smartphone-based head mounted display is used to reduce realization costs: the Samsung Gear VR in conjunction with Samsung S8 android smartphone represents a good compromise among costs, computational resources and scalability. It allows the user to move his field of view along the three rotational degrees of freedom. Two virtual environments - indoor and outdoor - have been developed in Unity 3D using mesh modelled with Blender and several free available Unity assets. The virtual environment runs on Samsung S8. The spatial variability of the earthquake motion is reproduced by three sinusoidal temporal histories with random amplitude applied in the three directions. When the virtual environment is shaken every object in the scene is affected and moves according the input signal: paintings fall off the wall, furniture tilts, in addiction sound effects are used to increase the realism and the emotional response of the user.

Microsoft Kinect sensor allows the system to track the user position along the 3 translational degrees of freedom in this way the third goal is accomplished. The user position is transmitted to the virtual environment by control software via Wi-Fi using a text based message protocol. The transport layer protocol chosen is TCP. The control software is developed using C# and Kinect SDK, it allows choosing which virtual environment to load, to define the maximum displacement and the duration of the experiment.



(a) (b)

Figure 1. VR indoor environment. Before (a) and after (b) the seismic event.

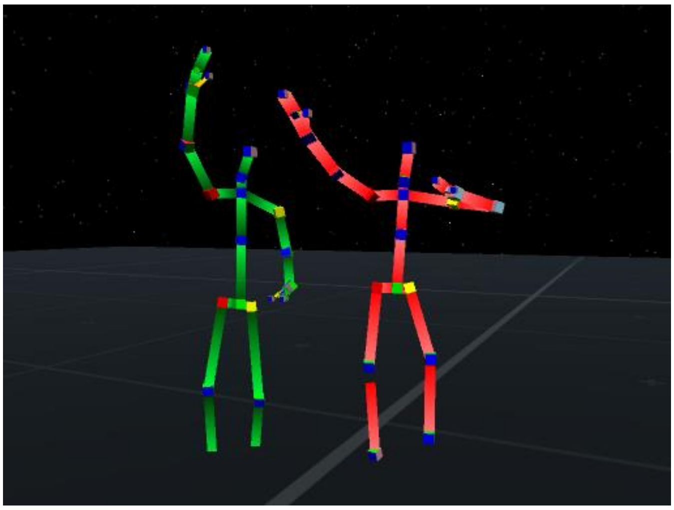


Figure 2. Body monitoring.

