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Human stability in the erect stance: Alcohol effects and audio-visual perturbations

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ABSTRACT

Aim: In this article, we discuss the connection between alcohol and the control strategies carried out by the central nervous system to maintain the erect stance. Audio-visual perturbations were coupled with the consumption of an alcoholic beverage to simulate the possible perturbation affecting people at disco clubs, and the effects measured with a stabilometric platform.
Methods: We studied the statokinesigrams (SKG) of 14 volunteers; 11 of them were healthy, 3 were injured. We made a series of numerical tests using a stabilometric platform to record the statokinesigrams.

The tests were carried out using statistical methods, time-series analysis, and applying the "*p*" parameter, recently proposed by Pascolo and Marini [2006. On the introduction of a new parameter for the analysis of posture. Europa Medicophysica, 42, 145–149] as a new tool to evaluate the reactions of the central control system with respect to posture-affecting diseases (for instance Parkinson) and perturbations.
Conclusion: This work shows that it is theoretically possible to define non-invasive parameters able to distinguish sober subjects from drunk subjects, with an evaluation that only uses a stabilometric platform.

1. Introduction

1.1. The problem

With this work, we wanted to study the reaction of the human body in the erect stance to the consumption of alcoholic drinks making 3 different types of tests.

We tried to find a parameter that could discriminate the behaviour of subjects under the influence of alcohol associated or not with some perturbations.

Considering the limited number of subjects examined, this should be considered a preliminary study. However, the trends highlighted in the data presented here will guide the design of further experiments, the acquisition of new data and the development of new parameters.

1.2. Inverted pendulum

In the first approaches to the problem of studying stability (see Bottaro et al., 2005), an easy approximation was made in order to analyse the erect stance and the sway, where the movement of the human body was modelled through the use of a simple inverted pendulum.

However, the scheme of the inverted pendulum is definitely too simple to explain how the human body acts, as it has only one degree of freedom. The feet are assumed to be fixed and the rest of the body is considered as a whole: the only strategy of muscular activity control is necessarily the ankle strategy (Casadio et al., 2005), neglecting all other possible movements. The inverted pendulum scheme, with its only 1 d.o.f., is definitely too simplified to be effective (Fig. 1).

1.3. The pluri-segmental model

To avoid the limitations of the inverted pendulum model, a 2D pluri-segmental model was introduced (Pascolo and Saccavini, 2004), incrementing the number of joints. The target of this model is to understand how the center of mass (COM) and the center of pressure (COP) behave.

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Pascolo and Saccavini (2004) studied a 2D-coupled system: the motions and the forces between the various parts were computed by a multi-body code. The model proposed was developed via the coupling of 2 separate bidimensional models, one representing the sagittal plane and one representing the frontal plane (Fig. 2). For the simulations they used a multibody model integrated by a system of dynamical equilibrium equations that determine the postural act with an optimal control criterion for the evaluation of the instantaneous muscular activity (Fig. 3).

A further improvement was the 3D model (Fig. 4): in this case the segments have 6 d.o.f. each. So considering n segments there are $6n$ d.o.f., and therefore $6n$ equations. The criterion of stabilization used in this case is the minimization of the functional of energy. A system of stiffness was also applied in correspondence of every joint between the segments. The lag times of the muscular activation and the internal respiration are also considered (Pascolo et al., 2003; Pascolo, 2004). Finally, Pascolo et al. (2004, 2005) discussed the implications of nonlinearities and the possible presence of chaos in the postural sway.

