Effects of Aging on Human Gait Stability

Mustafa Maher Saleh, S. Parasuraman
School of Engineering
Monash University, Malaysia
Bandar Sunway, Malaysia.

D. Kingsly Jeba Singh
Department of Mechanical Engineering,
SRM University, Chennai.603203,
India

C. Deisy and S.Padmavathy
Dept. of Computer Science Engineering
Thiyagarajar College of Engineering,
Tamilnadu, India.

M. K. A. Ahamed Khan
University Selangor, Faculty of Engineering,
45600 Bestari Jaya,
Selangor Darul Ehsan, Malaysia

Abstract— **This project aims to investigate the effects of aging on different gait parameters such as the spatiotemporal, kinetic and kinematic. Previous researches have focused on the effects of muscle fatigue on the gait characteristics under single and dual task conditions and other have focused on the effect of ageing and falls history on the Minimum Foot Clearance (MTC) during level walking. However, what was missing in most of the latest researches is a comprehensive analysis on all the major gait parameters that affect the stability. The findings on this project showed the relationship between the different gait parameters and the effect of such on the human motion stability. Results obtained showed that there is a difference in the cadence and stride length between healthy elderly people and young ones at normal walking speed (4Km/h). The findings also showed that elderly people have localized pressure distribution on their feet and a smaller ankle flexion angle that resulted in lower MTC. All these factors if not properly corrected and controlled can significantly induce fatigue, cause muscle and joints pain and even increase the chances of tripping.**

Keywords— Biomechanics; Human Aging; Motion Stability; Trips and Falls; Spatiotemporal; Kinematics; Kinetics.

I. INTRODUCTION

Walking is a critical quality of life and self-management. It is required for almost everyday activity to complete tasks and have useful interaction with others. However, with aging, the chances of tripping and falling get higher. According to the Centre for Disease Control and Prevention (CDC), falls among the elderly -aged 60 and above- have been reported to be very high. In 2013 alone, the CDC stated that there have been 2.5 million nonfatal reported falls among older adults. Among those people, 734,000 were hospitalized and 25,500 died from unintentional fall injuries [1]. Walking discrepancies and falls in the elderly has also been shown to be a major public health concern because of the associated social and financial cost and morbidity rates. The CDC estimated the direct medical costs of falls, adjusted for inflation to be USD 34 billion. In Australia, statistics has shown that the annual health costs associated with falls related hospitalization is on the rise every year. It is estimated that the annual cost is AUD 4,546 million [2]. These global statistics show that falls among the elderly is something that should not be underestimated or ignored.

With ageing, the walking patterns change due to various reasons. Most can be associated with the decline in the cognitive and sensoring motor processes that can be related to the impaired balance, reduction in the muscle activation and loss of coordination [3]. Various gait analysis researches have been going on in the past 10 years trying to better understand the ageing effects on the gait biomechanics. While others looked at the relationship between basic gait variables (such as, step length, walking speed and stance swing time) and the relationship with joint moments/powers [4]. However, one important factor that many have not focused on while evaluating the task of walking is the type of footwear and the sole's material. It is an important factor to be considered for assessing the walking pattern and monitoring the stability. Tripping while walking is responsible for more than one third of falls during locomotion [3]. Tripping usually occurs during the swing phase of walking when the foot fails to clear either obstacles or ground irregularities. The foot ground clearance is critical during the swing phase. It can also be described as the MFC that occurs approximately halfway through the swing phase. Uncomfortable shoes as well as lack of fitness would significantly affect the walking pattern as well as increasing the chances of fatiguing and tripping. Although many researches have been going on in the past few years trying to understand the influence of aging on the stability of human motion, no conclusive results have been shown so far that can connect all the major spatiotemporal, kinetic and kinematic factors. For instance, one of the latest experiments by Hanatsu Nagano et al. (2014) showed that walking induced fatigue results in an increase in step length and longer double support time with greater MFC on the non-dominant limb as the aging of humans occur. Therefore, the purpose of this project is to investigate the effect of aging and walking speed variability on the kinetic, kinematic and spatiotemporal variables of the gait cycle. This would define the exact weaknesses elderly people are prone to and the associated impact of that on the general motion stability.

II. EXPERIMENTAL STUDIES

A. Subjects

An examination on a group of six fit and healthy young (23years ±1.5) and six elderly (62 years ±3.9) participants was carried out. The anthropometric characteristics of the subjects is shown in

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table 1 below. All selected participants were free of conditions impairing normal locomotion as determined from a self-reported health and fitness questionnaire. Participants wore the same type of footwear (AXEL sports shoes with soft sole material -2.8cm sole thickness-).

