Fractal regulation of human motor activity and its manifestation at circadian and ultradian time scales

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Introduction: Human activity exhibits a fractal behaviour, characterised by scale-invariant patterns over time scales ranging from minutes to 24 hours. This suggests the existence of a control mechanism with feedback interactions. Aging and Alzheimer's disease, both marked by an alteration of the suprachiasmatic nucleus (SCN), the circadian pacemaker, have been associated with a reduced scale-invariant correlation. However, the impact of this reduction on ultradian or circadian activity dynamics and its comparison with in-lab circadian measures, remains unclear.

Methods: Forty-nine healthy elderly participants (69±5.9 years, 43% female) underwent a 40-h multiple nap constant routine (CR). Activity was recorded using actimetry during 11 days. First, fractal correlations, α^{ultra} and α^{circa}, calculated using detrended fluctuation analysis over time ranges [0,200] min. and [200,1440] min. were confronted to the relative circadian modulated-amplitude in behaviour, as measured by psychomotor vigilance task (PVT), every 4h during the CR. Then, using actimetry, fractal correlations were tested as predictors of activity fragmentations occurring at various time scales: at circadian time scales, using the fraction of rest time (fSoD) over a typical wakefulness afternoon period and at short ultradian time-scale (typically [10-20] min.) using daytime activity (kAR) and night sleep (kRA) fragmentations, quantified with state-transition probabilities. The link between scale-invariance and the ultradian locomotor inactivity dynamics during sleep (LIDS, typical time scale: 100 min.) were also investigated.

Results: Linear mixed effect regressions indicated that PVT relative circadian amplitude (b=-1.15, p=0.012), daytime rest (fSoD, b=-0.36, p=0.001) and activity fragmentation (kAR, b=-2.35, p=0.001) were associated with α^{circa}, as well as an association between LIDS amplitudes and α^{ultra} (b=-14,48, p=0.050). A link between kAR and α^{ultra} was also observed (b=1.35, p=0.002).

Discussion: Our results link fractal indices, measured with actigraphy, to in-lab circadian markers. Interestingly, fractal scaling in the circadian regime is associated with both daytime rest, interpreted as a fragmentation of sustained daytime activity, and shorter ultradian daytime activity fragmentation. These results also highlight the link between LIDS oscillations at night and scale-invariance at ultradian time scales. Overall, our analysis suggests that previously reported indices of activity dynamics occurring at various time scales might be associated with a common underlying regulation mechanism, involving the SCN.

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