FROM THE CENTER OF PRESSURE

TO THE CENTER OF GRAVITY

Gagey B., Ouaknine M**, Bourdeaux O*, Gagey PM *
Institut de Posturologie, Paris
** Université de la Méditerranée, Marseille

Introduction

Stabilometric observations measure the «Centre of Pressure» (CoP) and most studies use the raw results, though they mix the position of the «Center of Gravity» (CoG) and its acceleration. But now it is possible to deduce CoG from CoP. Using this CoG instead of CoP not only preserves most of the clinical observations, but often improves them, and moreover, this opens promising areas such as the study of the acceleration of CoG. So if this advance seems inevitable, it cannot really be profitable if all of us do not use the same «standard». Indeed, it is physically and mathematically impossible to have the «true» value of CoG, therefore we must choose, «normalize», the same algorithm, which alone will enable us to pool clear benefits.

This transition is possible

So far, various studies have made proposals that correspond more or less to a low pass filtering of the CoP, with all hypotheses, formulated or not, that implies; these approximations were validated, testing them by direct observation. But recently has been proposed a direct method starting from the simple inverted pendulum model and from the equation that has been derived by DA WINTER (1995):

$$P = G - (h / g) * G''$$

P: position of the CoP; G: position of the CoG; h: height of the CoG; g: acceleration of gravity; G'': acceleration of CoG.

Thanks to some mathematical and physical observations, this differential equation can be solved; it gives an almost exact value of CoG.

(The algorithm, written in Matlab, can be found in Annex 1, and some mathematical explanations were published by B. Gagey in 2010).

This method gives results consistent with previous approaches and therefore with experimental verification, but it has the advantage of clearly situating its ONLY assumption of validity: the simple inverted pendulum model. For this reason, and also because, in this hypothesis, it gives the acceleration of the CoG, this method represents a major step forward, of which normalization should enjoy.

This transition does not change our habits

Some parameters remain exactly the same as the X and Y means, so important for clinicians.

The area of the confidence ellipse containing 90% of the sampled positions of the CoG is always a standard statistical measure of the stability of the subject (Takagi, 1985). Moreover, this measure is more precise than the one carried out from the CoP because it does not take into account the displacements of the point of application of the reaction forces due to acceleration of CoG.

The ventilatory rate is not changed by this transition from CoP to CoG; it is always around 0.2 Hz we have to verify its absence or presence on the recordings (Gagey PM, Toupet M, 1998).

The standard deviation of the speed of the CoP displacements is clearly recognized for what it is: a marker of CoG acceleration (correlation coefficient between these two parameters: 0.990). So, in our analyses we have just to replace this parameter of the speed standard deviation of the CoP by the acceleration parameter of the CoG.

This transition brings benefits

Speed

The speed of the CoG displacements replaces the speed of the CoP that has no mechanical consistency since it contains information of position and acceleration. The two figures of these speeds are final (Fig. 1).