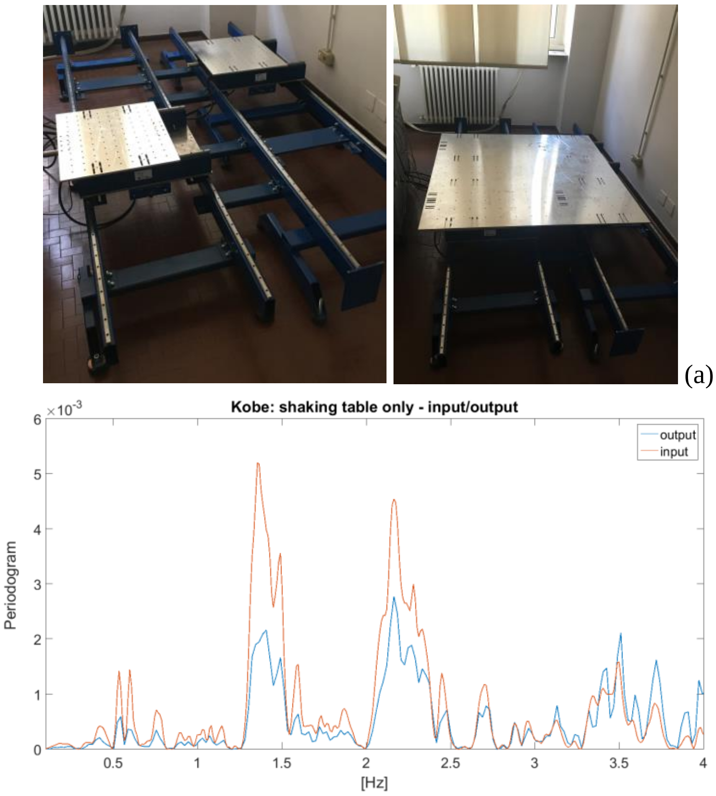
<u>Shaking table</u>

The shaking table used in these experimental tests is two degrees of freedom driven by four linear electric actuators. For these preliminary tests, only uniaxial motions have been simulated. The structure itself consists of steel profiles, whereas the upper platform, where specimens can be fixed, is made of aluminium. Basically, there are two parallel tracks located side by side and connected through transversal rectangular sections. Tracks' profiles are 3 meters long and the section's size is 40x100x4 mm. Upon the steel profiles there are aluminium guides in order to allow the motion, along the longitudinal direction, of sliders that support two 600x500x10 mm aluminium platforms. Each track has its own platform, which is moved by a linear electric actuator anchored under it. On the small platforms, other two tracks are fixed. Type and section of the steel profiles are the same of the bottom ones, while the length is shorter (600 mm). The two mobile carriages are positioned at a certain distance along the longitudinal direction in order to receive the upper platform that is

1500x1500x10 mm big (Figure 3a). The other two actuators that accomplish the motion in the transversal direction are fixed under the large platform and between the tracks of the underlying mobile carriages.

The linear electric actuators adopted are manufactured by the company LinMot and each is made of a stator, a slider and a motor. The longitudinal ones have a slider's length of 800 mm and a maximal stroke of 510 mm, whereas the transversal ones have a slider's length of 500 mm and a maximal stroke of 330 mm. The power supply, the two transformers and the four drivers to control the motors are provided by LinMot as well. The drivers are fundamental for the tuning of the motors that is the initial configuration of all the control parameters in order to have a response coherent with the input data. This operation is done through the software LinMot-Talk that is also used to switch on the actuators and to bring them in the home position.

The software used for the activation and control of the shaking table is LabView. A specific code has been written to handle the input and output data. The seismic input is actually sent to the shaking table by a myRIO device provided by National Instruments. This device is physically connected to the motors' drivers and also to an accelerometer, which is located on the platform and allows catching the actual response of the system. Simply, it is possible to connect a USB pen drive containing the seismic signal in terms of displacements to the myRIO device. The LabView code is used to set the input and output sampling rates, to generate a sinusoidal seismic signal or to load a real one, to scale it, to start and stop the motion and finally to compare the data obtained from the accelerometer with the theoretical ones. Figure 3b depicts the target input accelerogram (KOBE 01/16/95 2046, NISHI-AKASHI, 090 – PEER STRONG MOTION DATABASE) in the frequency domain and the recorded one (output) on the table without individuals.



(a)

(b)

Figure 3. Shaking table (a), input/output in frequency domain without samples on the table (b).

Figure 4 depicts the recorded outputs in terms of acceleration for different performed tests, with and without individuals on the table. In particular, it shows the satisfactory repeatability of the shaking and an essential independency of the output signals to the presence/absence of mounted specimens. It is worth noting that the tuning control parameters of the table remained constant.