Table 1 The anthropometric characteristics for the 12 participants

Anthropometric characteristics of the subjects		
Variable	***Young Participants***	***Elderly Participants***
Age (yrs.)	23 ± 1.5	62 ± 3.9
Height (m)	1.69 ± 0.065	1.60 ± 0.18
Mass (kg)	65 ± 7.4	62 ± 2.5
BMI	23 ± 2.25	24 ± 1.1
Shoe Size (UK)	7,8	7,8
Leg Length (m)	0.87 ± 0.04	0.83 ± 0.03
Resting SPO_2	98 ± 0.5	97 ± 0.6
BPM	83 ± 10	96 ± 7

B. System Setup

Two main systems were used to monitor the participants gait patterns. The first system was the 3D motion capturing system (QTM) and the 2nd system used was the Moticon Insoles and Moticon Beaker software. Six infrared camera motion analysis system (247 Hz, Qualisys Oqus Capture System) was used to obtain the three-dimensional (3D) lower limb kinematics during testing. Qualisys Track manager (QTM) was used to capture the motion of reflective markers that were placed on certain parts of the body. The Moticon system (50Hz) allowed dynamic data acquisition and storage for the pressure distribution and COP change on different parts of the feet at different gait phases.

C. Markers Placement and data Acquisition

Markers were placed on the Femur greater Trochanter (to define the hip/thigh joint) and 4 tracking markers were placed on each thigh to capture the motion of the thigh segment during the motion phase. Another 4 markers were placed on the Femur Medial Epicondyle and Femur Lateral Epicondyle. This was done to define the radius of the knee as well as to track the knee angle change at different walking speeds. Four other markers were placed on the Fibula Apex of Lateral Malleolus and Tibia Apex of Medial Malleolus on each leg to define the radius of the ankle and tracking markers were placed on each shank.

Static Trial: The static trial involved a short 10 seconds, 247Hz Qualisys capture of the participant in a stationary position with all the necessary markers placed at the locations discussed earlier. Moticon insoles, 50Hz were also used to take the actual pressure readings on feet at this stationary pose.

Motion Trial: In the motion trial, the subject's movement was captured by the Qualisys system and the kinetic parameters were recorded by the Moticon insoles. All the tracking markers had to be in the exact position recorded during the static trial. 2 motion trials were performed for each participant at 3 different walking speeds (3Km/h, 4Km/h and 5 Km/h). Two trials were performed instead of one due to the occasional pause in Moticon insoles recording. The second trial was used to ensure that the readings taken during the first trial were accurate and match the other trial's recordings and to also ensure that no recoded data was missing at different walking speeds.

D. Data Analysis

All analyses were performed on the non-dominant foot due to its role in providing stability for the body [6,7,12]. Data Analysis was done using Microsoft excel and Matlab. Statistical Analysis was performed using SPSS version 22.0 statistical analysis software. 2 Way Analysis of Variance (2Way-ANOVA) was performed to analyze the effects of aging and different walking speeds on the different gait parameters. LSD post-hoc tests were used to determine the exact significant differences between the different walking speeds among each age category and a T-test was used to determine if the differences were influenced by aging. Differences between the parameters of each group were considered significant if $p<0.05$.

III. RESULTS

Different gait variables were analyzed in this paper. In terms of the spatiotemporal parameters, the stance time (s), swing time (s), stride length (m), cadence (steps/min) and MTC (mm) were analyzed. The hip angle, knee angle and ankle angle were analyzed under the kinematic parameters. Finally, for the kinetic parameters, the force on heel force to body weight ratio (HBW), force on toe to body weight ratio (TBW), the horizontal displacement of the COP (COPx) and the vertical displacement of the COP (COPy) were examined. All the changes in these variable with reference to age and speed were documented and thoroughly analyzed. Tables 2, 3 and 4 show the summary of the mean and standard deviation of all the main tested variables.

IV. DISCUSSION

Young people exhibited higher average stance time for all the walking speeds compared to the elderly. The standard deviation among the elderly at speed 3 Km/h was relatively high. This shows that older adults tend to have different walking patterns that are more associated with their neural and musculoskeletal capabilities. The walking environment in terms of speed and shoe type did not play a big role in giving them the same stance time at their preferred walking speed (3Km/h). However, as the speed increased, the older adult's stance mean time got closer to the younger participants and the standard deviation significantly reduced. A previous study conducted by Wert D. (2011) showed that the variability in the stance time was lower on treadmill walk compared to the ground level walking.

A. Spatiotemporal Parameters:

Table 2 The different spatiotemporal parameters measured for the 2 age groups at different walking speeds.