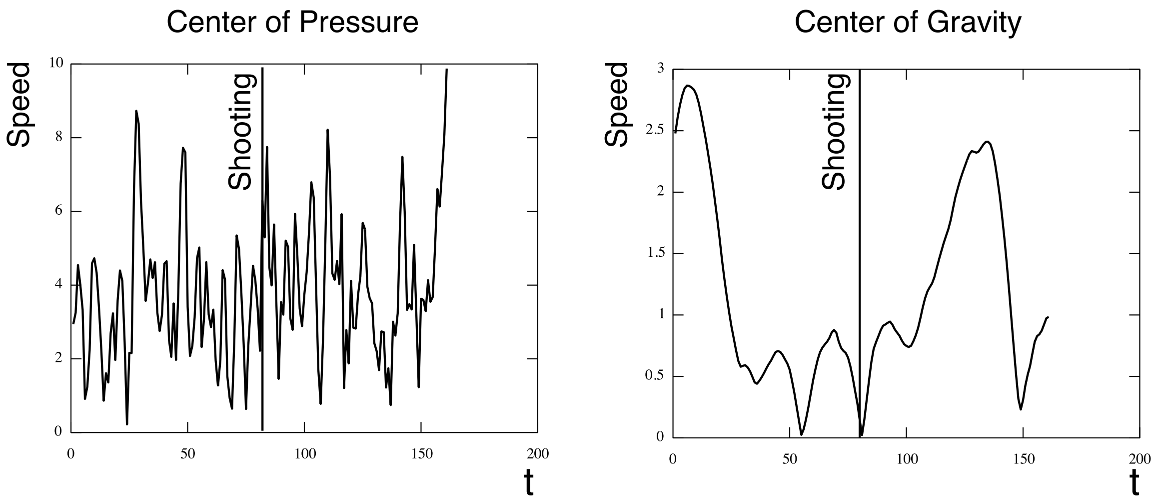

FIG. 1 - Comparison of figures: CoP and CdG speed.
The speed of the CoP and CoG are plotted against time, two seconds before and after firing (Very high level marksman). Following the course of the speed of CoG it is clear that the marksman shoots at the right moment when his speed is almost zero. Following the course of the speed of CoP nothing appears at this firing time.

Sampling rate

The transition from the CoP to the CoG solves the issues of standardization of the sampling rate because, whatever the sampling rate between 20 and 300 Hz not only the parameter values of position, velocity, acceleration of the CoG do not change (Fig. 2) but even the length of the displacements of the CoG remains the same whatever the sampling rate (Fig. 3). This shows that the integration of the differential equation that gives the positions of the CoG eliminates the fractal appearance observed on the position of the CoP. (This finding casts doubt on the fundamentally fractal CoP signal.)

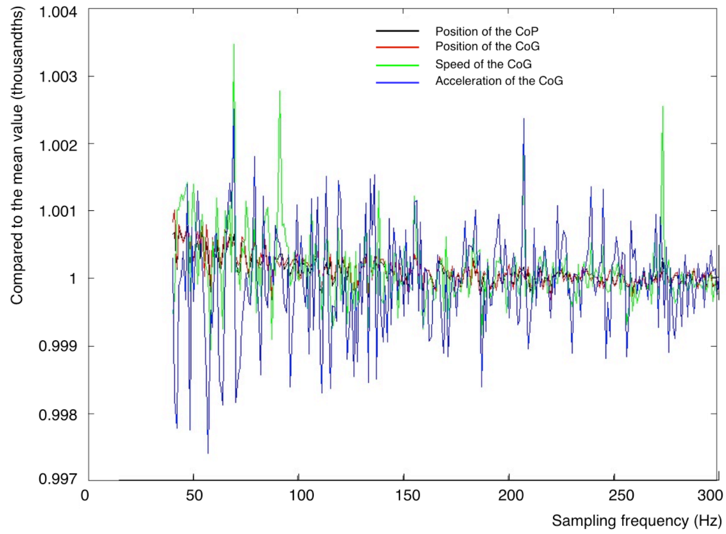

FIG. 2 — Report to their mean values of the parameters of position, velocity and acceleration of CoG and of CoP position according to the sampling rate, from 0 to 300 Hz
Note that this report is about one to two thousandths.

