

Fractal Analysis of Stride Interval in Human Gait



STATISTICS

KEYWORDS : Fractals, fractal dimension, gait, stride interval, repeated measures ANOVA

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ABSTRACT

The application of chaos theory and non-linear dynamics to problems in biological time series has resulted in rapid advancements in medicine. Recent research has demonstrated that many biological structures and physiologic fluctuations exhibit complex fractal patterns. Fractal dimension has been proved useful in quantifying the complexity of dynamic biomedical signals like heart rate variability, electromyography, electrocardiograph and electroencephalograph. This paper provides a statistical perspective to the fractal dynamics of typical stride-interval time series. Higuchi's(1988) algorithm for the computation of fractal dimension and repeated measures of the ANOVA are used in the analysis.

1. INTRODUCTION

The pattern of how a person walks is called their gait. Walking consists of a sequence of steps partitioned into two phases: a stance phase and a swing phase. The stance phase is initiated when a foot strikes the ground and ends when it is lifted. The swing phase is initiated when the foot is lifted and ends when it strikes the ground again. The stride interval are the time to complete each cycle (Fig 1).

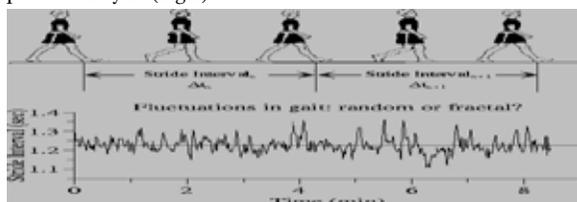


Fig.1

More recently, the stride interval time series have been identified as fractals-sets that exhibit self-similarity across all scales of magnification. Fractal dimension, a non-integer quantity is used to quantify the complexity of fractal patterns.

In this paper, stride interval fluctuations were studied in 10 young, healthy men who had no history of any medical disorders. Gait cycle duration from these subjects were recorded in both free and metronome constrained walking at three different paces. The fractal dimension of this stride interval time series was calculated using Higuchi(1988) algorithm. The mean and standard deviations of fractal dimension for each pace under free and metronome walking were calculated and the difference among groups evaluated through repeated measures of ANOVA.

2. MATERIALS AND METHODS

Ten healthy subjects were made to walk for 1 hour at their usual, slow and fast paces under constant environmental conditions. They were also made to walk in time to a metronome at normal, slow and fast paces. The stride interval time series recorded was acquired from the physiobank archive (<http://www.physionet.org>).

2.1 Fractal dimension algorithm

Higuchi(1988) has provided a distance based measure to estimate fractal dimension. Given a finite set of time series observations $x(1) x(2), \dots, x(N)$ the algorithm consists the following steps :

1. Construct 'k' new series with components as $X_m^k = \left\{ x(m) x(m+k), \dots, x\left(m + \left[\frac{(N-m)}{k} \right] k\right) \right\}$, for $m = 1, 2, \dots, k$ where m is the initial time value and k the discrete time interval between points and $[]$ is the Gauss' notation. Each of them

may be represented by a plane curve.

2. Compute the length of each curve as

$$L_m(k) = \frac{\left\{ \sum_{i=1}^{\left[\frac{N-m}{k} \right]} |x(m+k) - x(m+(i-1)k)| \right\} \left[\frac{N-1}{k} \right] k}{k}$$

$$3. L(k) = \frac{1}{k} \sum_{m=1}^k L_m(k)$$

4. If $L(k) \sim k^{-D}$, then the curve is fractal with dimension D.

3. RESULTS

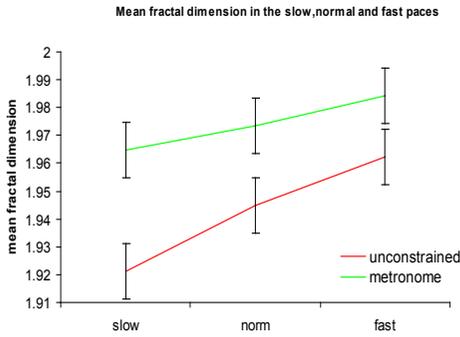
The gait cycle duration of a healthy subject is fairly stable with a mean and standard deviation of 1.0368 ± 0.016 , 1.167 ± 0.0269 , 1.0059 ± 0.0195 , 1.0457 ± 0.147 , 1.1674 ± 0.0169 and 1.0101 ± 0.0123 during 3 paces of walking -normal, slow and fast-under free and metronome walking respectively.