Age	Speed	Stance Time (s)	Swing Time (s)	Stride Length (m)	Cadence (steps/min)	MTC (mm)
Young	3 Km/h	0.7585 ± 0.04687	0.4998 ± 0.02680	0.7709 ± 0.04357	92.51 ± 5.22	20.2000 ± 3.56371
	4 Km/h	0.6846 ± 0.03023	0.4492 ± 0.02470	0.8855 ± 0.03955	106.25 ± 4.76	29.2500 ± 2.99583
	5 Km/h	0.6068 ± 0.0362	0.4083 ± 0.02500	0.9561 ± 0.05556	114.73 ± 6.66	36.8333 ± 5.30723
	Total	0.6833 ± 0.07325	0.4524 ± 0.04536	0.8708 ± 0.08996	104.50 ± 10.79	28.7611 ± 7.97556
Old	3 Km/h	0.7464 ± 0.08233	0.4679 ± 0.06609	0.7520 ± 0.08320	90.24 ± 9.98	18.9333 ± 5.98888
	4 Km/h	0.6455 ± 0.02361	0.4364 ± 0.02106	0.8384 ± 0.03134	100.60 ± 3.76	25.9167 ± 5.82595
	5 Km/h	0.5903 ± 0.01563	0.3963 ± 0.02583	0.9300 ± 0.02438	111.59 ± 2.92	31.8333 ± 2.48328
	Total	0.6607 ± 0.08157	0.4335 ± 0.05021	0.8401 ± 0.08995	100.81 ± 10.79	25.5611 ± 7.19576

B. Kinematic Parameters:

Table 3 The different lower extremity joints kinematic parameters (hip, knee and ankle angles) measured for the 2 age groups.

Age	Speed	Hip Angle (degrees)	Knee Angle (degrees)	Ankle Angle (degrees)
Young	3 Km/h	17.0346 ± 1.61566	52.9075 ± 4.20825	16.7142 ± 1.92309
	4 Km/h	18.8092 ± 2.27398	53.8621 ± 6.58191	19.7992 ± 2.34862
	5 Km/h	20.8742 ± 1.70954	55.2629 ± 5.68550	23.4063 ± 4.15933
	Total	18.9060 ± 2.39891	54.0108 ± 5.33370	19.9732 ± 3.96452
Old	3 Km/h	20.1650 ± 5.67270	51.5875 ± 9.08270	14.6983 ± 4.82664
	4 Km/h	22.6683 ± 5.05755	54.2533 ± 4.39894	18.1017 ± 4.65273
	5 Km/h	24.1650 ± 4.99907	56.6846 ± 3.66468	20.4288 ± 3.55051
	Total	22.3328 ± 5.21739	54.1751 ± 6.20425	17.7429 ± 4.77385

C. Kinetic Parameters:

Table 4 The different kinetic parameters (HBW, TBW, COPx and COPy) measured for the 2 age groups.

Age	Speed	HBW	TBW	COPx (mm)	COPy (mm)
Young	3 Km/h	0.9700 ± 0.12113	0.9691 ± 0.05759	27.7708 ± 6.60870	134.333 ± 12.886
	4 Km/h	1.0401 ± 0.10605	1.0138 ± 0.11614	27.7708 ± 6.60870	136.234 ± 12.675
	5 Km/h	1.2145 ± 0.11298	1.0761 ± 0.15211	30.2625 ± 2.61361	145.283 ±8.400
	Total	1.0749 ± 0.15023	1.0197 ± 0.11741	28.6014 ± 5.40009	138.983 ± 12.110
Old	3 Km/h	0.8262 ± 0.20820	0.9412 ± 0.21990	21.6833 ± 6.96668	117.995 ± 36.853
	4 Km/h	1.0105 ± 0.23159	0.9451 ± 0.14343	24.4417 ± 8.29688	119.500 ± 25.201
	5 Km/h	1.0670 ± 0.15628	1.0301 ± 0.17640	23.5792 ± 6.70482	139.837 ± 28.933
	Total	0.9679 ± 0.21656	0.9721 ± 0.17665	23.2347 ± 7.01062	125.777 ± 30.618

D. *Statistical Analysis of Variance between the 3 different walking speeds (3Km/h, 4Km/h and 5Km/h)*

Table 5 The statistical analysis results for the 3 different walking speeds.