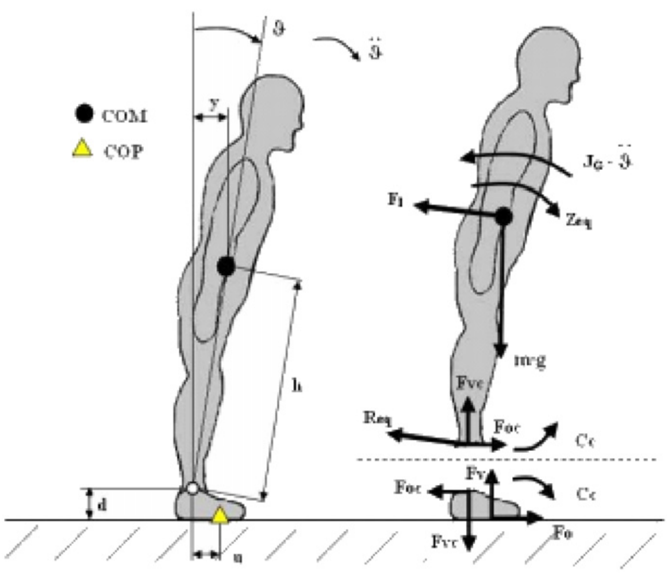

Fig. 1. The inverted pendulum.

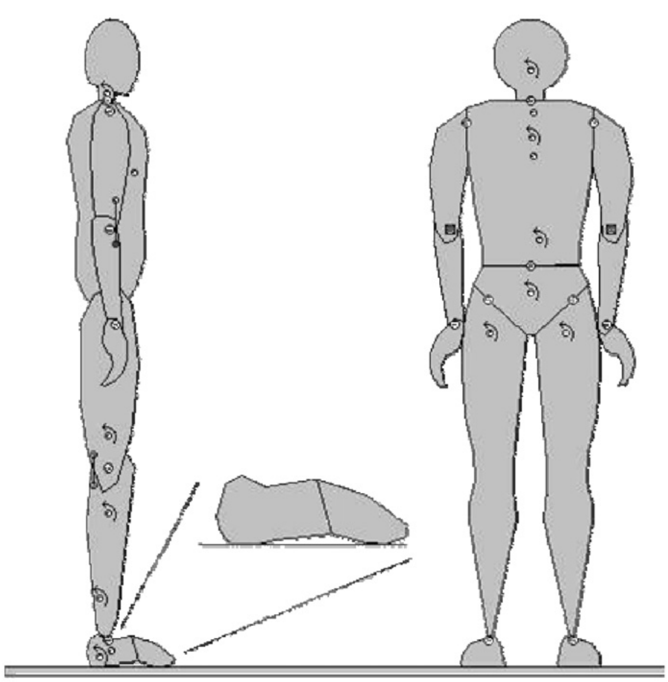

Fig. 2. The multi-body segmental model.

1.4. Our study

Our purpose was to study how an alcoholic beverage was able to change the reaction of the human neurological control system. According to World Health Organization statistics, there has been an increase in world-wide alcohol consumption, including in the youngest age group (Loranger et al., 1994). The most common alcoholic drink in the world is beer, while in Italy it is wine. We used wine for our experiment as an objective measure of the effects of alcoholic drinks on stability would help to quantify "in practice" the neurological impairment that results from alcohol and poses a serious risk to self or others.

We made a series of numerical tests using a stabilometric platform to record the statokinesigrams (SKG). The tests were carried out using several amplitude and spectral parameters (Chiari et al., 2003), including the recently proposed parameter "p" (Pascolo and Marini, 2006). This is an adimensional parameter which measures the degree of independence of motions and which is a ratio independent of the characteristics of the subject analysed, thus making preliminary anthropometry unnecessary. A diminished activity of the central control system (a typical example is Parkinson's disease), could increase the coupling of AP–ML motions, thus compromising the control on the postural act. A motion in one plane is followed, with a high probability, by a motion in the orthogonal plane. In this paper, we investigate the effect of alcohol rather than a diagnosed posture pathology on these parameters.

The second step was to couple the increased alcohol rate with the conditions typically observed at disco clubs. These conditions are generated with a high volume of music and the use of stroboscopic lights. Trance music is considered to be among the kinds of music that generates the highest perturbation for the neurological control system. A high volume of this music gives rise to a stress of the vascular system of the ear, and its frequency alters the cerebral waves (Ogawa et al., 2005). According to the chromo-therapy, we used a red light because this colour gives a mental agitation (Barber, 1999). If the trance music is associated with the stroboscopic lights it can even generate a hypnotic state. Therefore, we wanted to study what happens when this audio-visual perturbation is combined with alcohol consumption."

