# Kinematic Characteristics of gait in Middle-Aged Adults during Level Walking

Yu Wu, Yin-Zhi Wang, Fei Xiao, Dong-Yun Gu*

*Abstract*—**Middle-aged people have shown a high fall incidence and degeneration in gait stability, while few studies concern that. This study aimed to assess the kinematic characteristics of gait in middle-aged people compared with younger and older ones during level walking, and to find sensitive indicators to characterize degenerated gait stability in middle-aged people.**

**13 middle-aged (mean age=52.1 years), with 13 older (mean age=74.8 years) and 13 young (mean age=23.3 years) healthy adults participated in this study. We assessed following gait parameters of the subjects during their level walking: 1) temporal-spatial gait parameters: normalized gait velocity, stride length, step length and their variability; 2) gait stability parameters: acceleration root mean square (RMS) of COM and its variability; and instantaneous COM-COP inclination angles.**

**Compared with young and older subjects, middle-aged adults showed no significant difference in temporal-spatial gait parameters and their stride-to-stride variability (*P*>0.050); Compared with young subjects, middle-aged adults showed a significant higher value in medial-lateral (ML) direction of acceleration RMS of COM (*P*=0.038) and its stride-to-stride variability (*P*=0.030), as well as in COM-COP inclination angle (*P*=0.003). There was no significant difference in the above two parameters of gait stability between middle-aged and older subjects (*P*>0.050).**

**Results illustrated that middle-aged subjects showed similar degenerated pattern in gait stability as the older ones in ML direction. Gait stability parameters, including ML acceleration of COM and its variability, as well as ML COM-COP inclination angle may help to characterize this degenerated gait stability. It's necessary for us to develop early interventions for middle-aged adults to prevent falls during walking.**

## I. INTRODUCTION

Falls are a leading risk factor of injury and death among older people, which are mainly resulted from the age-related degeneration in gait stability [1-4]. Compared with the older adults, middle-aged adults progressively start to show physiological changes that begin to alter postural stability, along with lower levels of physical activity [5]. In Gill's study, middle-aged and older subjects performed similar trunk angular sway during some gait tasks, suggesting the middle-aged people should accommodate their stiffer and aging bodies during locomotion [6].

Although middle-aged people were reported to suffer a high fall incidence [5, 7, 8], few studies focused on their gait stability while more attention is given to older people [3, 9-11]. Middle-aged subjects were thought as healthy as the younger ones, since no significant difference of gait stability was found between these two age groups [4].

Compared with normal temporal-spatial gait parameters, acceleration of the center of mass (COM) provides more direct parameters of measuring gait stability [9, 10, 12]. The variability of this parameter is proved to be an indication of the repeatability of acceleration patterns [12, 13], and can effectively discriminate between populations with different balance control abilities [14, 15].

Additionally, the center of mass (COM) and center of pressure (COP) inclination angle has been recently defined to quantify gait stability and identify older people at a higher risk of falling [4, 16]. It can reduce the effect of subjects' statures by calculating the angles accounting for both the COM height and horizontal distance between the COM and COP [4, 16, 17].

Therefore, this study aimed to investigate the kinematic characteristics of gait in middle-aged people compared with younger and older ones during level walking. We aimed to find sensitive indicators to characterize degenerated gait stability among middle-aged people, so as to provide them with early trainings of balance control and fall intervention. We assessed following parameters: (1) temporal-spatial gait parameters: gait velocity, stride length, step length and their stride-to-stride variability; (2) gait stability parameters: acceleration root mean square (RMS) of COM and its stride-to-stride variability; and instantaneous sagittal and frontal COM-COP inclination angles. We hypothesized that middle-aged subjects would show a potential degeneration in gait stability similar to the older subjects.

## II. METHODS

### A. Subjects

This study protocol was approved by the Bioethics Committee from School of Biomedical Engineering, Shanghai Jiao Tong University. Subject consents were obtained prior to the scheduled test date.

*Corresponding author.

Research was supported by National Science Foundation of China (Grant NO.31170901) and Shanghai Committee of Science and Technology, China (Grant No.13441902900).

Yu Wu is with Biomedical Engineering School of Shanghai Jiao Tong University, and Engineering Research Center of Digital Medicine and Clinical Translation, Ministry of Education, Shanghai 200030, China.