			Stance Time	Swing Time	Stride Length	Cadence	MTC	Hip Angle	Knee Angle	Ankle Angle	HBW	TBW	COPx	COPy
Age	(I) Speed	(J) Speed	P-value	P-value	P-value	P-value	P-value	P-value	P-value	P-value	P-value	P-value	P-value	P-value
Young	3 Km/h	4 Km/h	**0.008****	**0.019***	**0.000****	**0.000****	**0.002****	0.442	0.781	0.164	0.463	0.616	1.000	1.000
		5 Km/h	**0.000****	**0.000****	**0.000****	**0.000****	**0.000****	0.102	0.494	**0.004****	**0.015***	0.235	0.514	0.42
	4 Km/h	3 Km/h	**0.008****	**0.019***	**0.000****	**0.000****	**0.002****	0.442	0.781	0.164	0.463	0.616	1.000	1.000
		5 Km/h	**0.005****	0.053	**0.021***	**0.021***	0.336	0.372	0.684	0.106	0.074	0.486	0.514	0.42
	5 Km/h	3 Km/h	**0.000****	**0.000****	**0.000****	**0.000****	**0.000****	0.102	0.494	**0.004****	**0.015***	0.235	0.514	0.42
		4 Km/h	**0.005****	0.053	**0.021***	**0.021***	0.336	0.372	0.684	0.106	0.074	0.486	0.514	0.42
Old	3 Km/h	4 Km/h	**0.000****	0.132	**0.006****	**0.006****	**0.013***	0.281	0.44	0.126	0.06	0.964	0.471	0.911
		5 Km/h	**0.000****	**0.001****	**0.000****	**0.000****	**0.000****	0.089	0.145	**0.013***	**0.016***	0.321	0.619	0.114
	4 Km/h	3 Km/h	**0.000****	0.132	**0.006****	**0.006****	**0.013***	0.281	0.44	0.126	0.06	0.964	0.471	0.911
		5 Km/h	**0.041****	0.057	**0.004****	**0.004****	**0.000****	0.516	0.481	0.29	0.554	0.343	0.821	0.14
	5 Km/h	3 Km/h	**0.000***	**0.001****	**0.000****	**0.000****	**0.000****	0.089	0.145	**0.013***	**0.016***	0.321	0.619	0.114
		4 Km/h	**0.041***	0.057	**0.004****	**0.004****	**0.000****	0.516	0.481	0.29	0.554	0.343	0.821	0.14

*Significant at *p< 0.05 and very significant at **p< 0.01*

E. *T-test results between the age groups (young participants vs. elders)*

Table 6 The statistical analysis results for the 2 different age groups.

Speed	(I) Age	(J) Age	Stance Time	Swing Time	Stride Length	Cadence	MTC	Hip Angle	Knee Angle	Toe Angle	HBW	TBW	COPx	COPy
			P-value	P-value	P-value	P-value	P-value	P-value	P-value	P-value	P-value	P-value	P-value	P-value
3Km/h	Young	Old	0.761	0.299	0.632	0.636	0.666	0.223	0.753	0.364	0.174	0.770	0.152	0.330
4Km/h	Young	Old	0.431	0.358	**0.045***	**0.047***	0.241	0.119	0.906	0.444	0.781	0.383	0.460	0.228
5Km/h	Young	Old	0.332	0.432	0.316	0.327	0.063	0.158	0.618	0.212	0.090	0.636	**0.046***	0.667

*Significant at *p< 0.05 and very significant at **p< 0.01*

Rider A. (2015) has observed a similar pattern in walking and running among different age groups. His findings have shown that, older people tend to walk or run slower than young people due to their shorter stride length. In this project, the difference in stride length was found significant at normal walking speed and this matches what Rider et. al. have found. In terms of cadence at speed 3Km/h, younger people had an average of 2 more steps/min compared to the elderly. But, the elderly category showed higher standard deviation which shows that there is very small difference in cadence between the age categories at slow walking speed. On the other hand, cadence at higher walking speeds seemed to be more affected by aging. Younger people exhibited at least 5 more steps/min compared to the older men. T-test has shown that it is statistically significant at speed 4Km/h (p=0.047).

Very few researches have given MTC a full analysis while analyzing the walking patterns of old people. The importance of MTC lies behind the fact that, a failure to achieve the minimum threshold for the toe clearance during the swing phase can result in trips and eventually falls [11]. A previous study by Morrison et al (2008) has shown that elderly participants exhibited larger variability in MTC at ground-level walking compared to younger ones. The study concluded that the absence of an increase in the median of MTC for elderly people can result in higher risks of tripping. In this project, the focus on the gait performance for Asian population has shown that MTC is affected by aging –but not significantly-. The mean MTC between the age groups was not very significant but the variability of the standard deviation was. Treadmill walking showed a similar effect on MTC as ground-level walking and the similar pattern in the median and variability was observed among the Malaysian population as what Morrison et. al. have shown.