2. Materials and methods

2.1. Volunteers

The population sample included 14 subjects: 11 healthy volunteers (H) and 3 with minor orthopedic impairments (OI) (torn knee ligaments, chronic ankle instability secondary to sprain and status post-meniscus repair), but not affected by diseases of the central nervous system. Subjects were aged 25–55 (average 32).

Only 3 of them were females, 2 of which only took part in the sober tests. The 3 injured subjects were males. The body mass index (BMI) of the subjects spanned the range between 18.3 and 38.0, with an average of 24.6.

2.2. Materials

For the data acquisition we designed and built a stabilometric platform, or force plate. We used a sampling frequency of 200 Hz, which is well above the typical frequencies of genuine postural motion, which are usually considered

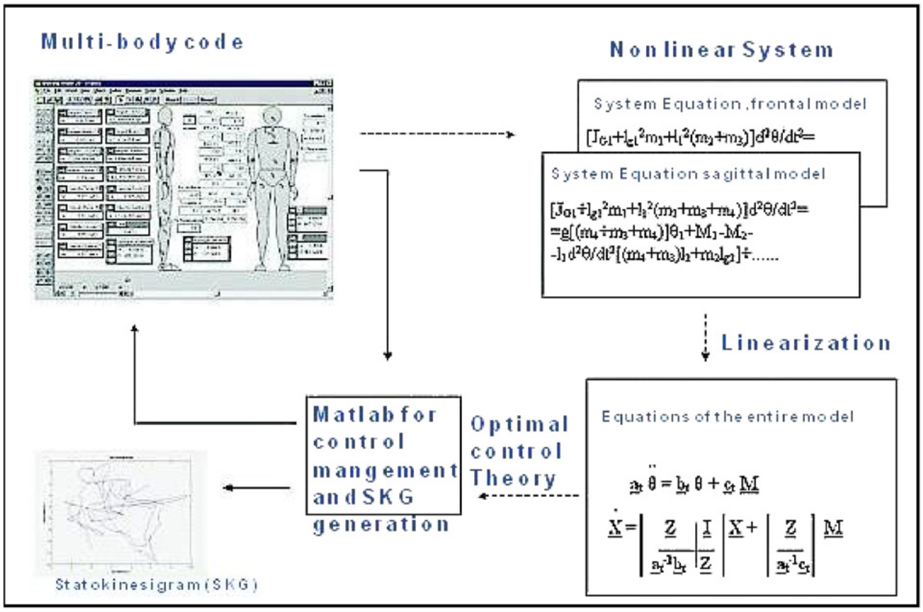

Fig. 3. Sequence of steps for the global model.

below 6–8 Hz in the literature (Dietz et al., 1993). This sampling rate allows us to study the COP trajectory in detail even for a single oscillation.

2.3. Tests procedure

Informed consent was obtained from all the subjects following an explanation of the experimental protocol. The volunteers were asked to stand on the stabilometric platform in one of the two conditions: eyes opened or eyes closed, trying to stand still, as naturally as possible, for about 60 s. We made a series of tests, starting with the sober condition and up to 5 glasses of wine (1 glass containing 0.1 l). A 20 min interval separated the consumption of 2 successive glasses of wine.

We made 3 different kinds of tests. The first was made without any perturbation, with closed eyes. The second one was made with a mechanical perturbation acted by a pendulum, and closed eyes; the energy of the hit was varied as a function of the biometric parameters of the volunteers. The taller the person, the higher the axis of the pendulum was raised. The heavier the person, the higher the starting point angle for the pendulum was used.

The last test used a compound perturbation: stroboscopic lights and trance music, with open eyes. The last one was called: "disco perturbation" because we wanted to simulate the typical effects that a subject could experience in a disco club.

