Walking analysis of young-elderly people by using an intelligent walker ANG

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Abstract

This paper proposed a new method to analyze the human walking by using a 3-wheels rollator walker instrumented with encoders and a 3D accelerometer/gyrometer. In order to develop the walking quality index and monitor the health state of elderly people at home, the walking of 23 young adults and 25 elderly people ($>$ 69 years) with the help of the walker, are compared. Besides of the comparison on walking ability which is described by gait parameters in the classical method, the walker can also offer the comparisons on the walking accuracy and stability. The results show that many general walking indicators such as walking speed, stride length have no obvious difference between two groups, but some indicators developed by using the walker are very discriminating, e.g., the lateral motion of elderly people is bigger, their walking accuracy is less, but their effort distributed on the handles are more symmetry.

Keywords: Intelligent walker; Walking analysis; Walking quality index; Elderly

1. Introduction

The elderly population is growing fast all over the world. Population ageing will cause significant challenges of care giving. One of the problems that affect the most of the elderly population is the reduction of mobility. Therefore, many personal assistance mobility devices are strongly desired to keep the elderly independent. Among the presented assistance devices, the walkers have large number of users because of its simplicity and rehabilitation potential. These devices use the person's remaining locomotion capability in order to move, which can avoid the early use of wheelchairs. Besides of the physical benefits of maintaining the standing position, there are also other important psychological benefits, such as increased self-esteem and relationship issues.

There are many studies and projects regarding advanced versions of walkers. According to the user's needs, the functions of existed walkers are not restricted to their primary task, i.e. physical support and mobility assistance. There are other functions such as sensorial assistance, cognitive assistance and health monitoring [1]. For example, the passive walker of MARC at Virginia University [2],the active GUIDO [3], HLRP [4], NURSEBOT [5], the sit to stand devices MONIMAD of LRP [6], IWalker [7], RT-Walker [8], the sophisticated CARE-o-BOT [9] and the omnidirectional walker of Chuy [10]. These walkers focus on mobility assistance, sit-to- stand transfer [11], [12], help for navigating [13], [7], obstacle avoidance and fall detection [8]. Besides of these, there are other multifunctional walkers such as PAMM SmartWalker [14], which was designed to offer extra support for walking, guidance, scheduling (reminding the time of medicines, for an example) and health monitoring for elderly users. The Medical Automation Research Center (MARC) smart walker [15], which was installed a pair of tridimensional force/torque sensors on it's handles, can be used to determine gait characteristics such as the heel strike, toe-off, double support, and single support[16], [17].

To study the extension of the functions of walkers we have developed our own family of walking aids, the ANG family [18]. We will focus on the simplest version, ANG-light (Fig. 1) which is based on a commercially available 3-wheels Rollator walker, the two fixed rear wheels having been instrumented with encoders while a 3D accelerometer/ gyrometer has been added at the front. A small, low energy consumption fit-pc computer manages the measurements and records all the data. Compared with the walkers proposed above, our walker is low cost, simple to be used at home and possible to be extended with multifunctions. This paper will present how it can be used for medical monitoring of walking patterns and what kind of medical information may be obtained.

Many studies have examined the effect of age on the walking by comparing the younger with older adults [19], [20], [21], [22], [23], [24], [25], [26]. Some studies calculated the gait parameters, such as step length, gait cycle, step width, cadence and gait speed [27], [28], [29], [26]. Especially gait speed or walking velocity is regarded as a very important indicator of health. Most of results showed that compared to the younger group that older subjects exhibited significantly reduced gait speed. Few studies also found significant interactions between sex and gait speed [27]. Other studies presented there were little or no differences in the gait speed between the healthy younger and elderly people [24]. In fact, [29] has showed that the measured gait speed is based on age, sex, use of mobility aids, chronic conditions, smoking history, blood pressure, body mass index, and hospitalization. Therefore, the traditional measurement of gait parameters is not sufficient to monitor the user's health, and then some studies have been considering the gait variability [22], [30], [23], [31]. The variability of gait parameters can be characterized by the coefficient of variance (CV) of kinematic gait parameters [32], [19]. It is an index of gait stability and complexity. The increased variability of gait parameters corresponds to decreased gait stability, complexity and increased risk of falling. However, gait instability is multifactorial and the results of previous studies are often inconsistent with each other according to the conditions of experiment. Therefore, we need to do more tests and find more indicators of walking. As written in [33], at least the components of a person's gait as follows should be examined in the walking examination, they are respectively initiation of gait, step length, height, and symmetry, step continuity, step path, trunk motion, walking stance, turning, and heel-to-toe walking. Presently, although some studies began to analyze other gait characteristics such as medial-lateral displacement, center of mass [34] and foot placement [25], [35], they are still not sufficient to describe the walking motion comprehensively.