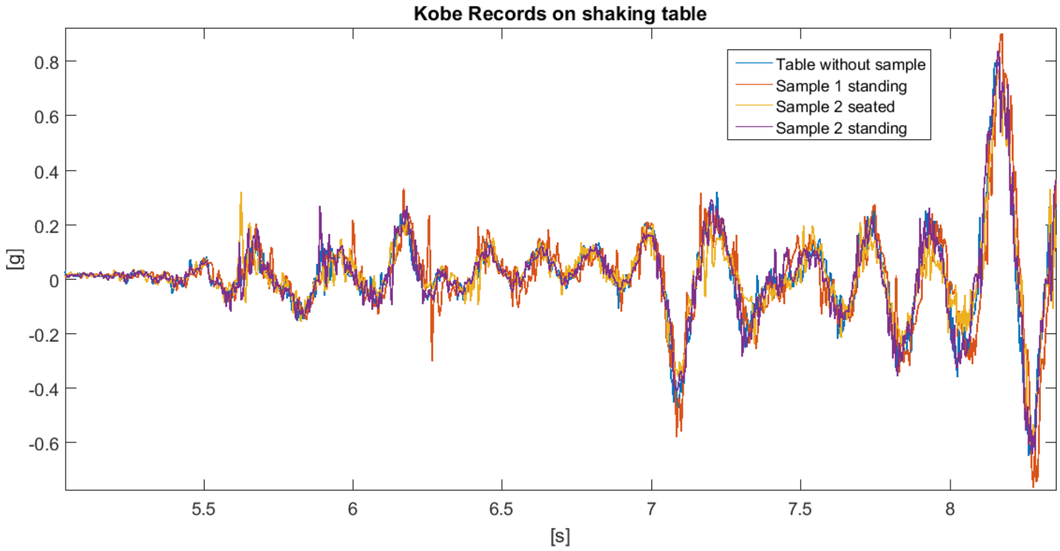
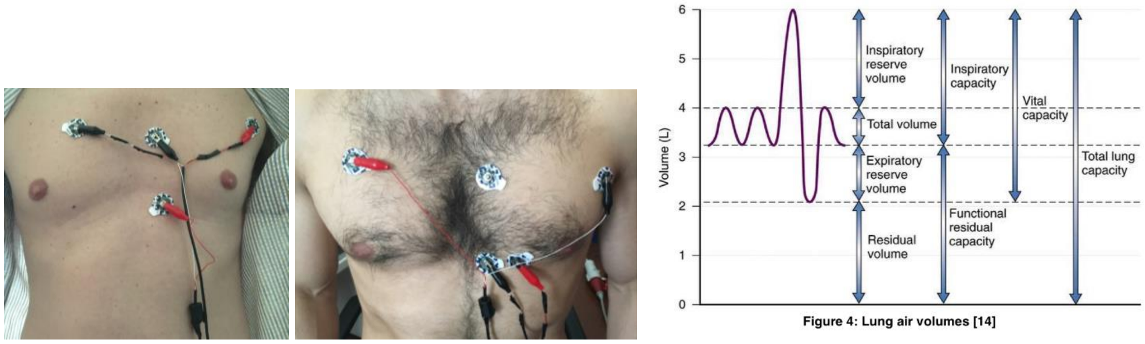


Figure 4. Comparison between shaking table outputs, with and without samples.

Monitoring and sensors

The monitoring systems for ECG (electrocardiogram) and breathing have been applied to the individuals (Figure 5a) in simple configurations. Figure 5b depicts the typical breathing diagram with interpretation details. Individual test was performed on two individuals: 40 and 30 years old, males. First specimen weight was 76 kgf and second one 65 kgf. A lab view code allows to plot the output signals (Figure 6). Finally, Figure 7 depicts standing and seating individual tests on the shaking table, equipped with the VR system and the ECG and breathing sensors. An external laptop allows controlling the whole system and collecting the monitoring data.



(b)

Figure 5. Arrangements of the ECG and breathing monitoring systems on the evaluated samples (a). Breathing interpretation (b).


Stop Data Streaming
Heart Rate 72
Respiration Rate 24
Lead Off Status IN2N IN2P IN1N IN1P

Stop Data Streaming
Heart Rate 91
Respiration Rate 39
Lead Off Status IN2N IN2P IN1N IN1P
Live Plot Selection ADS1292R

(a) (b)

Figure 6. ECG and breathing output signals (a). ECG and breathing board (b).

Figure 7. Standing and seating individual tests.

2.2 Civil Engineering Laboratory U. of Chile

Shaking table

The shaking table used at Universidad de Chile has six degrees of freedom. A 2x2 m platform structure was set up for the tested individual (Figure 8). For safety reason the testing area was surrounded by a rail covered with flexible polyethylene foam. Additionally, individuals used a harness to prevent abrupt collapse due to the motions.

The table is capable of reproducing acceleration in the order of 0.6 g and rotations up to 23 degrees. Maximum payload of the system is 1000 kg. Other table nominal capacities are described in Table I. These conditions limits the testing of individuals to environments were the predominant motions are on the low frequency side of the spectrum, in practical terms this corresponds to people inside structures were the predominant motions are below 5 Hz and the acceleration are below 0.6 g.

Figure 8. Shaking table testing system at University of Chile.

Table I. Motion system main features.

