ALTERED GRAVITY HIGHLIGHTS CENTRAL PATTERN GENERATORS MECHANISMS

White O[1,2], Bleyenheuft Y[1], Ronsse R[4], Smith A[5], Lefevre P[2,3], Thonnard JL[1]

[1]Rehabilitation and Physical Medicine Unit, Université catholique de Louvain, Belgium
[2]Center for Systems Engineering and Applied Mechanics, Université catholique de Louvain, Belgium
[3]Laboratory of Neurophysiology, Université catholique de Louvain, Belgium
[4]Department of Electrical Engineering and Computer Science, Montefiore Institute, Université de Liège, Belgium
[5]Centre de Recherche en Sciences Neurologiques, Département de Physiologie, Université de Montréal, Canada

INTRODUCTION

Many rhythmic patterns of activity such as locomotion are generated by neural networks at the spinal level called **Central Pattern Generators** (CPG). Under normal gravitational conditions, the energy efficiency and the robustness of human rhythmic movements are due to the ability of CPG to drive the system at a pace close to its **resonant frequency**.

Here, we theoretically test whether CPG mechanisms can adapt the frequency of a rhythmic movement of the arm in **new gravitational conditions**. Our predictions are confronted with data obtained in parabolic flights.

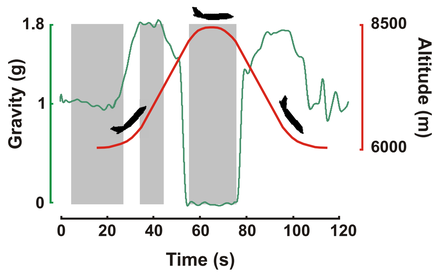
CONCLUSIONS

A model of a pendulum or a CPG alone cannot account for the observed data. However, when a feedback loop is created by coupling the two systems, this **closed-loop model** predicts the pace adopted by the participants in 2 rhythmic conditions (Self paced <> metronome paced).

We show that the innate modulation of rhythmic movements by CPG is **highly flexible across gravitational contexts**, which further supports the involvement of CPG mechanisms in the achievement of efficient rhythmic arm movements.

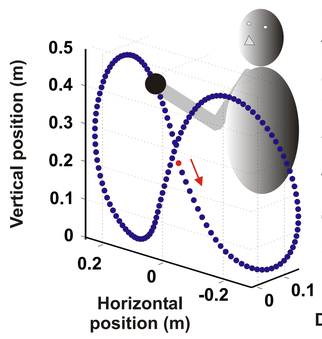
METHODS

The parabolic flight



A single parabolic flight profile generated a sequence of stable episodes of normal (**1 g**), hyper-(**1.8 g**) and micro- (**0 g**) gravity of about 20 seconds each. Gravity level relative to Earth ($g=9.81\ ms^{-2}$) is shown on the left Y-axis (green line) and flight altitude is reported on the right Y-axis (red line), both as a function of time.

The task



Participants traced lemniscate trajectories in 2 rhythmic conditions:
1. **Free pace**,
2. Follow a **1.5-second** period.

The blue dots represent the object position sampled every 50 ms.

CLOSED-LOOP CPG/PENDULUM MODEL

Central Pattern Generator

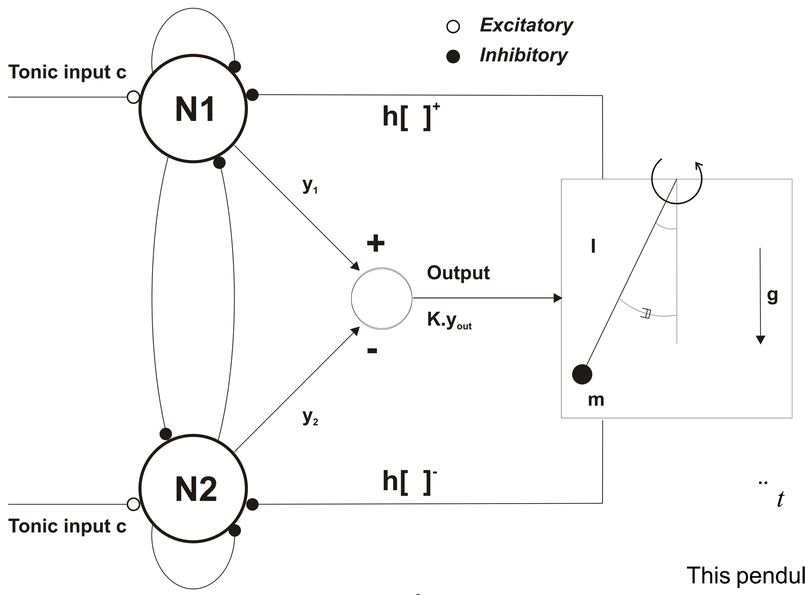
The CPG is composed of neurons N1 and N2. Black and white circles represent inhibitory and excitatory inputs, respectively. The connections parameterized by and correspond to self-inhibition and mutual inhibition, respectively.

