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EFFECTS OF LATERAL STEPPING GAIT AND DUAL TASKING DURING TREADMILL WALKING IN HEALTHY YOUNG AND OLDER ADULTS

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Abstract

Previous studies on lateral stepping gait have demonstrated decreased variability and also decreased involvement of central nervous system's active control in the direction of progression. This study sought to further explore this notion through the variability of stride interval time series (SIT) and signal magnitude difference time series (SMD) while forward and lateral walking using an inertial sensor mounted at the sternum. Additionally, this study also explored the effects of dual-tasking on forward and lateral walking variability. Seven young (age 22.6±2.5 years) and seven old participants (age 71.14±6.5 years) were recruited for this study. Participants performed forward and lateral walking on treadmill at their preferred speed with and without dual tasking. The dual task provided was a mental arithmetic task (counting backwards from a random provided number by subtracting the number three). We found that complexity of stride interval time series decreased significantly during lateral walking in both young and older adults (p=0.01). We also found lateral walking affected both young and elderly and the complexity of signal magnitude differences in angular velocity signals reduced (p=0.01) than that at forward walking. We also found significant interaction effects in complexity of SMD signals between direction of progression and age groups. Furthermore, it was also found that dual-tasking affected both forward and lateral walking and both age groups by decreasing fractal properties in SMD (p=0.02). This study explored the complexity (approximate entropy and multiscale entropy) of temporal structure of movement as well as magnitudes of angular velocities and found that there is loss of complexity in both young and older adults due to lateral walking. We also found dual-tasking induced anti-persistence in angular velocities.

Keywords

Lateral stepping gait; dual task; attention; Fall risk; inertial sensors

INTRODUCTION

Elderly individuals have higher fall risk and this has been correlated with several changes in movement dynamics and movement variability due to aging. Some studies have found that inter-stride variability in accelerations of trunk can differentiate frail older adults who are fall prone[1]. Other authors have reported increased gait variability as an indicator of fall risk, with variabilities of step time [2] and step width [3, 4]. It has been suggested that an increase in amount of stance time variability was associated with higher incidence of mobility disability in the elderly[5]. Researchers have also linked the increased amount of variability with decreased motor control in elderly individuals [6]. Thus variability is an important biomarker of stability of an individual during walking.

Theoretically considering inverted pendulum model, anterior posterior (AP) direction is stable from passive dynamics (spinal reflexes and mechanics constraints) whereas the stability in medial-lateral (ML) direction is maintained actively (supraspinal mechanisms) by higher brain centers [7]. Variability in ML direction while walking has been supporting these claims of direction specific active balance control while walking [7–9]. As most of these studies have aligned the direction of progression with the AP direction, which is a naturally expected bias since human direction of progression is AP. Other existing study with lateral stepping have looked into linear variability [10]. Nonlinear tools help in describing structure of the variability (as opposed to amount of variability described by linear statistics such as standard deviation, coefficient of variation, range etc.). The linear measures of variability do not accurately define constructs important in movement, such as stability, because they only provide insights into the amount of variability [11].

In addition to the direction of progression, dual-task related gait changes have also been found to increase in number of stops, lateral deviations, steps and walking time [12–14], and also increase in stride width, stride length, stride time variabilities [13, 15]. It has also been reported that attention demanding tasks during treadmill walking reduce step width variability in younger adults [16]. Intrasubject variability of kinematic variables is an index of movement consistency or stability of gait performance. Exploring dual-task related gait changes is of particular interest in understanding variability because a strong relationship exists between dual-task related gait changes and the risk of falling in older adults [14, 17, 18]. The primary objective of this study was to investigate the relationship between dual-task, direction of progression and movement variability using inertial sensors and nonlinear dynamics.

METHODS

Participants:

Seven young and seven old participants were recruited for this study. The younger population consisted college students of Virginia Tech campus, and older adults were retired people in Blacksburg area. The recruited participants were in a general good health condition, with no recent cardiovascular, respiratory, neurological, and musculoskeletal abnormalities. All participants were first familiarized with laboratory equipment’s and were provided a verbal explanation of the experimental procedure. Participants were requested to wear laboratory clothes and shoes, fitting to their sizes. Height and weight of participants were noted below the ID numbers assigned to the subject. This study was approved by the Institutional Review Board (IRB) of Virginia Tech. All participants who participated in this study provided written consent prior to the beginning of data collection. Demographic information for the participants is provided in Table 1.