Degree of Freedom	Displacement Comb. Motion	Displacement Single DOF	Velocity	Acceleration
Pitch	±22 deg	±21 deg	±30 deg/s	±500 deg/s^2
Roll	±21 deg	±20 deg	±30 deg/s	±500 deg/s^2
Yaw	±23 deg	±22 deg	±40 deg/s	±400 deg/s^2
Heave	±0.18 m (±7.1 in)	±0.18 m (±7.1 in)	±0.30 m/s (±11.8 in/s)	+0.5 G
Surge	±0.27 m (±10.6 in)	±0.25 m (±9.8 in)	±0.50 m/s (±19.7 in/s)	±0.6 G
Sway	±0.26 m (±10.2 in)	±0.25 m (±9.8 in)	±0.50 m/s (±19.7 in/s)	±0.6 G

Sensors

Three accelerometers were mounted on the platform, making a three-dimensional array. Measuring directions were set up according to the initial position of the testing individual: Front-Back (North-South), Side-Side (East-West) and Up-Down. The accelerometers used in test had sensitivity of 0.005 g and a measuring range of ±2g; sampling rate was set to 200 Hz.

A smart bracelet was used to monitor heart rate on the individual's wrist. It was connected to a smart phone via Bluetooth, to have control over the data collection. Every test was recorded and stored for posterior analysis. Sampling rate for this device was 1 Hz.

Video recording was use to monitored testing subject and table motions. Table displacements were monitored using visual targets attach to the table. Individual stability and anxiety was observed visually from videos and from inquiries to the testing subject.

Initial test was performed on three individual ages: 55, 29 and 25, two males, one female. Male weight was 80 kgf and female weight 55 kgf. Testing position was standing with the possibility of walking during testing. Some of the tests were performing using and eye cover to reproduce full blackout during shaking.

3. Results

Some of the initial results are shown in Figures 9 to 11. In this figures the motions of the table, the pulse rate and the individual characteristics are shown. Additionally the testing individuals report the indication of the level of anxiety and stability.

In Figure 9 it is presented (on the top) the pulse rate for a female testing individual. The motion, as recorded on the table, is presented on the bottom three figures, indicating the initial orientation of the individual with respect to the axes of motion (FB Front Back, SS Side to Side and UD vertical). As expected different results are obtained from each individual.

