Modulation of gait control under metronomic constraints assessed by long-range autocorrelations in healthy population and in Parkinson's disease.

Clémence Vandamme, Virginie Otlet, Renaud Ronsse, Frédéric Crevecoeur

UCLouvain

IoNS, ICTEAM, iMMC, IREC & Louvain Bionics, UCLouvain, Belgium

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Context

Patients with Parkinson's Disease (PD) suffer from gait impairments such as reduced gait speed, shortened step length, increased variability and alteration of the Long-Range Autocorrelation (LRA) naturally exhibited in series of stride duration.

On one hand, rhythmic cueing can improve some gait parameters in this population. On the other hand, such a rhythmic constraint modifies key gait parameters - such as LRA - in young and old walkers and in PD patients.

Here we investigated how patients adapt when transitioning from walking with a metronome to walking without one and vice-versa, and interpreted the results in the light of current theories associating the basal ganglia with a representation of motor cost.

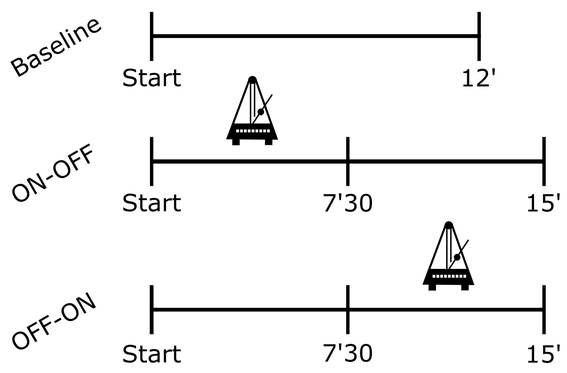
Patients were fully capable of modulating their gait control to adapt to the presence or absence of the metronome, but exhibited less anti-persistent series than age-matched controls.

They might also need more time to adjust to the sudden activation of the metronome.

Methods

Protocol

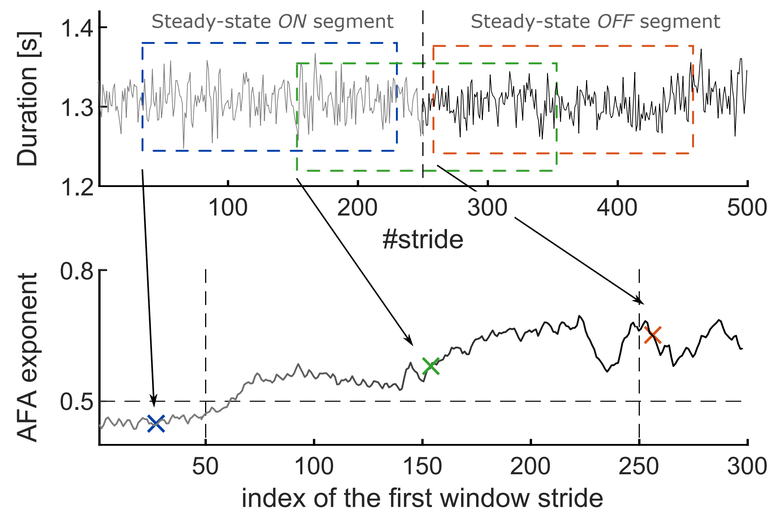
Free walking along a rectangular path with rounded corners, measuring 34m in length, in 3 conditions:



The metronome frequency was set to the baseline pace of participants.

Data analysis

LRA of series of stride duration was characterized by the Hurst exponent, evaluated through the Adaptive Fractal Analysis (AFA) over a sliding window.

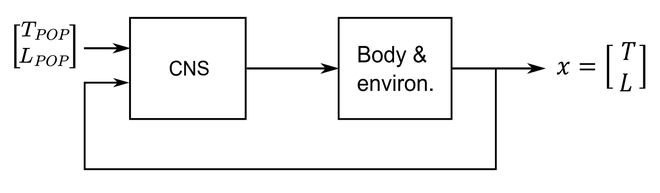


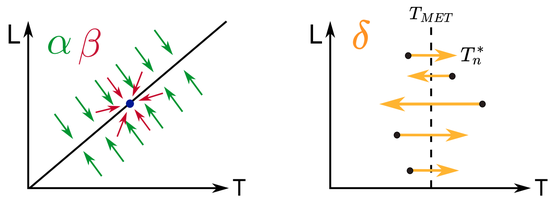
Gait model [1]