Each kind of test was carried out after every increase of alcoholic rate. So, for each subject, we made 3 tests for each glass of wine ingested, besides the sober case. Not every volunteer drank 5 glasses of wine, in particular the women. For this reason we cannot say anything about the possible different reactions that can depend on the sex of the volunteers.

To have a quick response, we asked the volunteers to take part in the tests after a fast of more than 3 h, because with empty stomach the alcohol effect is maximized. So after about 20 min from the ingestion we carried out the stabilometric tests.

The vital parameters, such as blood pressure and heart beats, were checked at the beginning and at the end of the experiment. We also stored the biometric parameters and then we calculated the "Body Mass Index".

2.4. Parameters computation

After verifying the absence of any significant drift in the acquired data, first of all we redefined the origin of the reference system

$$X_n \leqslant X_n - \frac{1}{N}\sum_{1\leqslant n\leqslant N} X_n$$

$$Y_n \leqslant Y_n - \frac{1}{N}\sum_{1\leqslant n\leqslant N} Y_n$$

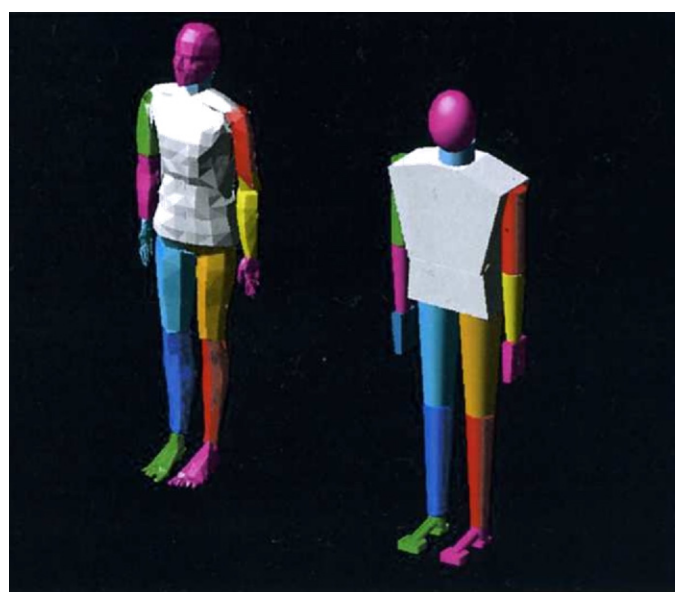

Fig. 4. The 3D model.

In this way we shifted the SKG centre of mass to (0,0). The next step was to compute the mean distance from the origin or mean displacement (r), mean velocity (v) and acceleration (a)

$$\bar{r} = \frac{1}{n}\sum_{1\leqslant n\leqslant N}\sqrt{X_n^2 + Y_n^2}$$

$$\bar{v} = \frac{1}{N}\sum_{1\leqslant n\leqslant N}\sqrt{\left(\frac{X_n - X_{n-1}}{\Delta t}\right)^2 + \left(\frac{Y_n - Y_{n-1}}{\Delta t}\right)^2}$$

$$\bar{a} = \frac{1}{N}\sum_{1\leqslant n\leqslant N}\sqrt{\left(\frac{X_n - 2X_{n-1} - X_{n-1}}{\Delta t^2}\right)^2 + \left(\frac{Y_n - 2Y_{n-1} - Y_{n-1}}{\Delta t^2}\right)^2}$$

$$\bar{p}_b = \frac{\bar{r}\,\bar{a}}{\bar{v}^2}$$

$$\overline{p*} = \frac{\bar{p}}{\bar{p}^0}$$

Table 1
r, *v*, *a*, and parameter *p* in 3 types of perturbation.