This paper will propose a new method of walking analysis by using an instrumented smart walker. A 10 meters straight line walking test has been done for two groups of younger and elderly people. The preliminary analysis of the results has been presented in [36]. Compared with the studies proposed above, it has some advantages as follows. Firstly, thanks to encoders and a 3D accelerometer/gyrometer, we can not only calculate the gait parameters such as gait cadence, walking speed and stride cycle, stride length and their variability, but also can obtain the trajectory of the walker. Due to this, the walking accuracy of two groups of people can be compared. In addition, we can use the direction of angular acceleration to estimate the proportion of left/right support and forward/rearward support during the whole walking. Overall, using our walker the gait characteristics can be described more comprehensively. Secondly, a drawback of the most studies is that these measures are presently best obtained with specialized laboratory equipment such as motion capture systems and instrumented walkways, which may not be available in many clinics and certainly not during daily activities. In contrast, the walker can be easily used at home and outdoors, so it is possible to develop it for individual medical monitoring of walking patterns.

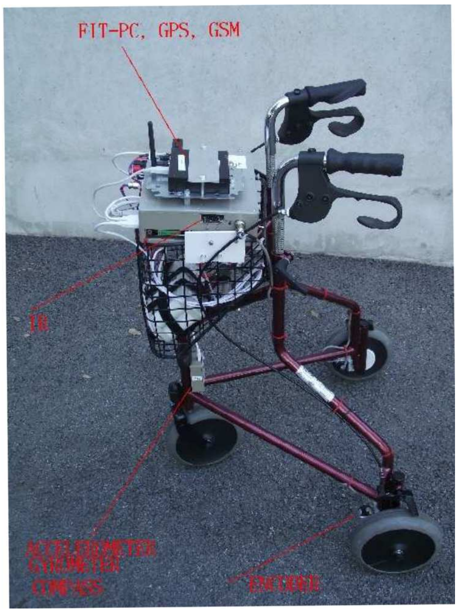

Figure 1: The walking aid ANG-light

This paper is organized as follows. Section 2 is a description of the experiments. The calculation of trajectory and the detection of stride are presented in Section 3. Next, Section 4 gives the results of the experiment. The walking accuracy, ability and stability of the younger and elderly people are compared respectively in three subsections. Finally, concluding remarks are made in Section 5.

2. Description of experiments

Physical functioning tests have showed significant aged-related differences for older adults [37]. Several classical tests used to assess the mobility of elderly people are $10m$ walk test (`10mWT`) [38], Timed Up and Go test (`TUG`) [39], Tinetti Test (`TT`) [40]. Such tests are easy to implement but are basically global (the time for the `10mWT` and the `TUG` may be identical for two subjects which have however very different walking patterns) or is subjective (for the `TT`). Furthermore these tests are performed only during medical visits and consequently are not appropriate to detect rare events in the walking patterns that may indicate the beginning of an emerging pathology. Hence we have decided to examine if the measurements of our walking aid allow one to refine the output of the above walking tests.

For that purpose we have led a large scale experiment that was approved by the regional ethical committee (Comit Protection des Personnes). In this paper only the results of a `10mWT` will be studied. Exactly, each subject was asked to walk along a $10m$ straight line trajectory with the help of the walker. The experiment takes place at INRIA and at Nice hospital. The subjects were 23 INRIA members (with age between 25 and 65 years, mean value 32) and 25 elderly people (age over 65 years) recruited by Nice hospital (see Fig. 2). No subject has pathological walking deceases. All the subjects were asked to perform twice the trajectory with the walking aid, the order of the twice results were selected randomly.

Figure 2: The walking aid ANG-light at Nice Hospital

3. Methods

As shown in Fig. 1, the two fixed rear wheels of the walker are instrumented with encoders and a 3D accelerometer/gyrometer is added at the front. In addition, a small fit-pc computer is installed to manage the measurements and record all the data. This section will explain how the walker can obtain the walking trajectory and determine the stride. During all the measurements, the calculation of walking trajectory and the detection of stride are the two most important issues. Because all the measurement of indicators about the walking accuracy depend on the calculation of the trajectory and all the measurement of the gait parameters and their variability are based on the detection of stride.