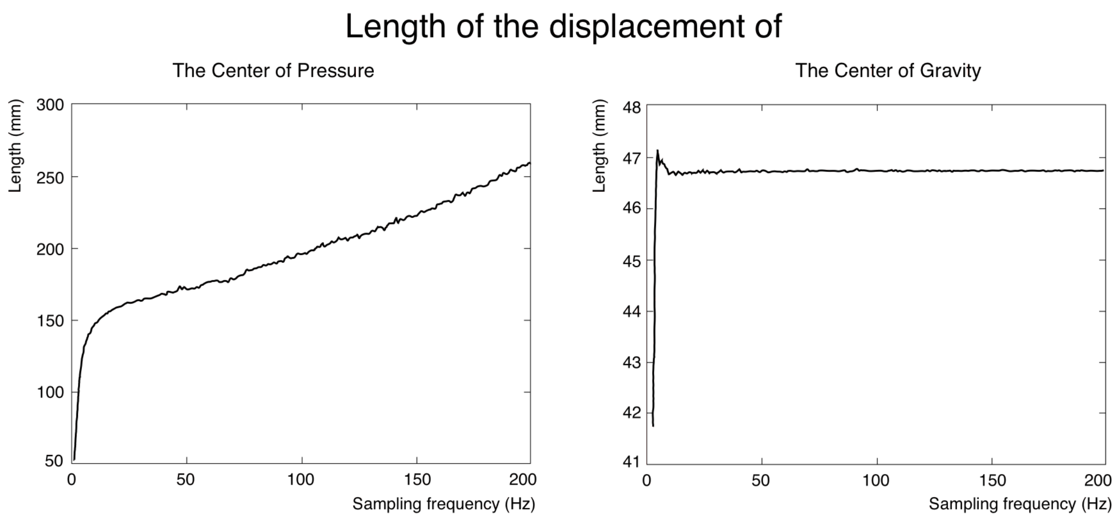

FIG. 3 — Comparison of the effects of sampling rate on the length of the CoP and CoG.

This transition promises further

Time constant

So far, we do not know any stabilometric parameter that evaluates the stability of the upright postural control system in time. The transition to the CoG enables calculating a new time parameter, the time constant (Ouaknine et al., 2011); it is the 0.5 crossing value of the autocorrelation function of the acceleration of CoG. Until now this parameter was used only once to evaluate its ability to discriminate between young and elderly subjects (Fig. 4), it seems promising.

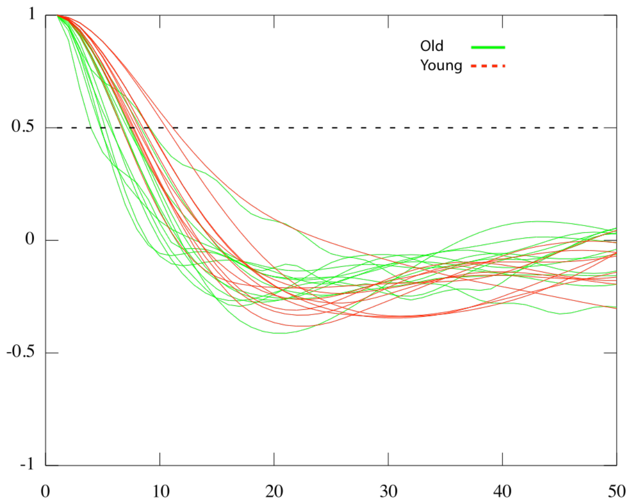

FIG. 4 — Autocorrelation function of the acceleration of CoG of young and elderly subjects. The first time the autocorrelation function crosses its 0.5 value, elderly and young subjects are well distinguished.
Only the first 50 values of the autocorrelation function are shown in this diagram.

This transition should be standardized

Whatever the algorithm chosen to go from CoP to CoG, the values are defined by "this" algorithm. We verified that for the position of the CoG, the values obtained by various algorithms are very similar. But for the speed of the CoG, and still more for its acceleration, differences may become important. It is therefore wise to consider that we must use the same algorithm to calculate the CoG form the CoP, if we want to understand each other.

Discussion

The algorithm we propose to pass from CoP to CoG, assumes that the behavior of the subject's body is likened to the behavior of an inverted pendulum, which is never the case in all rigor. This issue of the validity of the inverted pendulum model has been widely discussed, for example by Winter DA (1997). It is clear that this type of calculation may be used only with subjects standing at rest, to examine what we call the upright postural control system, i.e. the system that controls standing in a situation practically immobile. And we can notice that we know of no mathematical model of multistage pendulums that could be used to analyze postural control from the data given by a force platform. So we are obliged for the time being, and perhaps for a long time, to use the model of the inverted pendulum system to examine the upright postural control system and we find that even if this model is not strictly "true", it is effective and more efficient if we use it to pass from the CoP to the CoG.

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Appendix 1

Subroutine to pass from the CoP to the CoG

Bernard Gagey> bernard.gagey @ gmail.com <

Language

Octave (Matlab compatible)

Restrictions

The program

• Applies to test where the approximation of the individual by an "inverted pendulum" is valid.