	Non-perturbed		Mechanical perturbation		Audio-visual perturbation	
	Sober	5th glass	Sober	5th glass	Sober	5th glass
r	2.56	4.35	1.82	5.9	3.45	4.48
v	19.3	21.99	21.68	28.40	18.16	16.31
a	6765	8300	7520	8367	6272	5849
p	57.8	78.4	29.47	65.39	78.16	122.4

The results are reported in Table 1 for "*r*", "*v*", "*a*" and "*p*". Table 3 shows some basic statistics of the distribution of these parameters. In the figures presented ahead 3 different cases are shown: no perturbation, mechanical perturbation and disco perturbation.

2.5. Data stability

We evaluated the time stability of "*r*", "*v*", "*a*", and "*p*". We made a series of "non-perturbed" tests, with the same subject, in different days. We evaluated the stability of these parameters in case of audio-visual perturbations as well. With this last kind of perturbation we made a different type of investigation: we asked a volunteer to repeat the same test, only in the sober case. The time between tests was only about 5 min, and at the end we made a long perturbation of 6 min but we recorded the data only in the last minute, in order to investigate the effect of a longer stress. We analysed the time evolution of the parameter "*p*" evaluated in different time windows as well.

3. Results

Vital signs, heart rate, blood pressure, rate of respiration did not show any significant effect related to alcohol consumption. Only the blood pressure has a dim decrease but the reason could also be ascribed simply to the fasting condition. As a matter of fact, the subjects started the experiment after a fast of 3–4 h and at the end of the tests their fast was about 7 h long.

The "Body Mass Index" analysis shows how a higher or lower BMI influences the displacement on the erect stance of the human body under the alcohol effect. We remind the reader that a higher BMI involves a lower alcoholic rate for the same quantity of alcohol assumed for two different subjects. We can model a person with a low BMI with a slender beam and a person with a high BMI with a stocky beam. It is easy to think how the same perturbation on a slender beam must be bigger than a perturbation on a stocky beam. The results were consistent with this reasoning.

As can be clearly seen from Table 1, almost all the parameters increase their value from the sober case to the 5th glass of wine.

The data reported in Table 1, with respect to the mechanical perturbation, are relative to the reaction of the subjects after 20 s have passed from the hit.

Velocity and acceleration are higher in the mechanical perturbation case than in the other two. The audio-visual perturbation gives the lowest velocity and acceleration. This can be explained if we think about the type of perturbation: stroboscopic lights associated with trance music generate a temporary hypnotic state, which implies the reactions of the subjects to be slower.

The evolution of "*r*", "*v*", and "*a*" as a function of the number of glasses of wine are reported in Figs. 5–7.

The "*r*" (mean displacement) values of the audio-visual tests are almost all over the "*r*" values of the non-perturbed case (see Fig. 5). The values of average velocity (see Fig. 6) and acceleration (see Fig. 7) of the audio-visual tests are all under the values of the non-perturbed test.

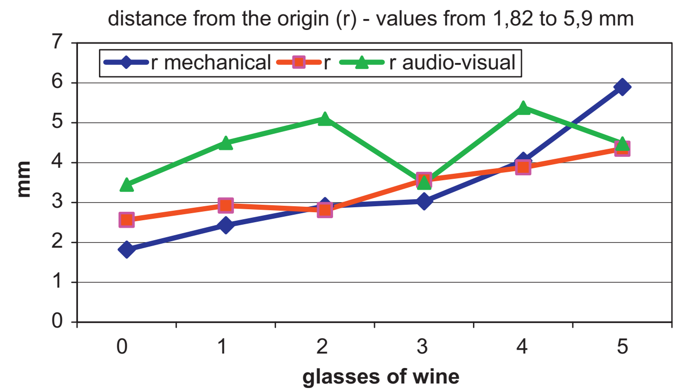

Fig. 5. Distance from the origin (*r*), average values.