Protocol:

The experiment was divided into two sessions: normal session and dual-task session. Each session was separated by 4 days and each participant was randomly assigned to either normal or dualtask as his/her first session.

Treadmill walking: Participants were asked to walk with four different conditions on a treadmill for 4 minutes, 1) Forward Walking- participants had to face forward along the direction of progression while walking. 2) Forward Walking with counting backwards- Participants had to face forward along the direction of progression while walking and had to count backwards. 3) Lateral stepping- participants had to walk sideways on a treadmill and had to face orthogonal to the direction of progression while walking. 4) Lateral stepping with dual tasking: participants had to walk sideways on a treadmill and had to face orthogonal to the direction of progression while walking along with counting backwards (Figure 1). Participants were corrected if they made an error in counting.

Participants were asked to face to their left, such that their right leg is leading leg and left leg is lagging leg. They were also asked to keep their head up while stepping, and not to cross their legs at any time, and not to have both of their feet off the ground at any time. Participants were asked to walk at their own preferred speed and this speed was determined by incrementally increasing the treadmill speed at 0.45m/s [19], until the participant indicated that his/her preferred speed was reached. Speed was incremented again to get a reconfirmation from the participant that it was fast and was reduced back to preferred speed. If it was not confirmed by the participant that the speed is preferred walking speed, then the process was repeated until the preferred speed was reached. After selection of preferred speed by the participants, they were given 10 minutes to get used to the treadmill; this amount of time has been previously found to be adequate to achieve a proficient treadmill walking pattern [20]. This was followed by a minimum of 3 minute rest. Then the participants were requested to perform all four conditions of walking. The order was random for all four conditions.

Stride Interval Time series (SIT): The temporal fluctuations in stride intervals time series has been widely used as a non-invasive technique to evaluate effects of neurological impairments on gait and its changes with aging and disease[21, 22]. A customized MATLAB algorithm was used to identify peaks from gyroscope signals from trunk mounted inertial sensor. The time difference from one peak to the other was considered as stride interval and all these consecutive intervals made up Stride Interval Time Series (SIT).(Figure 2)

Signal Magnitude Difference Time series (SMD): The differences in peak heights of angular velocity signals are categorized as signal magnitude differences. These differences in magnitudes of angular velocity were used to construct a time series which was named as Signal Magnitude Difference (SMD) time series. The total length of SMD time series is one less than the total number of strides walked by the subject.

RESULTS

It was found that there was significant decrease in Stride interval time series complexity during lateral stepping gait for both young and older adults (p=0.01) (Figure 3). It was also found that lateral stepping gait had decline in complexity for SMD time series for both young and older adults (Figure 4). We also found significant interaction effects between age groups and direction of progression (Figure 5).

DISCUSSION

The findings support the use of inertial sensors as a tool for understanding variability in healthy young and older adults and augments preexisting knowledge of variability structure during lateral stepping and dual-task gait in young and elderly population. Time series were derived from trunk kinematics: Stride interval time series and signal magnitude difference time series. These time series were investigated for the changes in structure of variability while walking on a treadmill with four conditions (forward, lateral and with/without dual-tasking). We found that lateral stepping gait resulted in loss of complexity as found by ApEn and MSE values for SIT and SMD. Loss of complexity is known to reduce one's capacity to adapt to stress with aging and disease [23]. This reduced complexity [23], is dependent on the nature of the intrinsic dynamics of the system and one's ability for short time adaptive change, which is required to meet an immediate task demand is reduced [24].

Dual tasking resulted in loss of fractal properties in trunk kinematic signals, which implies less anti-persistence or less neuronal-control involved in the movement. This study revealed the structure of variability during treadmill walking with the four conditions (forward, lateral and with/without dual-tasking). Structure of variability is actually temporally organized and is quantified by the degree to which values emerge in an orderly (i.e., predictable) manner [11]. The structure of variability pertains to the time ordered variance within the human movement [25]. Variability may be viewed as increased flexibility of skill to allow adaptation to external perturbations. Thus it is important to understand how much is variability regulated in healthy young and older adults and this information is critical in assessing fall risk.

CONCLUSIONS

This study has contributed in measuring nonlinear variability using portable inertial sensors while walking on a treadmill with four conditions (forward, lateral and with/without dual-tasking). This study is an important ground work for launching inertial sensors in understanding kinematic variabilities in clinical settings for measuring patients with pathologies. For healthy young and old adults' various nonlinear variability parameters were determined using inertial sensors which showed promising results.