To gain more information about the dynamics in stride interval at all three walking rates during unconstrained and metronome walking, fractal dimension using Higuchi's algorithm is calculated and the results presented in Table1

Table 1: Fractal dimension of stride interval

subjects	Free Walking			Metronome walking		
	slow	norm	Fast	slow	norm	fast
1	1.922737	1.948875	1.971697	1.998326	1.989892	2.001004
2	1.91995	1.948692	1.940851	1.84703	1.898182	2.001182
3	1.875971	1.948815	1.968276	1.998047	1.98982	1.946785
4	1.925911	1.944175	1.970103	1.998191	1.966808	1.988487
5	1.925371	1.948775	1.941497	1.998657	1.988955	1.905458
6	1.930056	1.947359	1.968819	1.813807	1.989767	1.99799
7	1.928653	1.939935	1.968776	1.998124	1.945839	2.000496
8	1.929455	1.940194	1.956894	1.999968	1.989742	2.001106
9	1.929572	1.940458	1.968776	1.998019	1.988622	2.00036
10	1.92525	1.939965	1.96826	1.997691	1.987928	1.999682

It is clear that the mean fractal dimension is significantly increased in subjects walking in time to a metronome compared to free walking (Fig 2)



To determine the overall, general difference in mean fractal dimension between the groups (walking with/without constraint) at 3 different paces, a repeated measure ANOVA with two within subject factors was employed. A significant main effect of groups ($p < 0.01$) suggests that a change in the walking pattern due to any constraint placed on the subject produces significant effect on the mean fractal dimension of stride interval. (Fig 3a & Fig 3b)

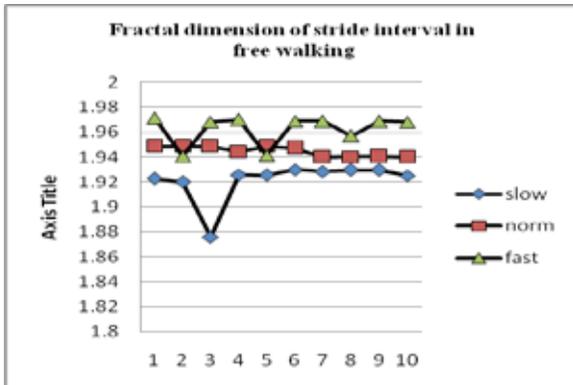


Fig. 3(a)

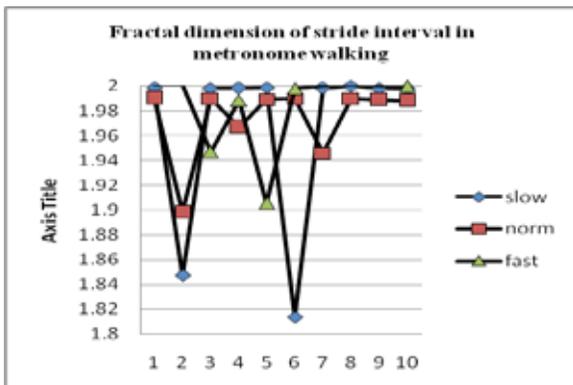


Fig 3(b)

The main effect of pace was not significant ($p > 0.01$) indicating that the walking rate does not have any significant effect on the fractal dimension of stride-to-stride variation. There is also no significant interaction between groups and walking pace. ($p > 0.01$)

4. DISCUSSION

Walking is a complex process and is regulated through the motor control system which consists of a network of neurons from the central nervous system. The stride interval time series characterized by fractal pattern depend upon several biological and stress constraints. The fractal pattern is disturbed when one is asked to walk in time to an outside timing mechanism instead of one's own instinct to walk. This linear change in fractal dimension is reflected even in healthy subjects who walk with and without constraints. Walking abnormalities are unusual and uncontrollable walk patterns are usually caused by diseases or injuries in the legs, feet or brain. Fractal dimension analysis can be used to identify patients with gait disorders by observing their walking rhythm.

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