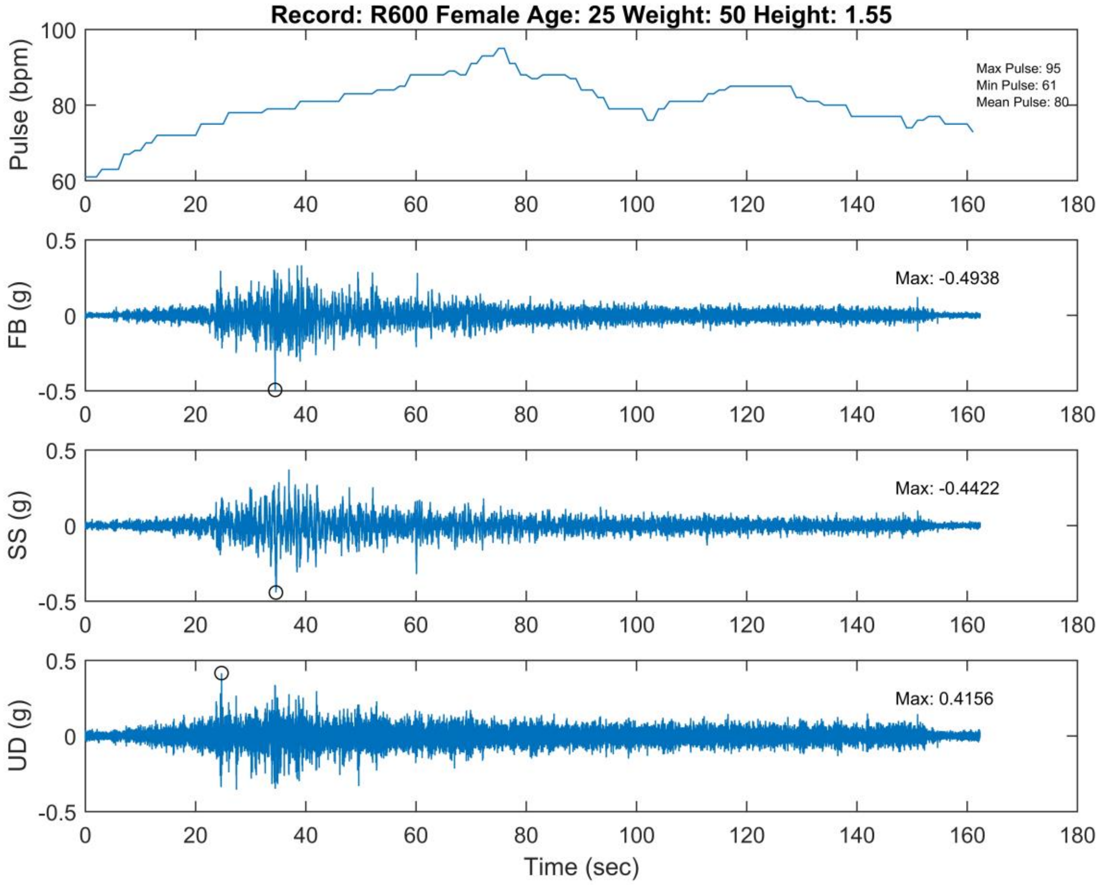


Figure 9. Sample 1 – University of Chile.

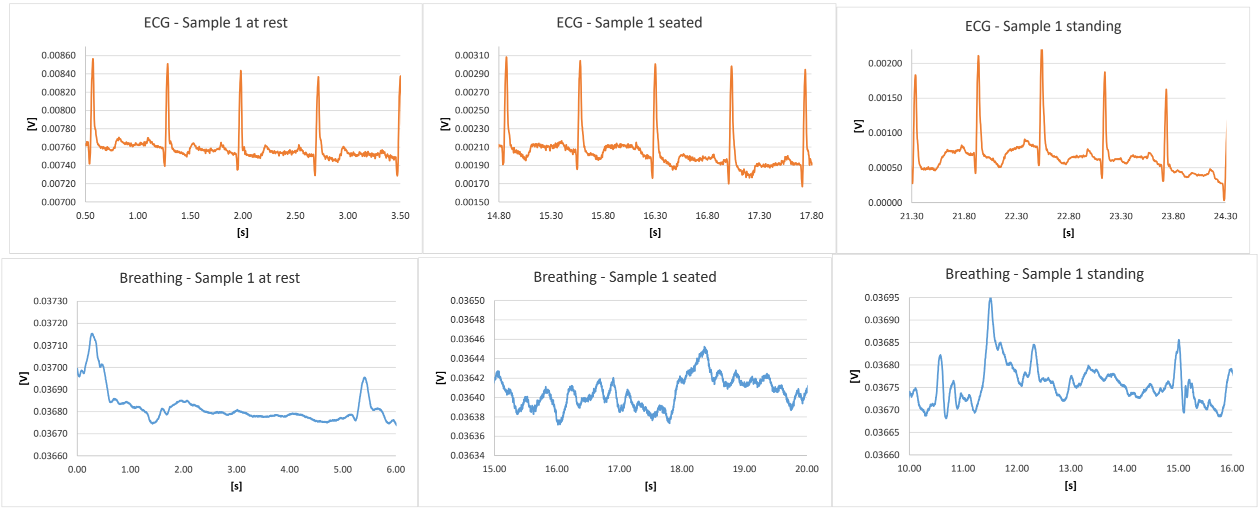


Figure 10. The first tested individual: top ECG, bottom breathing.

Moving to the Politecnico di Torino outcomes, Figure 10, on the first tested individual, highlights increments in the hearth beats from condition “at rest” to “standing” one, passing through “seated” condition. Breathing at rest results steady with regular and clear peaks (inspiration-expiration). On the contrary, when the first tested individual is under shaking (emergency) breathing is disturbed,

irregular and uncomplete. Indeed, the breathing sensor is sensible to body movements, arms in particular. When the individual has been shaken, the first body reaction is to lift and opens arms for improving equilibrium.
The second tested individual confirms the first tested one behaviour, even if the breathing “at rest” gives unexpected information owing to arms movements. In fact, as previously discussed, breathing signal can be affected by the chest extension due to breathing but also moving.