Yin-Zhi Wang and Fei Xiao are with Department of Orthopedic Surgery, Ninth People's Hospital，Shanghai Jiao Tong University School of Medicine, Shanghai 200011, China.

*Dong-Yun Gu is with Department of Orthopedic Surgery, Ninth People's Hospital， Shanghai Jiao Tong University School of Medicine, Biomedical Engineering School of Shanghai Jiao Tong University, and Engineering Research Center of Digital Medicine and Clinical Translation, Ministry of Education, Shanghai 200030, China. (phone: 86-21-23271133; fax: 86-21-63167020; e-mail: dongyungu@gmail.com).

13 middle-aged adults [7 female, 6 male; mean age= 52.1±2.3 SD (range 47-55)], with 13 older adults [9 female, 4 male; mean age= 74.8±3.3 SD (range 71-79)] and 13 young adults [5 female, 8 male; mean age= 23.3±1.6 SD (range 21-25)] were selected. All subjects were healthy, independent, community-dwelling individuals who were capable of ambulating independently without an assistive device.

### B. *Experimental design*

Subjects were instructed to walk at a comfortable pace across the walkway (8m in length) for 3 trails. They should initiate and terminate each trail a minimum of 1m fore and aft of the walkway to allow sufficient distance to accelerate to and decelerate from a steady walking state.

### *C. Data collection*

Vicon® T40 3D Motion Capture with 10 cameras were used to capture the body posture of the subjects at 100Hz. Two forceplates (AMTI® OR6-7) were placed front and back to register the ground reaction force at 1000Hz. (Subjects were asked to step on the forceplates one by one when they walk across the walkway.) The cameras and forceplates were time-synchronized.

39 reflective markers were placed on the subjects' bodies. Most of the markers were placed on the anatomical landmarks of the caregivers along with the rest to form the rigid bodies to track: head, left and right upper arms, left and right forearms, left and right hands, upper trunk, pelvis, left and right thighs, left and right shanks, left and right feet. Thus A 3D full body model with 15 segments was constructed.

### *D. Data analysis*

Mean temporal-spatial gait parameters, including gait velocity, stride length and step length of each subject across 3 trials were calculated. The stride-to-stride standard deviations (SD) in the above parameters were also analyzed as the gait variability. These parameters were all normalized by subjects' leg length. (Unit of normalized gait velocity and its variability are '1/s'; normalized stride and step length along with their variability have no units.)

Acceleration root mean squares (RMS) of COM as a gait stability parameter were estimated from the subject's COM position in anterior-posterior (AP) and medial-lateral (ML) direction. The COM position was calculated as the weighted sum of all body segments [18]. The stride-to-stride standard deviations (SD) in acceleration RMS of COM were also analyzed as the gait variability. These parameters were all normalized by subjects' gait velocity to avoid the confounding effect of velocity on velocity dependent gait parameters [12]. (Unit of normalized acceleration RMS and its variability are '1/s'.)

Peak sagittal and frontal COM-COP inclination angles were calculated as another parameter of gait stability. Instantaneous COM-COP inclination angles are defined by the line connecting COM and COP referenced to the vertical axis passing through the COP in the sagittal and frontal planes, respectively (Fig.1). The resultant COP position was calculated for both feet using the COP and vertical ground reaction force from each foot [19].

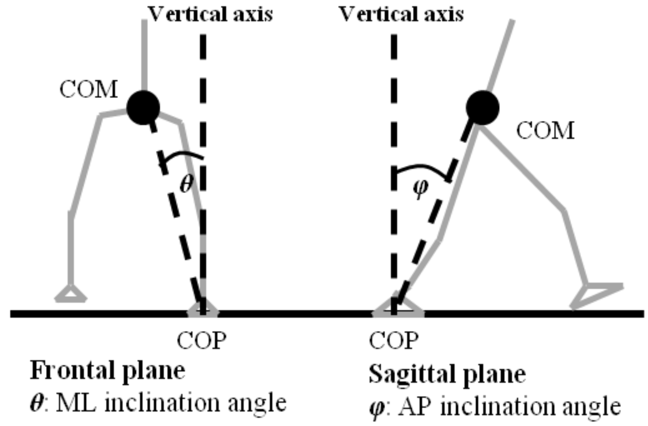


Figure 1. Illustration of COM-COP inclination angles in sagittal and frontal planes

The effects of age on temporal-spatial gait parameters and gait stability parameters were examined by one-way ANOVA tests. Turkey HSD for multiple comparisons within age was employed to determine whether significant main effects ($P$<0.05) were observed.