3.1. Calculation of the trajectory

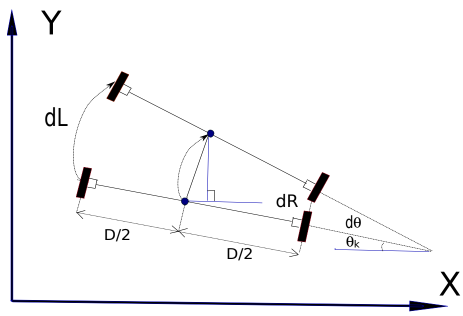

Figure 3: Simple kinematic model of the walker

During the experiment, the position of the walker is supposed as the position of the middle point of the two rear wheels. As shown in Fig. 3, in the coordinate system of the horizontal plane, it is described by $[x, y, \theta]$, where θ describes the walking direction of the rollator and it is the angle between the horizontal axis of two rear wheels and X axis. In our experiment of `10mWT`, we supposed $\theta = 0$ if the subject walks along a straight line. The trajectory of the walker is determined by using the encoders. Supposing at the $(k+1)_{th}$ sample moment the measurement of the encoders of two rear wheels are Δ_L and Δ_R, the displacement of the left and right wheel are obtained respectively by using (1) and (2):

$$dL = \frac{2\pi r}{4C \cdot 360}\Delta_L \tag{1}$$

and

$$dR = \frac{2\pi r}{4C \cdot 360}\Delta_R \tag{2}$$

where r is the radius of the rear wheel and C is a constant parameter of the transformation between the value of encoder and the radium. Next, the change of the direction angle θ during the $(k+1)_{th}$ sample time can be given as:

$$d\theta = \frac{dL - dR}{D}, \tag{3}$$

where D is the distance of two rear wheels.

According to the kinematic model shown in Fig. 3, the increased value of the walker's position can be obtained as follows:

$$dx = \frac{dL + dR}{2} sin(\theta_k + \frac{d\theta}{2}) \tag{4}$$

$$dy = \frac{dL + dR}{2} cos(\theta_k + \frac{d\theta}{2}) \tag{5}$$

Finally, the new position of the walker can be easily calculated by using:

$$\begin{cases} x_{k+1} = x_k + dx \\ y_{k+1} = y_k + dy \\ \theta_{k+1} = \theta_k + d\theta \end{cases} \tag{6}$$

Using the above equations, the trajectory of the walker can be determined accurately by using the encoders. The experiments have shown that after a roughly straight line walking of 10 meters the estimated positioning has an accuracy better than $1cm$.

3.2. Detection of the stride

The instruments generally used to evaluate human's gait are pedometers, accelerometers or gyrometers. To be appropriate for long-term measurements in everyday environments, these devices should be practical and not interfere with normal movement behaviour. Pedometers are small, easy to use and count the number of steps. The Yamax Digi-Walker SW-200 is considered the most accurate electronic pedometer, but its precision decreases at slower walking speeds, making it less suitable for seniors with low physical fitness or gait abnormalities [41]. Compared to pedometers, accelerometers have a higher accuracy and are utilized to detect the walking stride in many studies [42], [43]. Most of methods use the peak value of forward acceleration to detect the walking cycle. However, some steps often does not lead to a high-peak forward acceleration, then they are not counted although there is displacement during these periods. Therefore, a recent study [35] used thresholds on the magnitude of the gyroscope and accelerometer signals to identify the zero velocity instant and regarded it as the end of a step.

Our walker ANG also uses the gyrometer data to detect the walking stride. An interesting contribution of ANG is that it allows one to differentiate the right and left steps. Indeed when the subject is on the left (right) support phase the walking aid rotates on the left (right). Hence the rotational velocity of the walker around the vertical axis which can be easily obtained by the gyrometer is used detect the walking stride. Its zero value instant is regarded as the end of a step. An example of an elderly people is shown in Fig. 4.

Since the position of the walker at every moment has been calculated by using the method presented in Subsection 3.1, the displacement of the walker during every step, which is regarded as the step length of the subject, can be easily calculated as soon as all the steps are detected, as shown in Fig. 5.

Accordingly, the mean gait speed of every step can be obtained. Moreover, other spatial-temporal gait parameters can be analyzed. In view of the on-board computer enables to store the sensors data with a sampling time of $1ms$ for the encoders and $4.8ms$ for the gyrometer, the accuracy of the above calculations is guaranteed.