REFERENCES

[1]. Moe-Nilssen R, and Helbostad JL, "Interstride trunk acceleration variability but not step width variability can differentiate between fit and frail older adults," Gait Posture, vol. 21, no. 2, pp. 164–70, Feb, 2005. [PubMed: 15639395]

[2]. Hausdorff JM, Rios DA, and Edelberg HK, "Gait variability and fall risk in community-living older adults: a 1-year prospective study," Arch Phys Med Rehabil, vol. 82, no. 8, pp. 1050–6, Aug, 2001. [PubMed: 11494184]

[3]. Owings TM, and Grabiner MD, "Variability of step kinematics in young and older adults," Gait Posture, vol. 20, no. 1, pp. 26–9, Aug, 2004. [PubMed: 15196516]

[4]. Brach JS, Berlin JE, VanSwearingen JM, Newman AB, and Studenski SA, "Too much or too little step width variability is associated with a fall history in older persons who walk at or near normal gait speed," J Neuroeng Rehabil, vol. 2, pp. 21, Jul 26, 2005. [PubMed: 16042812]

[5]. Brach JS, Studenski SA, Perera S, VanSwearingen JM, and Newman AB, "Gait variability and the risk of incident mobility disability in community-dwelling older adults," J Gerontol A Biol Sci Med Sci, vol. 62, no. 9, pp. 983–8, Sep, 2007. [PubMed: 17895436]

[6]. Buzzi UH, Stergiou N, Kurz MJ, Hageman PA, and Heidel J, "Nonlinear dynamics indicates aging affects variability during gait," Clinical Biomechanics, vol. 18, no. 5, pp. 435–443, 2003. [PubMed: 12763440]

[7]. O'Connor SM, and Kuo AD, "Direction-dependent control of balance during walking and standing," J Neurophysiol, vol. 102, no. 3, pp. 1411–9, Sep, 2009. [PubMed: 19553493]

[8]. Bauby CE, and Kuo AD, "Active control of lateral balance in human walking," J Biomech, vol. 33, no. 11, pp. 1433–40, Nov, 2000. [PubMed: 10940402]

[9]. Dean JC, Alexander NB, and Kuo AD, "The effect of lateral stabilization on walking in young and old adults," IEEE Trans Biomed Eng, vol. 54, no. 11, pp. 1919–26, Nov, 2007. [PubMed: 18018687]

[10]. Wurdeman SR, Huben NB, and Stergiou N, "Variability of gait is dependent on direction of progression: Implications for active control," Journal of Biomechanics, vol. 45, no. 4, pp. 653–659, 2012. [PubMed: 22245103]

[11]. Harbourne RT, and Stergiou N, "Movement variability and the use of nonlinear tools: principles to guide physical therapist practice," Phys Ther, vol. 89, no. 3, pp. 267–82, Mar, 2009. [PubMed: 19168711]

[12]. Beauchet O, Dubost V, Aminian K, Gonthier R, and Kressig RW, "Dual-task-related gait changes in the elderly: does the type of cognitive task matter?," J Mot Behav, vol. 37, no. 4, pp. 259–64, Jul, 2005. [PubMed: 15967751]

[13]. Beauchet O, Kressig RW, Najafi B, Aminian K, Dubost V, and Mourey F, "Age-related decline of gait control under a dual-task condition," J Am Geriatr Soc, vol. 51, no. 8, pp. 1187–8, Aug, 2003.

[14]. Lundin-Olsson L, Nyberg L, and Gustafson Y, ""Stops walking when talking" as a predictor of falls in elderly people," Lancet, vol. 349, no. 9052, pp. 617, Mar 1, 1997.