The results of the knee angle flexion show that the average angle motion was almost identical between the 2 age groups. No significant maximum angle difference was observed between the 2 age groups. However, the standard deviation was observed to be higher among the elderly especially at speed 3Km/h. Although the difference between the 2 age categories at different speeds was not significant at this stage, excessive hip extension and irregularities in the ankle's plantarflexion and dorsiflexion can induce fatigue and increase the chances of tripping. The muscle fatigue can even affect the normal knee's flexion and extension and result in irregular flexions in them. This would also significantly increase the chances of falling. Aging has been found to have some influence on the ankle's flexibility. At low walking speed, elderly men had 2 degrees lower flexibility in their ankle and higher variability compared to the younger people. The same was observed at different walking speeds.

V. CONCLUSION

As humans age, their spatiotemporal parameters that include stance time, swing time, stride length and MTC reduce. The reduction in MTC can be linked to the lower HBW ratio at heel strike, small dorsiflexion and constrained COP path. The hip angle extension has been observed to increase which can cause discomfort after long walking periods and might even induce fatigue. Moreover, the ankle's flexibility angle has been observed to drop as humans age (which can result in tripping if not properly controlled). The overall ANOVA results have shown that the significant statistical mean differences in readings were more influenced by the walking speed and were not very significant as normal healthy humans aged.

REFERENCES

[1] Luis Mochizuki, Sandra Aliberti, Gait Stability and Aging, Locomotion and Posture in Older Adults, spingers Editors:Fabio Augusto Barbieri, Rodrigo Vitório, doi.org/10.1007/978-3-319-48980-3pp 45-54, 2017.

[2] Muir, Susan W., et al., Quantifying the magnitude of risk for balance impairment on falls in community-dwelling older adults: a systematic review and meta-analysis, Journal of clinical epidemiology 63.4 (2010): 389-406.

[3] H. Nagano, L. James, and W. Sparrow, Effects of walking induced fatigue on gait function and tripping risks in older adults, Journal of neuorengineering and rehabilitation, 2014.

[4] H. Nagano, R. Begg, and S. Taylor, A Comparison of Treadmill and Overground Walking Effects on Step Cycle Assymetry in Young and Older Individuals, Journal of Applied Biomechanics, 2013.

[5] Bizovska, L. , Svoboda, Z. , Vuillerme, N. , and Janura, M. Multiscale and Shannon Entropies During Gait as Fall Risk Predictors—A Prospective Study, Gait Posture, 52, pp. 5–10, 2017.

[6] Nagano H, Begg RK, Sparrow WA, Taylor S. A comparison of treadmill and overground walking effects on step cycle asymmetry in young and older individuals. J Appl Biomech. 2013;29:pp188–193.

[7] Seeley MK, Umberger BR, Shapiro R. A test of the functional asymmetry hypothesis in walking. Gait Posture, 28:pp24–28. doi: 10.1016/j.gaitpost.2007.09.006, 2008.

[8] D. Wert. Stance time variability and energy cost of walking in older adults. Available: http://d-scholarship.pitt.edu/10492/, 2011.

[9] Rider, About Stride Length and Aging and A Routine for Improvement. https://ridersite.org/Coach/Articles_pdf/AboutStrideAging.pdf, 2015.

[10] Mills P, Barrett R, and Morrison S, Toe clearance variability during walking in young and elderly men, Gait & Posture. 28 pp101-107 Etoims Walking| Toe Clearance| Falls., 2015.

[11] Lockhart T, Kim S, Evaluation of Gait Characteristics and Ground Reaction Forces in Cognitively Declined Older Adults with an Emphasis on Slip-Induced Falls, PMC. 21, 188-195, 2009.

[12] Graci V, Elliot DB, Buckley JG, "Peripheral visual cues affect minimumfoot-clearance during overground locomotion". Gait Posture 30, 370–374, 2009.

[13] Samira Ahmadi, Christine Wu, Nariman Sepehri, Anuprita Kantikar, Mayur Nankar and Tony Szturm, The Effects of Aging and Dual Tasking on Human Gait Complexity During Treadmill Walking: A Comparative Study Using Quantized Dynamical Entropy and Sample Entropy, Journal of Biomechanics Eng 140(1), 011006, 2017.

[14] Espi D, Yong F, Bhatt T, "Independent Influence of Gait Speed and Step Length on Stability and Fall Risk". Gait Posture 32, pp378-382, 2010.

[15] Graff A, Judge J, Thelen D, The effect of walking speed on lower-extremity joint powers among elderly adults who exhibit low physical performance. PMC. 86 2177-2183, 2005.