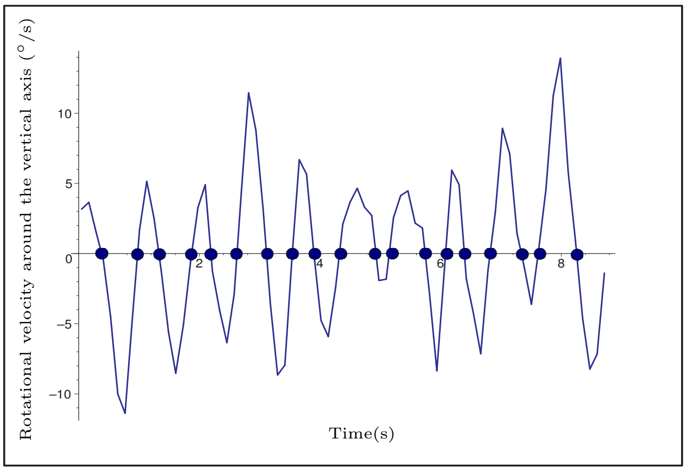

Figure 4: The rotational velocity of the walker around the vertical axis. One step is finished when it passes zero.

4. Results

The ideal walking motion for the test has several characteristics: the trajectory is almost a straight line as the reference trajectory, the walking speed, step length and other gait parameters are normal, and the walking motion is symmetric and stable. Therefore, in order to analyze the result comprehensively, the walking accuracy, ability and stability of the younger and elderly people are compared respectively in the follow three subsections.

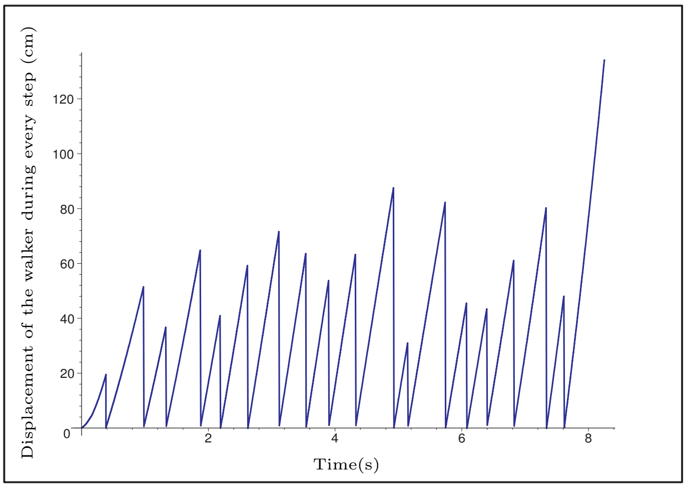

Figure 5: Displacement of the walker during every step. The results of left steps and right steps were put together and they appeared alternately.

4.1. Comparison of the walking accuracy

Using the calculation method proposed in Subsection 3.1, the trajectory of all the subjects for the `10mWT` are given in Fig. 6. Here and in the following figures the younger adults' trajectories are presented in red while the trajectories of the elderly are presented in blue. The reference trajectory is the horizontal axis and the vertical scale is amplified to illustrate the lateral deviations between the real and reference trajectories. Fig. 6 clearly shows that the elderly subjects have lager deviations than the younger.

Several indicators about the walking accuracy are calculated and compared, such as the maximum and mean value of the lateral deviations between the real and reference trajectory, the domain of the later deviation, the area between the real and reference trajectory, and the relative Standard Deviation (SD) values. Detailed results are given in Table A.1 at Appendix. Fig. 7 and Fig. 8 show the maximum lateral deviation and the area between the real and reference trajectory respectively, where the results of every group of subjects are sorted into ascending order. Two figures illustrate that the results of the elderly subjects are larger than that of the young subjects. In addition, in view to the blue curves change more precipitously than the red curves, we can say the differences among the elderly individuals are larger. This can also be validated by the SD values of the results.

In addition, several other indicators shown in Table A.1 at Appendix are also can be used to measure the walking accuracy of the subjects, because we found their values of the elderly people are obviously larger then that of the younger people. In a word, the lateral motion of the elderly is larger than the younger, and the indicators can be used are:

- the relative values of the lateral deviations between the real and reference trajectory,
- the area between the real and reference trajectory,
- the Manhattan distance between the real and reference trajectory,
- the relative values of the orientation angle of the walking aid.