## III. RESULTS

### A. *Mean gait velocity, stride length and step length & variability*

Mean values of gait velocity, stride length and step length normalized by subjects' leg length didn't significantly differ among all age groups. The stride-to-stride variability of these parameters also had no difference among age groups. (Table 1)

TABLE I. NORMALIZED TEMPORAL-SPATIAL GAIT PARAMETERS AND VARIABILITY OF ALL AGE GROUPS

| **Normalized value** [a] | ***Young adults (n=13)*** | ***Middle-aged adults (n=13)*** | ***Older adults (n=13)*** | ***P*** |
|---|---|---|---|---|
| Gait velocity (1/s) | 1.183±0.155 | 1.205±0.136 | 1.169±0.174 | 0.847 |
| Stride length (m) | 1.333±0.124 | 1.337±0.101 | 1.363±0.116 | 0.789 |
| Step length (m) | 0.669±0.065 | 0.673±0.052 | 0.684±0.053 | 0.805 |
| Gait velocity stride-to-stride SD (1/s) | 0.061±0.030 | 0.061±0.025 | 0.058±0.026 | 0.761 |
| Stride length stride-to-stride SD (m) | 0.055±0.021 | 0.053±0.023 | 0.051±0.020 | 0.781 |
| Step length stride-to-stride SD (m) | 0.030±0.013 | 0.028±0.017 | 0.025±0.015 | 0.815 |

a. Normalized values are group mean ± standard deviation (SD)

### B. *Acceleration root mean squares of COM & variability*

Compared with young adults (0.286 1/s), middle-aged (0.343 1/s) and older ones (0.375 1/s) showed higher acceleration RMS of body COM (normalized by gait velocity) in ML direction (*P*=0.038), while no difference was found between these two groups (*P*=0.336). (Fig.2)

In AP direction, middle-aged adults (0.562 1/s) and young (0.534 1/s) had a lower value of acceleration RMS than older ones (0.695; *P*=0.024).

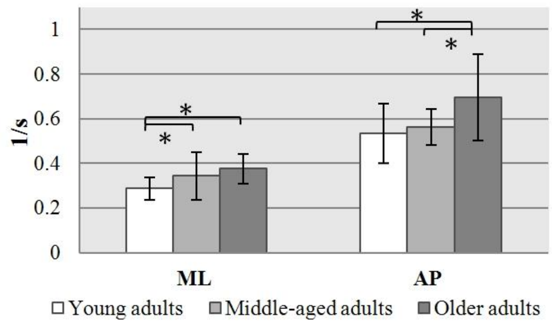


Figure 2. Normalized acceleration RMS of all age groups in ML and AP direction

Higher normalized variability of acceleration RMS was found in middle-aged (0.040 1/s) and older adults (0.050 1/s) than the young ones (0.023 1/s, *P*=0.030), while no difference was found between middle-aged and older adults (*P*=0.239). (Fig.3)

Significant difference of the variability in AP direction was not found among age groups (young: 0.053 1/s, middle-aged: 0.060 1/s, older: 0.061 1/s; *P*=0.317).

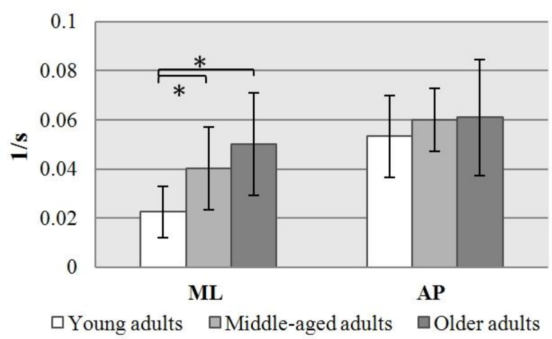


Figure 3. Normalized variability of acceleration RMS of all age groups in ML and AP direction

### C. *Peak instantaneous COM-COP inclination angles*

Middle-aged and older adults showed larger instantaneous COM-COP inclination angles (middle-aged: 3.804°, older: 4.310°) in ML direction than young adults (3.102°; *P*=0.003). (Fig.4)

Significant difference of COM-COP inclination angles in AP direction was not found among age groups (young: 12.652°, middle-aged: 12.317°, older: 13.105°; *P*=0.466).