[15]. Grabiner PC, Biswas ST, and Grabiner MD, "Age-related changes in spatial and temporal gait variables," Arch Phys Med Rehabil, vol. 82, no. 1, pp. 31–5, Jan, 2001. [PubMed: 11239283]

[16]. Grabiner MD, and Troy KL, "Attention demanding tasks during treadmill walking reduce step width variability in young adults," J Neuroeng Rehabil, vol. 2, pp. 25, Aug 08, 2005. [PubMed: 16086843]

[17]. Bloem BR, Steijns JA, and Smits-Engelsman BC, "An update on falls," Curr Opin Neurol, vol. 16, no. 1, pp. 15–26, Feb, 2003. [PubMed: 12544853]

[18]. Verghese J, Buschke H, Viola L, Katz M, Hall C, Kuslansky G, and Lipton R, "Validity of divided attention tasks in predicting falls in older individuals: a preliminary study," J Am Geriatr Soc, vol. 50, no. 9, pp. 1572–6, Sep, 2002. [PubMed: 12383157]

[19]. Myers SA, Johanning JM, Stergiou N, Celis RI, Robinson L, and Pipinos II, "Gait variability is altered in patients with peripheral arterial disease," J Vasc Surg, vol. 49, no. 4, pp. 924–931 e1, Apr, 2009. [PubMed: 19217749]

[20]. Matsas A, Taylor N, and McBurney H, "Knee joint kinematics from familiarised treadmill walking can be generalised to overground walking in young unimpaired subjects," Gait Posture, vol. 11, no. 1, pp. 46–53, Feb, 2000. [PubMed: 10664485]

[21]. Aziz W, and Arif M, "Complexity analysis of stride interval time series by threshold dependent symbolic entropy," Eur J Appl Physiol, vol. 98, no. 1, pp. 30–40, Sep, 2006. [PubMed: 16841202]

[22]. Fasano A, Marmelat V, Torre K, Beek PJ, and Daffertshofer A, “Persistent Fluctuations in Stride Intervals under Fractal Auditory Stimulation,” PLoS ONE, vol. 9, no. 3, pp. e91949, 2014. [PubMed: 24651455]

[23]. Lipsitz LA, and Goldberger AL, “Loss of ‘complexity’ and aging. Potential applications of fractals and chaos theory to senescence,” JAMA, vol. 267, no. 13, pp. 1806–9, Apr 1, 1992. [PubMed: 1482430]

[24]. Vaillancourt DE, and Newell KM, “Changing complexity in human behavior and physiology through aging and disease,” Neurobiol Aging, vol. 23, no. 1, pp. 1–11, Jan-Feb, 2002. [PubMed: 11755010]

[25]. Wurdeman SR, and Stergiou N, “Temporal structure of variability reveals similar control mechanisms during lateral stepping and forward walking,” Gait Posture, Dec 11, 2012.