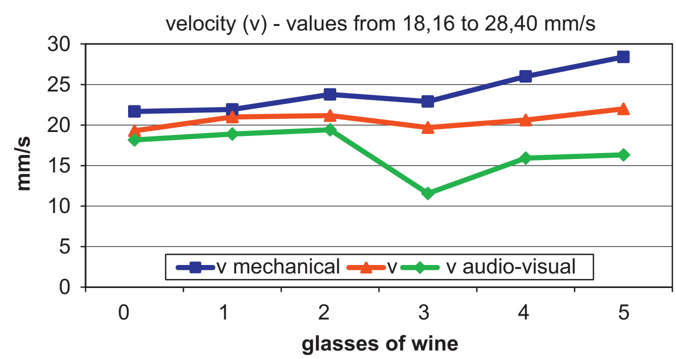

Fig. 6. Velocity, average values.

The parameter "*p*" (see Fig. 8) shows the highest values for the audio-visual case. The values of the parameter are related to the reactions and efficiency of the central control system. The audio-visual perturbation generates a state of confusion and the values of the parameter "*p*" would confirm this hypothesis.

As can clearly be seen from Fig. 8, the parameter "*p*" almost always increases its value as a function of the quantity of ingested alcoholic beverage.

The parameters are indicators of how the central control system reacts to a perturbation; it is noteworthy that the audio-visual perturbation causes a delay in the response for velocity and acceleration.

3.1. Data stability

The time-stability analysis showed that "*r*", "*v*", "*a*" and "*p*" are stable. In the two tests that were made with a time separation of a few days we did not find any substantial difference: "*r*", "*v*", "*a*" and "*p*"—only referring to the "non-perturbed" case—were almost unvaried. Only the series of tests carried out under audio-visual perturbation showed that, while velocity and acceleration were absolutely stable, the parameter "*p*" had some variation. In this case, "*r*" and the parameter "*p*" changed sensibly their values in the consecutive tests generating a state of confusion. Analysing the 5th test (about the long perturbation), we discovered that "*r*" and the parameter "*p*" decreased sensibly their values from the 4th test. As can be seen from Table 2, "*r*" has the same trend of the parameter "*p*".

It is also interesting to note that the values of "*r*" and "*p*" in the long perturbation are the lowest. This is an indication about how the subject gets used to the unusual situation. The time-evolution

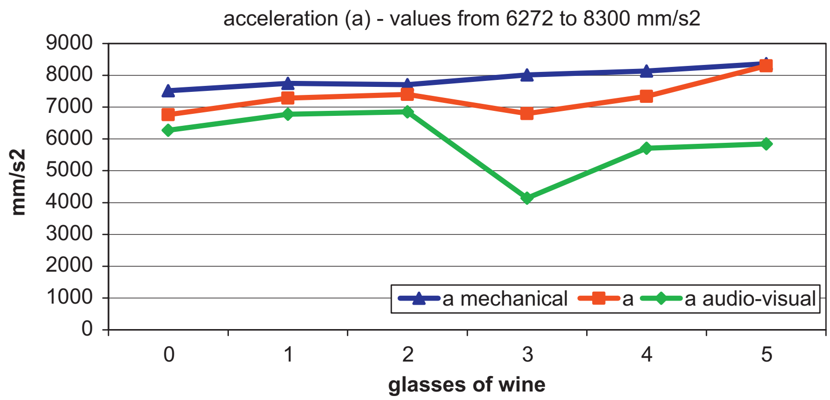

Fig. 7. Acceleration, average values.

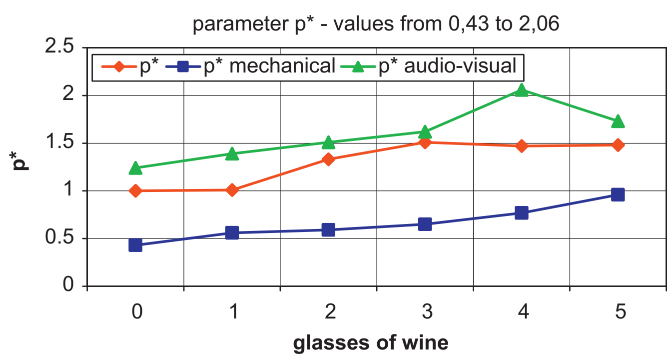

Fig. 8. Parameter *p*, average values.

Table 2
Data-stability analysis.