Each stride is characterized by its duration and length ($x_n = [T_n, L_n]$) and is generated iteratively from the previous one (Eq. 1). The control objective is to maintain a constant velocity v. This task being redundant, a secondary objective is to keep a comfortable stride length L_{POP} and duration T_{POP}. The cost function (Eq. 2), used to compute the motor command, reflects these objectives.

$$x_{n+1} = x_n + u(x_n) + noise \quad (1)$$

$$Cost_n = \alpha(L_n - vT_n)^2 + \beta[(T_n - T_{POP})^2 + (L_n - L_{POP})^2] + \gamma(u_1^2 + u_2^2) + \delta(T_n - T_n^*)^2 \quad (2)$$





The metronome effect was captured by iteratively computing the appropriate stride duration T^* to catch up with the metronome. This was included in the cost function by setting δ to a non-zero value.

Results

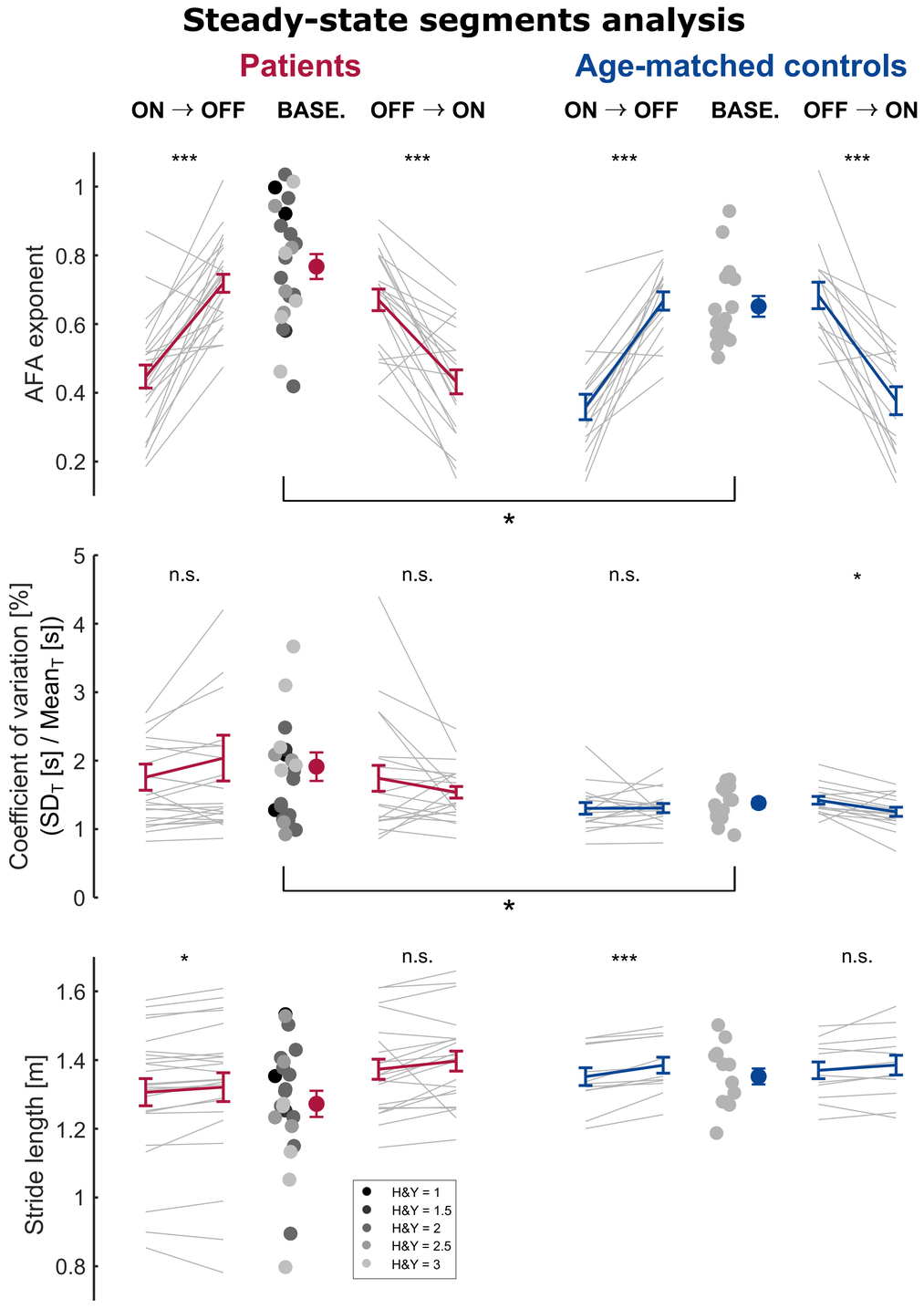
Characteristics of the study population

	PD patients	Controls
n (M/F)	25 (20/5)	18 (10/8)
Age [y]	67,8 ± 7,7	69,2 ± 6,6
Height [cm]	173,7 ± 8,5	173,9 ± 7,2
Weight [kg]	70,8 ± 12,2	70,3 ± 8.9

For all PD patients, the severity of the disease was assessed through the H&Y scale:

H&Y	1	1.5	2	2.5	3
n	2	1	12	5	5

Steady-state segments analysis

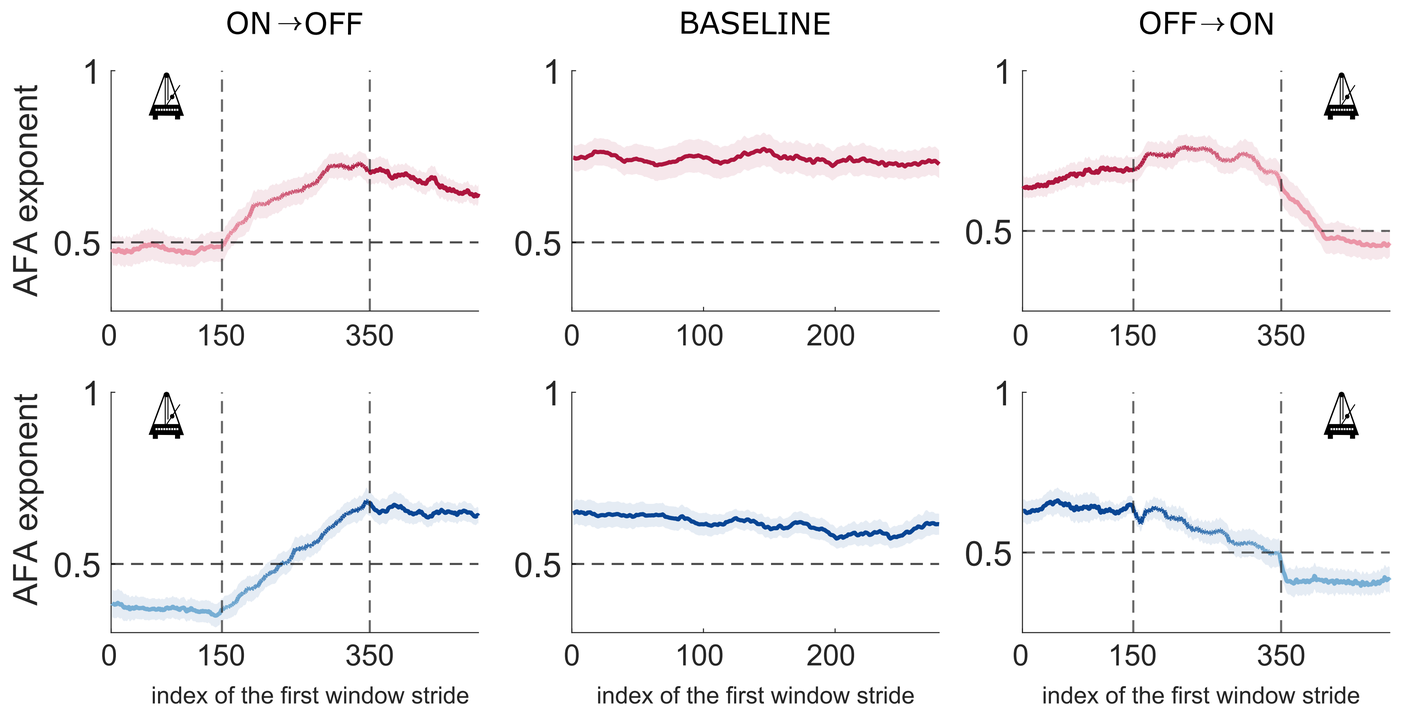


In baseline condition, PD patients display higher AFA exponents and higher coefficients of variation than age-matched controls, but similar stride length.