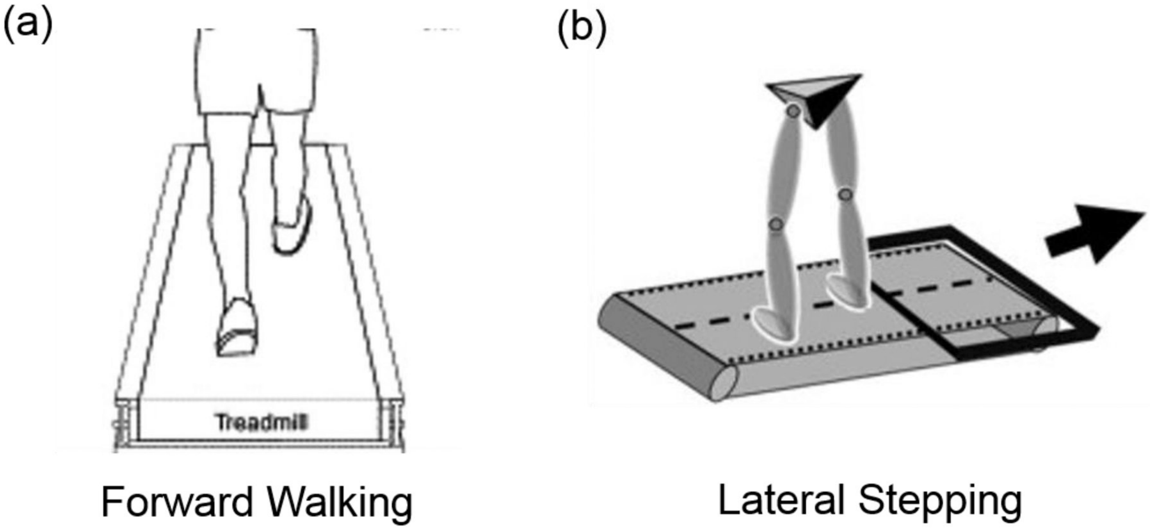

Figure 1.
(a) Forward walking and (b) lateral walking on treadmill

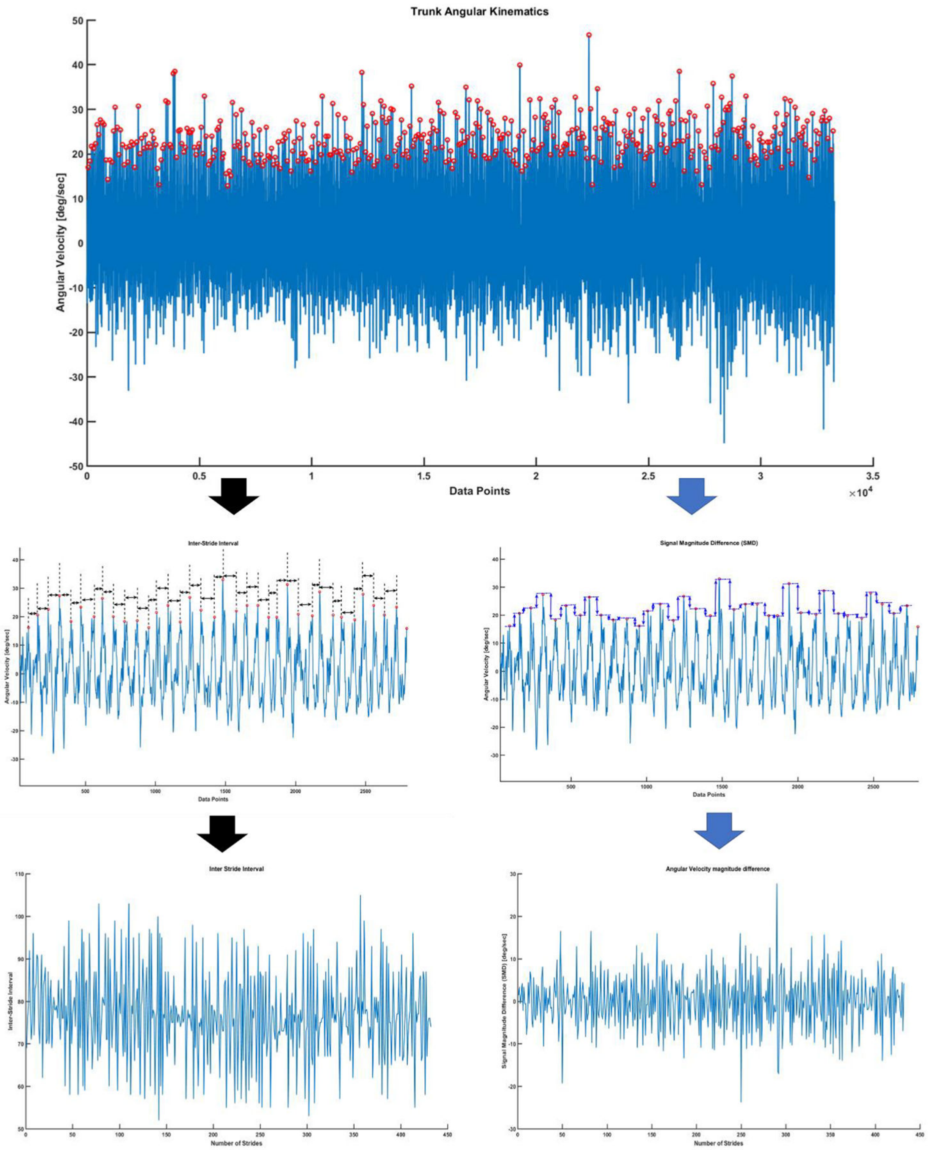

Figure 2:

Schematic diagram of derivation of SID and SMD time series from angular velocity signals from trunk IMU during walking on treadmill.