	1st	2nd	3rd	4th	5th: long perturbation
r	4.06	3.14	2.31	3.64	1.82
v	12.67	12.51	12.87	12.99	12.52
a	4531.55	4460	4592	4639	4464
p	114	89	64	100	52

analysis over successive time windows confirmed the stability of the parameter "*p*" during the recording. Therefore, we can say the evaluated parameters are stable, but the audio-visual perturbation generates a state of confusion that the subjects are able to counteract with a longer time of adaptation.

3.2. Statistical analysis

The analysis showed the standard deviation (s.d.) in the direction "*y*" is greater than the s.d. in the direction "*x*" in all the examined cases. When the consumption of alcohol is increased, the standard deviation increases its value in both directions (see Table 3).

The analysis of covariance did not give consistent variations as a function of the alcohol level.

The computed correlation coefficient was always different from zero (although with low values), which means that there might be a dependence between the movements along the two directions "*x*" and "*y*" (see Table 3). The average of this coefficient was almost always negative, therefore when there is a movement in the direction "*y*", in the positive axis, there is also a movement on the left ("*x*" axis, negative). When there is a movement in the direction "*y*" but in the negative axis there is also a movement on the right ("*x*" axis, positive).

The kurtosis, in the direction "*y*", in the sober tests, was always smaller than in the direction "*x*". When the subject drank the 5th glass of wine the kurtosis in the direction "*y*" was greater than in the direction "*x*". In general, the kurtosis increased its value in the direction "*y*" with the consumption of alcohol. In the non-perturbed and in the mechanical perturbation cases the kurtosis was positive (leptokurtic distribution), only in the audio-visual perturbation it was negative (platykurtic distribution) (see Table 3).

Table 3
Statistical analysis.

	Non-perturbed		Mechanical perturbation		Audio-visual perturbation	
	Sober	5th glass	Sober	5th glass	Sober	5th glass
sdx	1.35	2.62	1.45	3.05	2.47	3.03
sdy	2.17	3.82	2.03	4.61	2.80	4.00
corr	−0.15	−0.15	−0.04	−0.16	0.07	−0.38
curt *x*	2.61	1.12	2.60	1.16	−0.46	0.05
curt *y*	1.17	1.61	1.17	1.85	−1.28	0.25

4. Discussion and conclusions

The spectral analysis has shown that the human body sway shows most of the energy at frequencies under 4 Hz in the erect stance. The statokinesigrams gave us useful information about the trajectory of the COP in the different cases. The COP had higher values in the direction "*y*" (see Fig. 9).

The injured subjects showed in general distance from the origin (*r*), velocity (*v*) and acceleration (*a*) higher than the healthy subjects even in the sober tests.

This study has shown how "*r*", "*v*", and "*a*" increase their values with the increase of the alcoholic rate. In the audio-visual tests the reaction of the subjects are slower, because the values of "*v*", and "*a*" are lower than in the other cases. This kind of perturbation creates a state of confusion in the central control system, therefore the reactions of the subject are not as fast as they are in the other situations analysed. This is also confirmed by the stability analysis with the long perturbation test.

The parameter "*p*" best discriminated the effects of the amount of alcohol drunk on the human stability. It boosted its value with