4.2. Comparison of the walking ability

By using the walker, many gait parameters presented in the classical method can be calculated or estimated, such as gait cycle, gait or walking speed, step length, cadence and forward acceleration. Detailed results are given in Table A.2 at Appendix. Although the step width cannot be calculated precisely, but the analysis of the walker' lateral motion in the previous

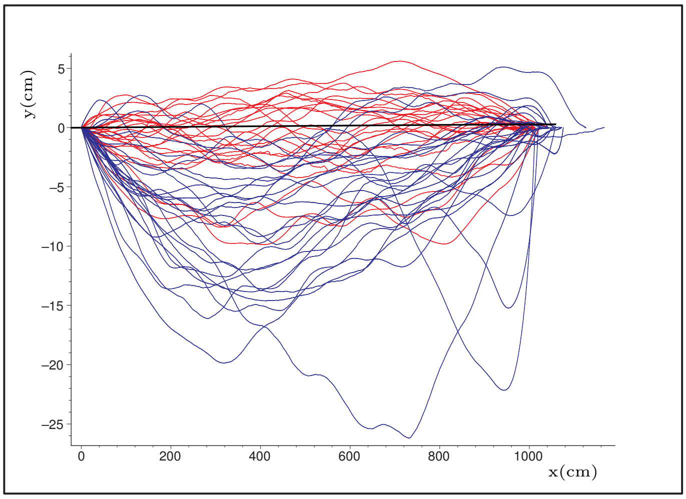

Figure 6: Trajectory of the subjects, where the color blue denotes the elderly subjects and the red denotes the young subjects.

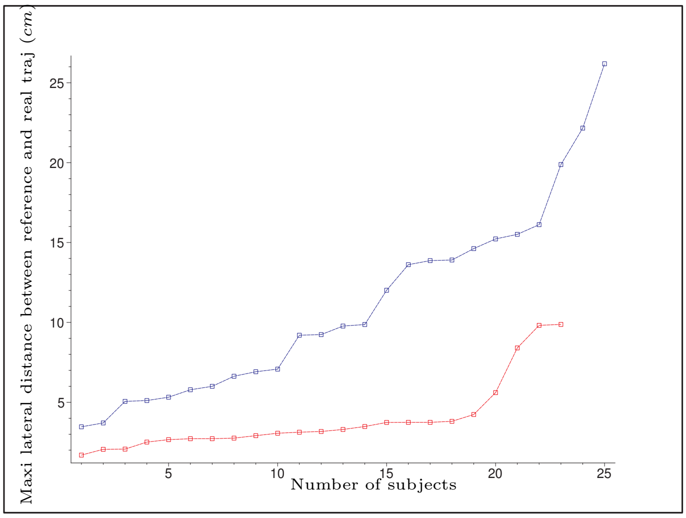

Figure 7: The maximum lateral deviation between the real and reference trajectory, where the color blue denotes the elderly subjects and the red denotes the young subjects. The results of every group of subjects are sorted into ascending order.

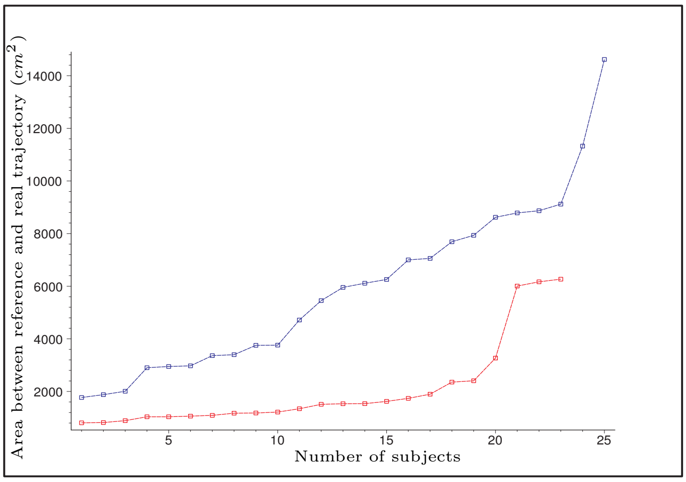

Figure 8: The area between the real and reference trajectory, where the color blue denotes the elderly subjects and the red denotes the young subjects. The results of every group of subjects are sorted into ascending order.

subsection can reflect the characteristic of the subjects' step width. In addition, since the trajectory of the walker are calculated, the instantaneous walking velocity can be estimated. Assuming the walking motion is continuous, we can obtain the function of the displacement with time at first and then compute its derivation to obtain the instantaneous walking velocity. All the calculations are done by using MAPLE, in which the relative tools can be applied directly.

