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Analysis of altered complexity of gait dynamics with aging and Parkinson's disease using ternary Lempel–Ziv complexity

Chandrakar Kamath

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BIOMEDICAL ENGINEERING | RESEARCH ARTICLE

Analysis of altered complexity of gait dynamics with aging and Parkinson's disease using ternary Lempel–Ziv complexity

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Abstract: Fluctuations in stride interval series show complex dynamical behavior in healthy young adults. Hypothesizing that these stride interval complexity changes would be altered by changes in neurological function associated with aging and certain disease states, we aimed to develop a tool to facilitate clinical judgments to assess the complex dynamical behavior in the stride series in discerning young, elderly, and Parkinson's disease (PD) classes. This novel approach, which employs a new variant of coarse-graining in conjunction with Lempel–Ziv complexity measure, yields useful, reliable, and predictive results. We also show the presence of nonlinear deterministic structures in the stride time series and appropriateness of the application of our nonlinear approach through surrogate data analysis. The findings show that the fluctuations are more complex/random in elderly and PD classes than those in young class. These findings may add to the growing body of literature supporting the clinical utility of this new approach to stride time series.

Subjects: Biomedical Engineering; Computational Neuroscience; Health and Social Care

Keywords: coarse-graining techniques; complex dynamical behavior; Lempel–Ziv complexity; Parkinson's disease; stride interval time series

ABOUT THE AUTHOR

Chandrakar Kamath received his BE degree from Mysore University in the year 1978 and MTech degree from Mangalore University in the year 1989. Till recently he has been working as a professor in the Department of Electronics and Communication Engineering at Manipal Institute of Technology, Manipal University. He has published several papers in International and Indexed Journals. His research interests include nonlinear dynamics, chaotic theory, biosignal processing, in particular nonlinear signal processing.

PUBLIC INTEREST STATEMENT

Despite continuous and extensive preventive efforts, falls remain a major cause of morbidity and mortality among older subjects and neurodegenerative disorder patients. Falls usually lead to fractures, hospitalization, and may be, sometimes even death. This important public health problem which demands right time interventions to reduce the risk of falling has been tried with varying degree of success. The severe effects of falls and these interventions, which often require high cost, necessitate an early diagnosis of subjects who are at high risk of falls. Some measures of gait have been found to be useful in identifying potential fallers. In this work, we propose a simple approach to develop a tool to facilitate clinical judgments to assess the complex dynamical behavior in the stride time series of healthy young controls, healthy elderly subjects, and patients suffering from Parkinson's disease and identify their risk of falls.

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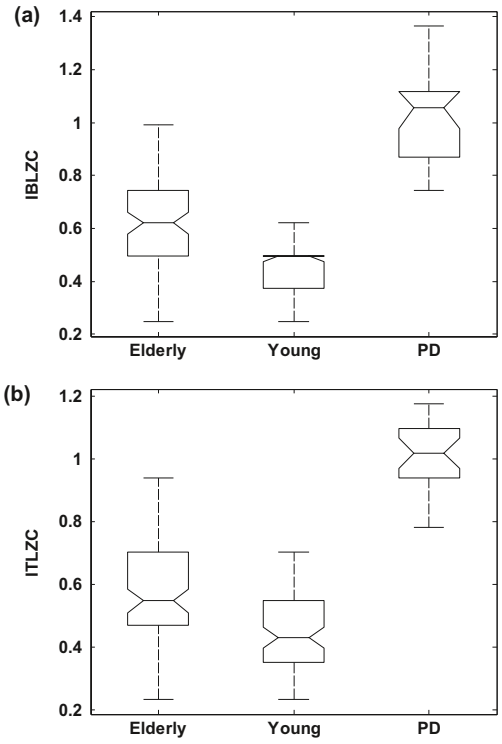

Figure 1. The distributions of (a) IBLZC and (b) ITLZC values for young, elderly, and PD classes from Group-I using box and whisker plots.

the respective IBLZC and ITLZC of the original and surrogate gait series for PD class, in both the groups, reveals no significant difference (p-value > 0.05). This means that the deterministic nature in the PD patients might have been either considerably decreased or lost because of the disease. One can use p-value as a marker of the order of deterministic nature. Comparison of the respective IBLZC and ITLZC of the original and surrogate gait series for young, elderly, and PD classes shows that the p-value is the least for the young class, intermediate for elderly class, and the highest for PD class. This shows that the deterministic nature is prominent in the young class, decreases with aging as noticed in the elderly class, and further diminishes or may break down because of the progression of the disease as observed in the PD class.

Table 3. Comparison of IBLZC with its surrogate IBLZC using Mann–Whitney rank sum tests for classes of Group-I and Group-II

Class	IBLZC	IBLZC_surrogate	p-value
Young1	0.470 ± 0.049	0.854 ± 0.081	5.16×10^{-21}
Elderly1	0.620 ± 0.083	0.951 ± 0.048	4.18×10^{-17}
PD1	1.029 ± 0.095	1.098 ± 0.090	0.803
Young2	0.707 ± 0.094	0.879 ± 0.092	7.90×10^{-04}
Elderly2	0.620 ± 0.091	0.859 ± 0.079	6.85×10^{-04}
PD2	0.888 ± 0.059	1.079 ± 0.058	0.153

Note: All values are expressed as mean ± SD.

This clearly shows that the alterations in gait dynamics in the elderly are due to subtle changes in the neuromuscular control making them prone to falls (for no apparent reason). On the other hand, the prominent alterations in gait dynamics of the PD subjects reflect neuropathology which increases their risks of falling. These findings could be of importance for clinical diagnostics, in algorithms for gait fall risk stratification, and for therapeutic and fall-preventive tools of next generation.

3.6. Applications of this approach

This tool can facilitate judgments to assess the complex dynamical behavior in the stride time series in discerning young, elderly, and PD classes in clinical settings. This study has application in clinical geriatrics and future gerontological research. We believe that this study has implications in sedentarism, perhaps somewhat like advances aging and disease.

3.7. Limitations

The present study focused on only level walking at their normal pace on an obstacle-free path. Therefore, further study is necessary to evaluate changes in gait pattern among different classes using different experimental designs, including gait adaptation strategy by gait condition. Another limitation of this study is the small sample size. Factors like high variance, age differences, and differing male-to-female ratios between groups will have an impact on the results when statistical analyses are carried out on small sample sizes. However, it has been shown that the effect of gender on usual gait patterns is considerably small (Gabell & Nayak, 1984). Though the effect of age on gait is complex, the effect of neurodegenerative disorder considerably predominates over the aging effects. This implies that the discrimination using this nonlinear method stands irrespective of the above limitations.

4. Conclusion

Though previous studies, in general, claim that a two-symbol sequence conversion to study dynamic complexity of a signal is suffice, our results show that a three-symbol sequence might give a more detailed insight into the differences among young, elderly, and PD classes stride time series. Thus, while using LZC in analysis there is a need to investigate the method of coarse-graining which is appropriate for the time series used. We found that the stride time series in young exhibits a less complex dynamical behavior for walking continuously at their normal pace on an obstacle-free level ground. This behavior may change with physiologic aging and as found in elderly subjects dynamical complexity increases resulting in local instability making them more disposed to falls. In the pathological case, dynamical complexity is significantly increased resulting in increased risk of falls.

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