The firing rates $dx_1(t)/dt$ and $dx_2(t)/dt$ are governed by the following equations:

$$\dot{x}_1 = x_1 + v_1 + x_2 + h + c$$
$$\dot{v}_1 = v_1 + x_1$$
$$\dot{x}_2 = x_2 + v_2 + x_1 + h + c$$
$$\dot{v}_2 = v_2 + x_2$$

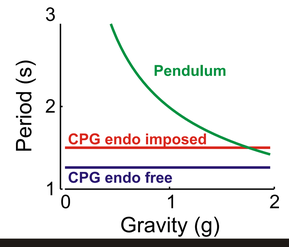
$$y_1 = x_1 + \max(0, x_1)$$
$$y_2 = x_2 + \max(0, x_2)$$

$$y_{out} = y_1 + y_2$$



The CPG alone has a constant endogenous period (free paced). The period of the **pendulum** alone decreases as gravity increases and is **infinite in 0 g**.

What period does achieve the closed-loop system?



Pendulum

The proprioceptive feedback signal h[ ] is the angular displacement of a damped pendulum under the action of gravity.

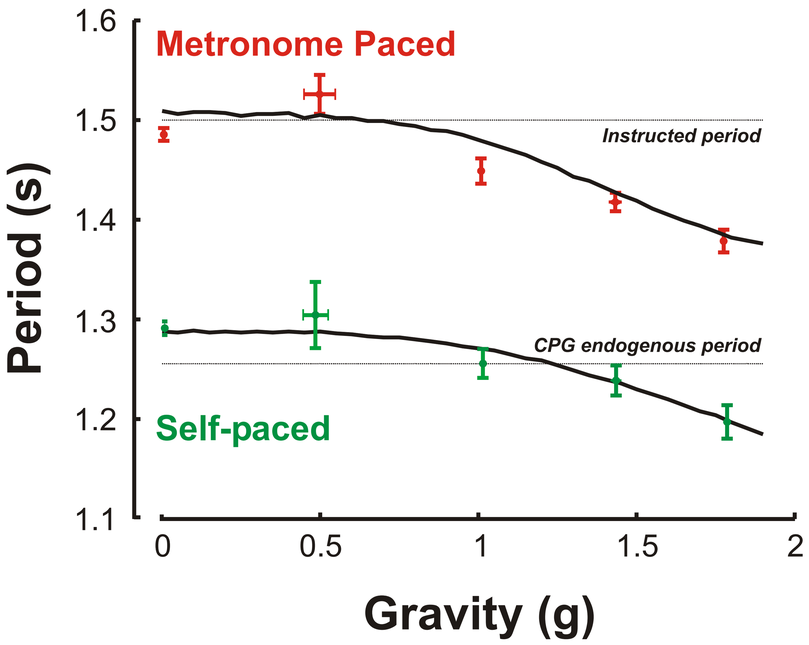
The position t of a mass m attached to a fixed point by a string (length l) and damped by a factor is given by:

$$\ddot{\ } t \quad \frac{}{ml^2} \dot{\ } t \quad \frac{g}{l}\sin \quad t \quad F_{out}\ t$$

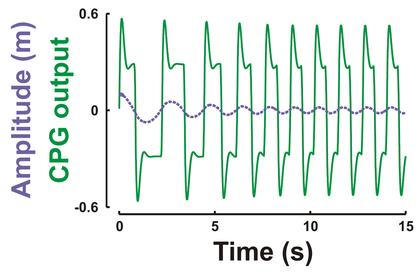
This pendulum system is driven by a torque that depends on the CPG output following:

$$F_{out}\ t \quad \frac{K}{ml^2} y_{out}\ t$$

DATA

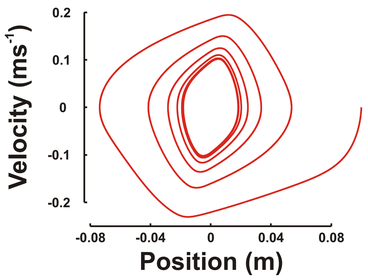


CPG entrainment in 0 g



The oscillator (green line) gets locked onto the frequency of the input (blue line).

Phase plot of mass motion



The system quickly converges to a limit cycle behaviour as shown on this phase plot of the mass motion.

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