The instantaneous walking velocity is given in Fig. 9. It shows that there is no obvious difference between the elderly and young subjects. Fig. 10 gives their maximum values and it illustrates that the result of the elderly subjects is a little larger than that of the younger, and 50% of the subjects have the maximum velocity between 110 cm/s and 140 cm/s. Moreover, by using the displacement and the cycle of every step, the mean value of the gait speed can be obtained and the result is shown in Fig. 11. Our previous work [36] has shown that there is no difference between the left steps and the right steps so here and in the following contents the results of two steps are put together. Fig. 11 also illustrates that two groups' walking speed are very close and about 77% of the subjects' (38 of 48) gait speed are between 90 cm/s and 130 cm/s.

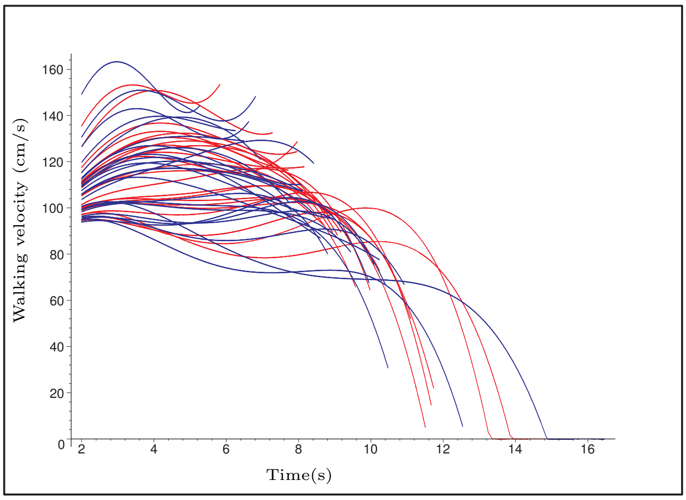

Figure 9: Instantaneous walking velocity, where the color blue denotes the elderly subjects and the red denotes the young subjects. In order to estimate it more precisely, only the middle part of the trajectory is used to do the derivation.

It has been presented that a comfortable walking speed for young adult lies in the range 130 cm/s–160 cm/s while for elderly people this speed is given by the formula $117 - 0.4 \times age$. Obviously, the mean speed value for elderly people is coherent with the formula while the result of the younger adults is lower than the normal walking speed. Experiences without the walking aid have shown that the younger subjects were presenting a mean velocity that was close to the normal walking speed. Our interpretation is

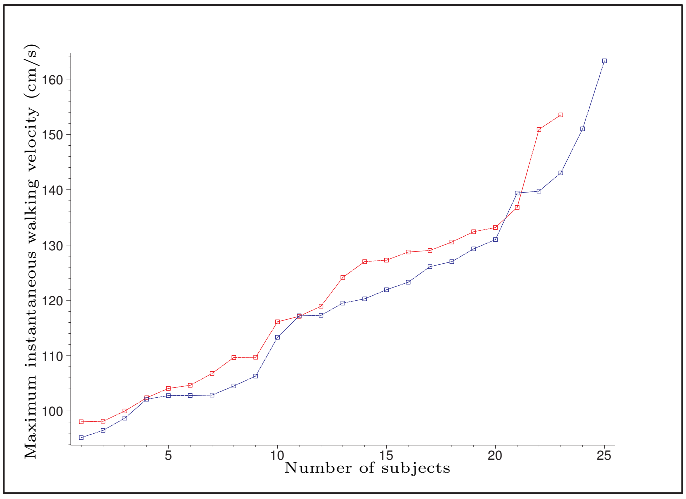

Figure 10: Maximum instantaneous walking velocity, where the color blue denotes the elderly subjects and the red denotes the young subjects. The results of every group of subjects are sorted into ascending order.