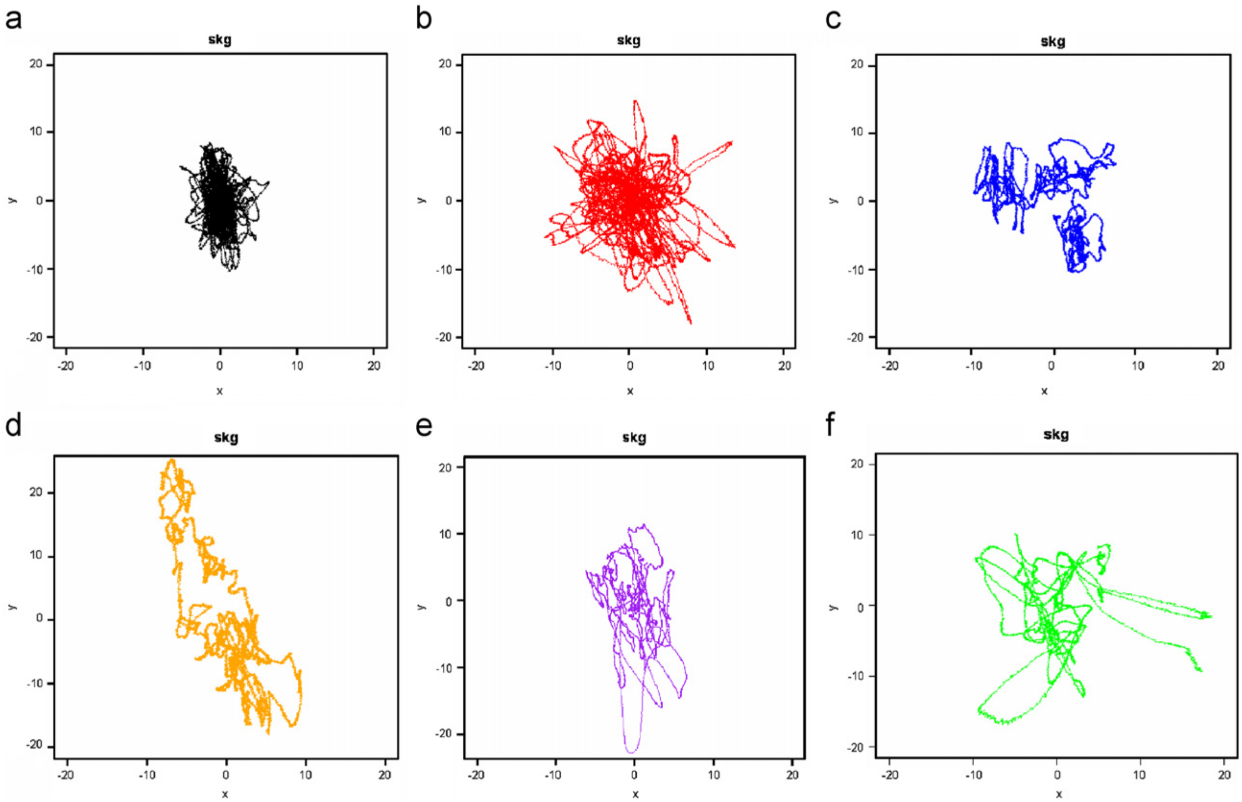

Fig. 9. Statokinesigrams: (a) sober non-perturbated, (b) after the 5th glass non-perturbated, (c) sober with disco perturbation, (d) after the 5th glass with disco perturbation, (e) sober with mechanical perturbation and (f) after the 5th glass with mechanical perturbation. All the values are in cm.

the increased quantity of alcoholic drinks ingested in every kind of test (see Fig. 8 and Table 1).

The statistical analysis showed how the movements in the two directions "x" and "y" (see Table 3) are possibly not independent from each other, and also it gave us information about the type of reactions of the human body in this kind of situations.

We propose the calculation of the parameter "p" in order to use it in the definition of a—perhaps more complex—parameter that could quantify the effects of alcohol on the human stance. Additional tests could be realized using the "Brain machine" (Shoham et al., 2005) and possibly using the EEG, especially for the case of the audio-visual perturbation. Following this direction, it will be possible to better understand what happens to the central control system when it is stimulated simultaneously in different ways. This is what occurs, e.g., in a disco club where music, lights, alcohol and drugs, very often, act all together. In this environment there are two other factors that may influence the central control system: the first one is the time of the day when people get together (usually at night), while the second one is the intense physical activity (usually people dance for hours). It could be interesting to carry out similar tests outside disco clubs, when the effects of these perturbations are still acting on the human body.

Conflict of interest statement

The authors declare that no financial or personal relationships exist with other people or organizations that could inappropriately influence (bias) their work.

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