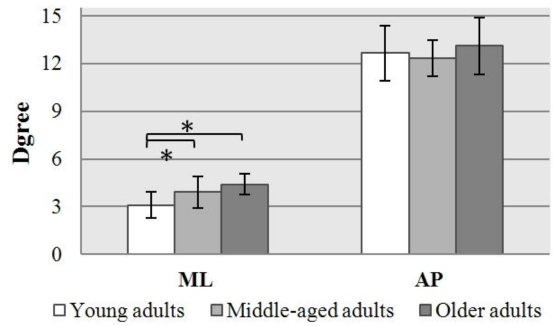


Figure 4. Instantaneous COM-COP inclination angles of all age groups in ML and AP direction

## IV. Discussion

We investigated the kinematic characteristics of gait among healthy middle-aged, older and young age groups during their level walking. Compared with young and older subjects, middle-aged adults showed no significant difference in temporal-spatial gait parameters. By measuring the gait stability parameters, middle-aged subjects showed a similar degenerated pattern of gait stability as the older ones in ML direction, which is scarcely reported in previous studies.

In this study, we found no significant age effect on the typical temporal-spatial parameters and their variability. This finding is somewhat unexpected, as compared with the younger ones, gait velocity, step and stride length were reported consistently to decrease in older adults [10, 11, 13]. Increased stride-to-stride variability of gait velocity and step length were also found in older adults to characterize their degenerated gait stability [11, 20]. However, results concluded from other studies support our findings that no age-related differences in gait velocity, step length and their coefficient of variation [11, 21, 22]. This might be explained by the vigorous activity level of our middle-aged and older subjects. They completed all trials successfully with the same time and no more rest than the younger subjects, indicating they may be more active than broader elderly population.

Acceleration of COM or trunk and its variability are thought as important and more direct parameters of gait stability [9, 10, 15, 23].This is proved by the results that our middle-aged subjects showed a similar condition of body acceleration as the older ones in ML direction, and significantly differed from the young subjects. Our result is also compatible with a notion that ML trunk acceleration and its variability may play an active role in balance control during elderly walking [12].

In current study, the acceleration RMS of COM was directly derived from COM displacement data, while usually trunk acceleration is registered by the accelerometer and its stride-to-stride variability is assessed by autocorrelation procedure [9, 10]. This reflects possible difference in the age effect on the body acceleration and its variability: Our older adults showed a greater variability in ML direction, while no different variability in AP direction during level walking. Moe-Nilssen et.al found that less able subjects performed reduced ML variability and increased AP variability [13]. It needs further investigations to decide the acceleration of

COM in which direction may be a more suitable indicators of the gait stability in middle-aged and old people.

Instantaneous COM-COP inclination angle provides information about the ability to control COM position in relation to the corresponding COP [4, 16]. The ML COM-COP inclination angle is suggested to be a sensitive parameter of gait stability in older people [4], which is compatible with our results that larger COM-COP inclination angles in ML direction were found in middle-aged and older adults. This may indicate that middle-aged people have similar difficulties as older people in controlling sideways COM motion and have a higher risk of sideways fall during gait.

There are two noteworthy limitations in this study. Firstly, a limited number of subjects were recruited, and only level walking task was evaluated. Thus, more trials are needed to achieve a more logical and statistically convincing result. Secondly, a shorter walkway was built considering the limited area of the lab. It may influence the adequate number of strides during a walking trial required to accurately measure gait variability. On the other hand, it is suggested that variability over a small number of strides is statistically similar to variations that occur over thousands of strides [20].

## V. Conclusion

Middle-aged subjects showed similar degenerated pattern in gait stability as the older ones in ML direction. Gait stability parameters, including ML acceleration of COM and its variability, as well as ML COM-COP inclination angle, rather than temporal-spatial gait parameters, may help to characterize this degenerated gait stability. It's necessary for us to develop early interventions for middle-aged adults to prevent falls during walking. Further investigations are needed to determine the relationship between the gait stability parameters and falls risk with aging.

## Acknowledgment

The author thank Fei Hu, Jin-ling Chen for the help in data collection and analysis in this study. The authors would also like to thank the subjects who participated in this study.

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