• The result is not guaranteed in the first and last second (1 to 3 seconds)

• The program contains a parameter "Correction" which is 1 + the moment of inertia of the body relative to the center of gravity divided by the mass. De-fault knowledge, this value is approximated to 1.2.

Input parameters

- Vector 1-dimensional coordinates of the curve from the center of pressure as complex x + iy
- Sampling frequency
- Height of the individual

Output

1-dimensional vector of coordinates of the curve center of mass as complex x + iy

Note: To avoid the complex, one can work successively with abscissa x and the y-coordinates: complexes here are a trick to avoid this doublet.

Explanation

The body is supposed to behave like an inverted pendulum, and satisfactory to the differential equation:

$$P = G-(h / g) * G''$$

All solutions of this equation are given, from a first solution Mø by:

$$G = Gø + (ae^{kt} + be^{-kt})$$

It first looks for the solution that would Ø Gø to the top, next and previous measurement.

For this we write the differential equation at each point:

$$P (j) = G (j) - (h / g) * (G (j-1) + G (j +1)-2G (j)) / dt^2$$

Having assumed that G (ø) and G (N +1) = Ø, this is a system of N linear equations in N unknowns it suffices to resolve, or in other words:

P = vector matrix G A.Vecteur

Vector G = (Matrix A)-P 1.Vecteur

The first stage of the program is to build the matrix.

The second step is to solve the linear system directly or through inversion of the matrix. The third step is to find good coefficients a and b: they are mathematically impossible to find, but physically the points M (ø) and M (N +1) must at least be on the platform. The formula utilized in the program has been found empirically, but we know it is not by far perfect. In a second comment is made formula easier to understand. Anyway, after 1 to 2 s, the importance of this correction is negligible.

```
% Starting sub-program 'From the CoP to the CoG'

function[g]=SpG(posi,freqech,taille);
%Program to find the curve G
% input parameters:
% posi : the curve CoP as complex
% freqch : sampling frequency (Hz)
```

```
% taille (cm): subject's height
% (corrected if the Center of gravity is not fixed to 0.55 )
% return g the last estimation of the curve g that satisfies : posil = g—kg"
gravite=9.8066;
H_gravite=.55; %_____________ratio center of gravity height / total height
Correction=1.2; % correction coefficient of k ;
ak=H_gravite*Correction/gravite;
coeffaccel=ak*taille ;
kacc=(1/coeffaccel)^.5;
 Nbm=length(posi);
% centering for the point (0,0) is not absurd
meanposi=mean(posi);
posi=posi-meanposi;
% calculating the coefficients of the matrix
co1=-freqech*freqech*coeffaccel;
co2=-2*co1+1;
% creation of the matrix with its good diagonal
ma=co2*eye(Nbm,Nbm);
% filling sur and sus-diagonal
for k=2:1:Nbm-1;
 ma(k,k-1)=co1;
 ma(k,k+1)=co1;
endfor
ma(1,2)=co1;
ma(Nbm,Nbm-1)=co1;
 % First method by matrix inversion, it seems faster under Octave due to the
% shape of the matrix
na=inv(ma);
g=na*posi;
% The second method (commented) by solving the linear system which should
%be faster
%g=ma\posi;
% search start and end
% First iteration that gives the first-before the first point and the same ...
correc=zeros(Nbm,1);
for jj=1:1:Nbm;
 correc(jj)=e^(-kacc*jj/freqech);
endfor;
deb=g(1)/(1-correc(1));
fin=g(Nbm)/(1-correc(1));
% Second iteration
mul1=76;mul2=75;
deb=mul1*g(1)-mul2*g(2)+deb*(mul1*correc(1)-mul2*correc(2));
```

```
fin=mul1*g(Nbm)-mul2*g(Nbm-1)+fin*(mul1*correc(1)-mul2*correc(2));
% Another possibility to consider that the extreme points of Vg are those of Vp
%deb=(Vp(1)-Vg(1))/correc(1);fin=(Vp(Nbm)-Vg(Nbm))/correc(1);
% Perform the addition of the correction and remove the centering
g=meanposi+(g+deb*correc+flipud(fin*correc));
endfunction
```