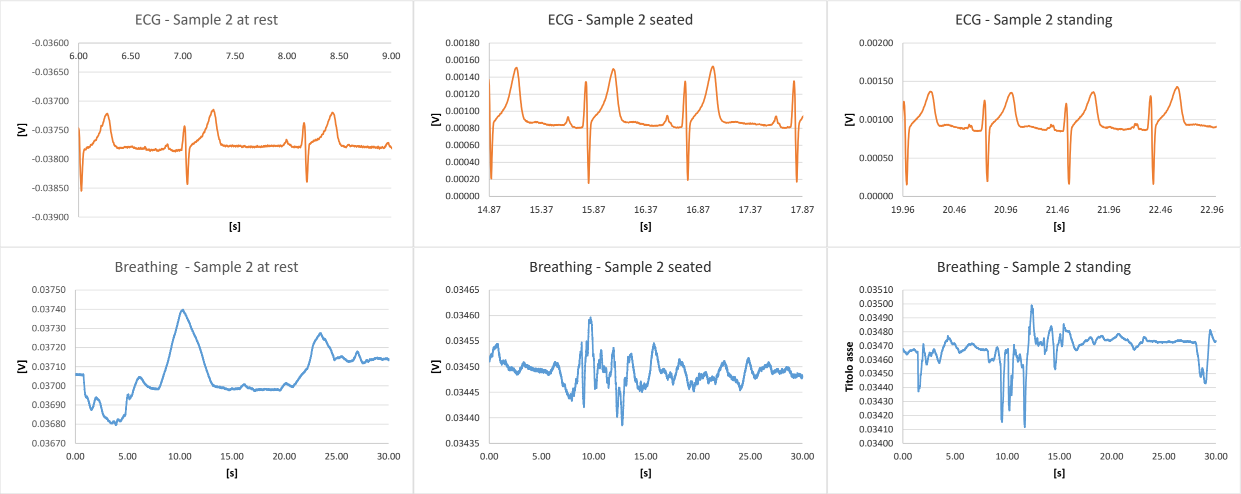


Figure 11. The second tested individual: top ECG, bottom breathing.

4. Conclusions

Several initial conclusions can derived from the performed testing.

Regarding table motions. The results are highly dependent on the number of degrees of freedom of the motions. The standing individual, as he feels instability, try to reposition himself on a more comfortable position. Multiple axis of motion restricts this possibility. Additionally the rotation components augment considerably the instability. Perception of vibrations starts at very low acceleration levels vibration. Literature indicates that sensitivity and reaction are larger in the frequency range from 0.1 Hz up to 80 Hz. Nevertheless inside structures this frequencies are considerable filtered to bands that are lower than 25 Hz. Additionally, for stability, the most critical frequency are lower than 15 Hz. Table motion should be capable of reproducing this motions.

Individual response is highly dependent on people expectations, experience and mental preparation. In Chile due its high rate of seismicity with a magnitude 5 earthquakes, or higher, occurring in average 70 times a year and Mercalli Intensity V occurring every two week, on average in the country, individuals are more trained reacting to earthquake events. Individuals were tested for several different motions and they learned quickly how to reposition themselves on more stable position. Additionally if the motions contained predominant simple periodic motions (like Chile Concepcion 2010 record) the individual quickly detached the motion of his lower part from upper part. High frequency motion produces higher anxiety but not necessarily uncontrollable stability.

Detection of human responses based on the basic sensors used in this stage of the research indicated that they are not as reliable to described stability and anxiety when compare to tested individual verbal description and visual monitoring of overall body position and foot contact with surface.

Increments in the hearth beats from condition “at rest” to “standing” one, passing through “seated” condition are usually detected. Furthermore, breathing at rest results steady with regular and clear peaks (inspiration-expiration). On the contrary, when tested individuals are under shaking (emergency) breathing is disturbed, irregular and uncomplete. Indeed, the breathing sensor is sensible to body movements, arms in particular. When the individual has been shaken, the first body reaction is to lift and opens arms for improving equilibrium.
In general the band wrist sensor shows that in some conditions, especially the long durations of Chilean records, increase of heart rate occurred which was not always consistent with the level of motions. But, as soon the motion was starting to decay the heart rate was higher than at rest conditions.

As expected blindfolded individual, reproducing dark environments, presented much less stability and higher anxiety that individual that had a reference frame. When Virtual devices are use the reference frame is gone and the stability is again diminish indicating the importance of recreating as a real environment as possible for this type o testing.

Acknowledgements

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