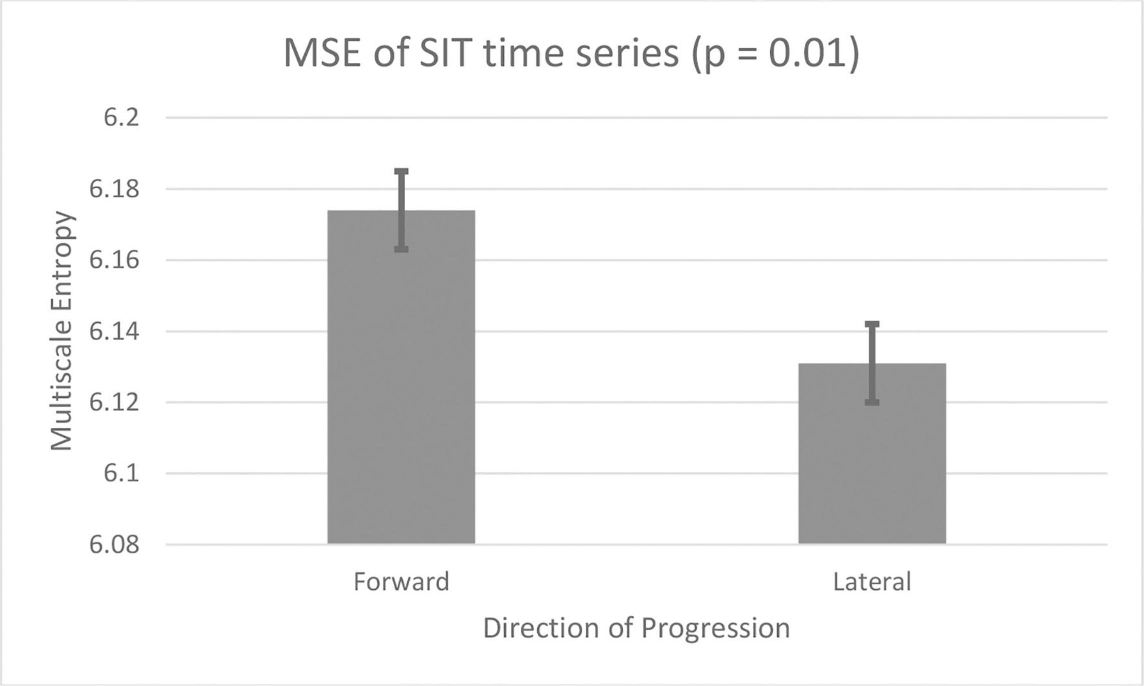

Figure 3:

Effects of direction of progression in multiscale entropy of SIT signals

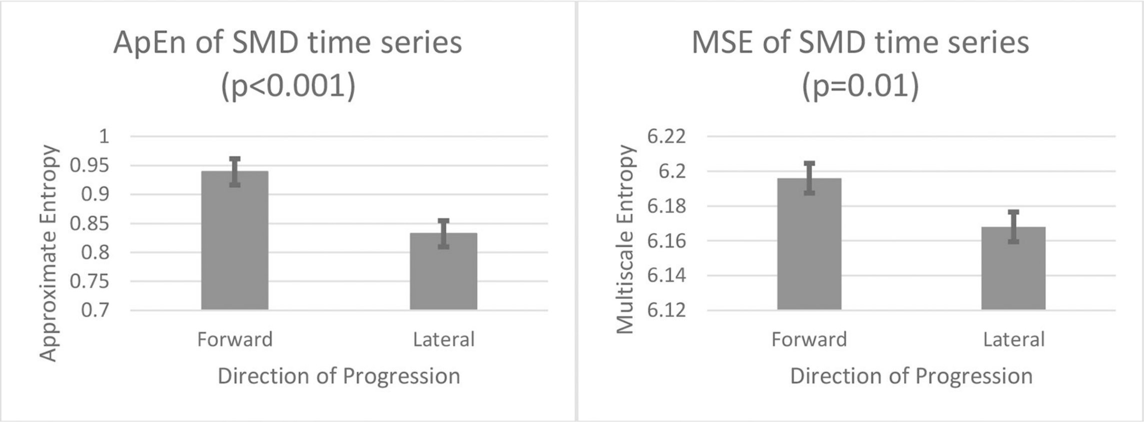

Figure 4:

Effects of direction of progression on complexity (ApEn, MSE) of SMD time series signals