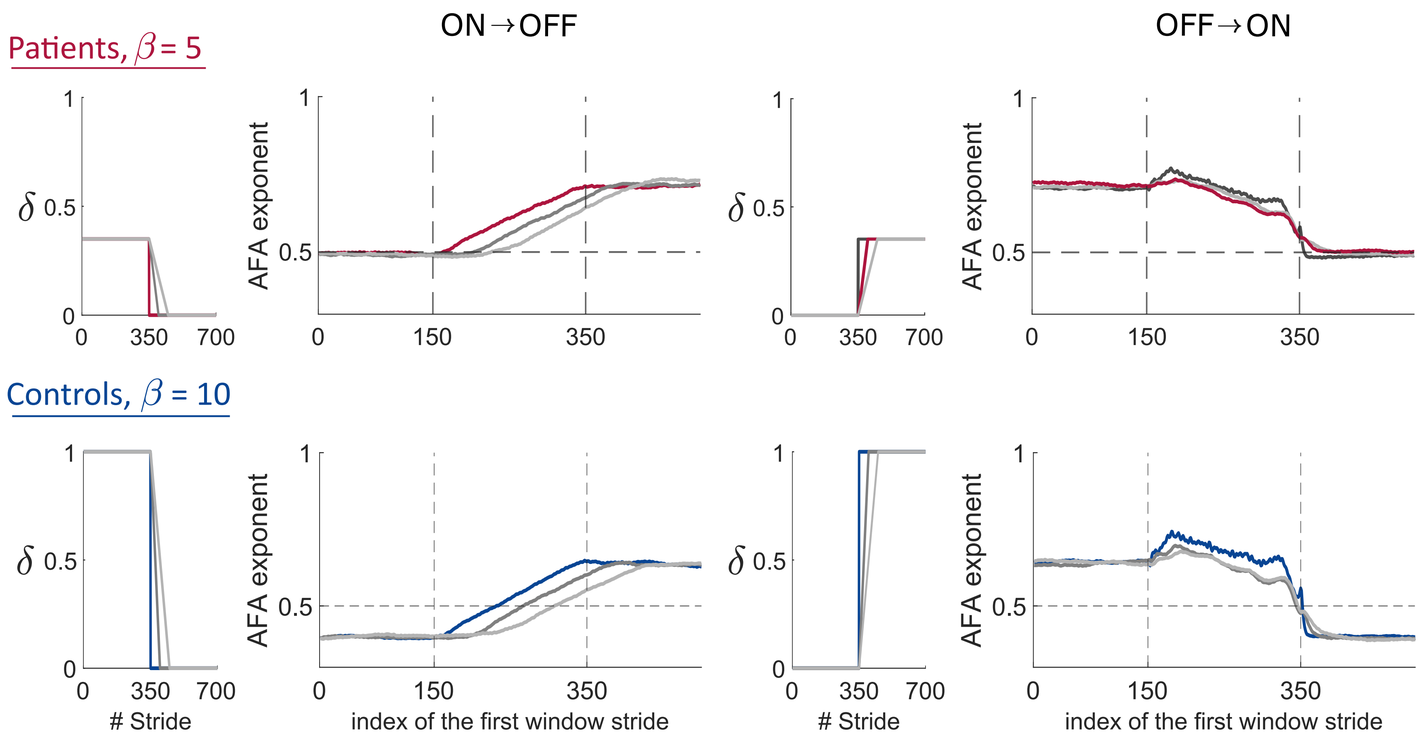
We observe the same modulation of the AFA exponent in both population.

We did not observe any increase in stride length with the metronome within a session.

Mean evolution of AFA exponent over all participants



Reproduction of the results with the model



[1] Dingwell J.B., John J., Cusumano J. P., "Do humans optimally exploit redundancy to control step variability in walking?" PLoS Comput Biol, 6(7), 2010.