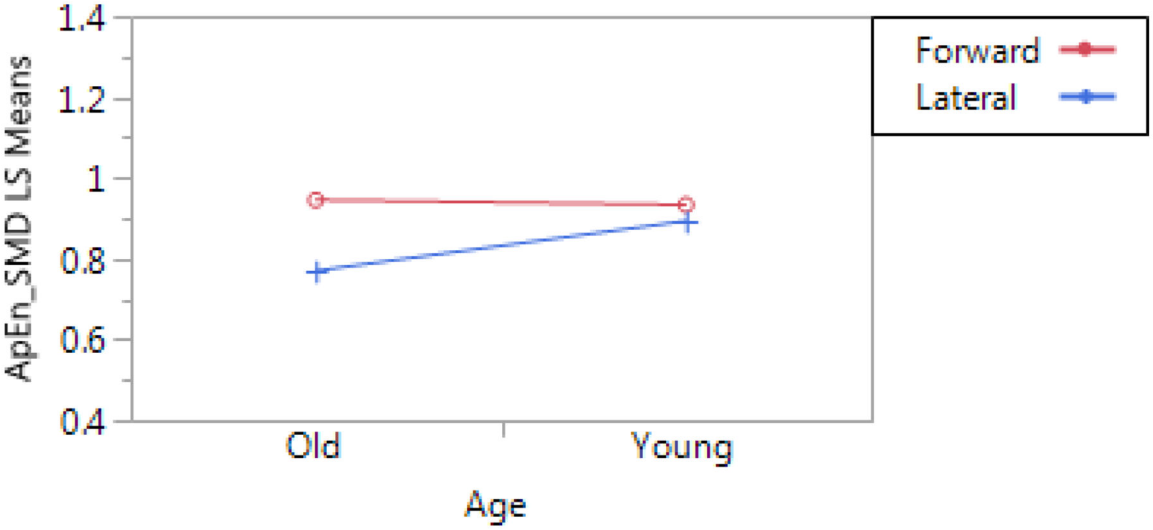

Figure 5:

Interaction effects between age and direction of progression for ApEn ($p<0.01$)

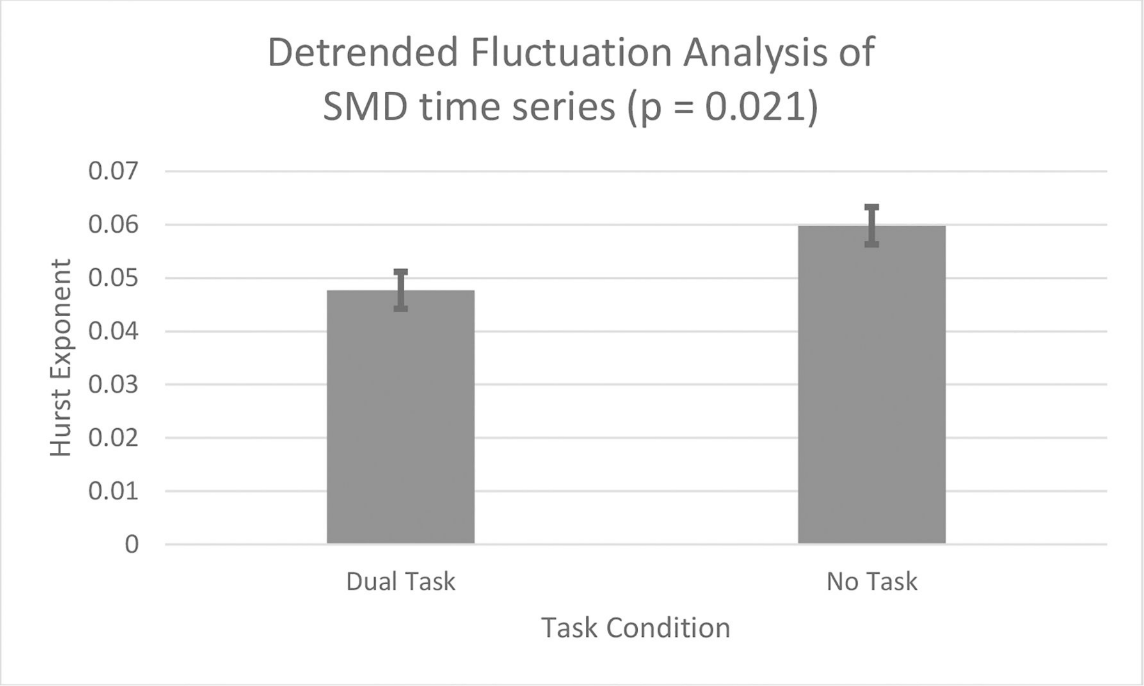

Figure 6:

Effects of task condition on hurst exponent.

Table 1

Background characteristics of study participants

	Age Group			
	Old		**Young**	
	Mean	**SD**	**Mean**	**SD**
Age	71.143	6.5174	22.643	2.5603
Height [cm]	174.571	10.2446	170.376	9.3302
Weight [Kg]	78.559	18.2576	69.651	15.5270
BMI	25.529	4.2731	23.786	4.0004