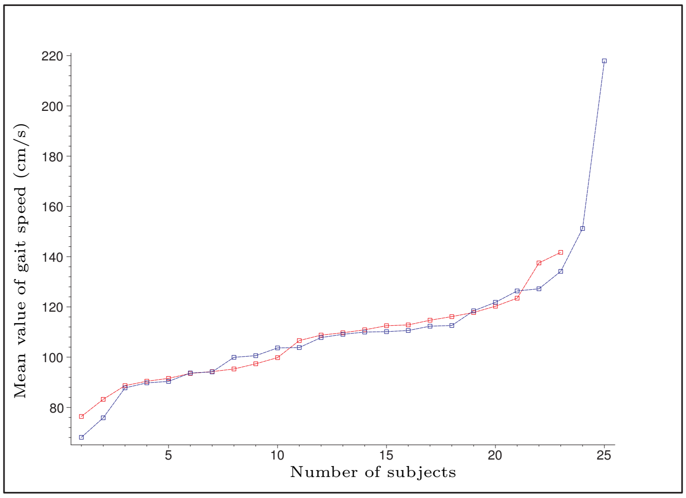

Figure 11: Mean value of the gait speed, where the color blue denotes the elderly subjects and the red denotes the young subjects. The results of every group of subjects are sorted into ascending order.

that elderly people are more familiar with walking aids and have walking patterns that benefit from such an aid while younger people have a more dynamic pattern that is jeopardized by the aid. This can explain why the maximum velocities of the younger are higher, as shown in Fig. 10.

Since the mean walking speed depends on the step period and step length, the mean values of them are also given. As shown in Fig. 12 and Fig. 13, the results illustrate that there is almost no difference between two groups and that is why the two groups have the similar walking speed. Exactly, about 78% of the subjects (37 of 48) have the step period between 0.4 s and 0.6s, and 75% of the subjects (36 of 48) have the step length between 40 cm and 60 cm,

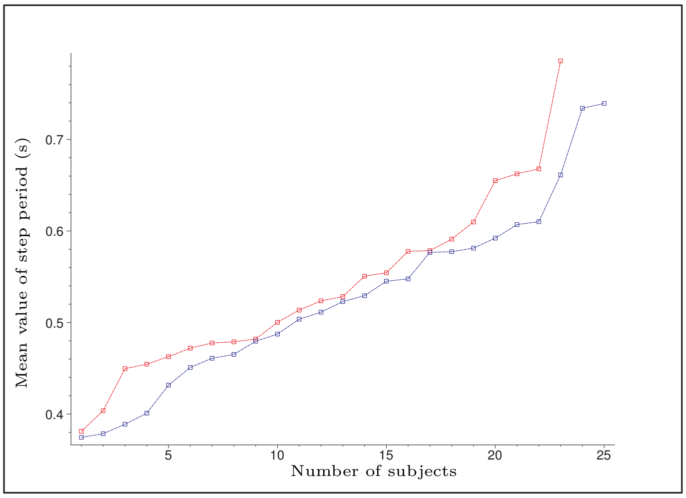

Figure 12: Mean value of step period, where the color blue denotes the elderly subjects and the red denotes the young subjects. The results of every group of subjects are sorted into ascending order.

Next let's look at the mean value of forward acceleration shown in Fig. 14. It illustrates that the forward accelerations of the elderly are larger than that

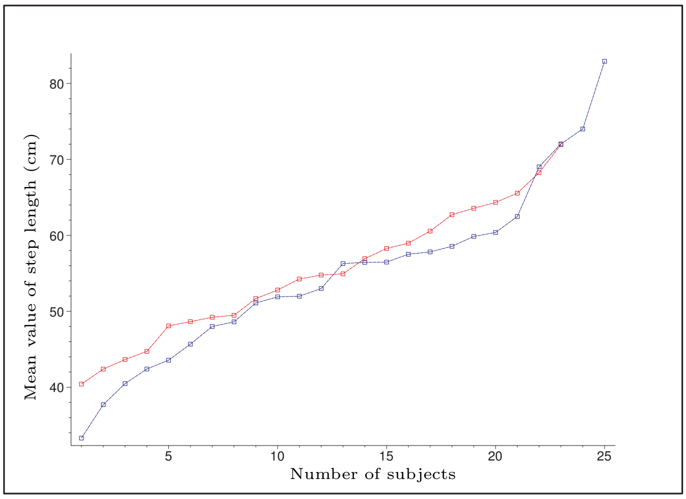

Figure 13: Mean value of step period, where the color blue denotes the elderly subjects and the red denotes the young subjects. The results of every group of subjects are sorted into ascending order.

of the younger. In addition, almost 70% of the younger (16 of 23) 's mean forward accelerations are less than zero while for the elderly this number is only 40% (10 of 25). Therefore, we can deduce that the minimum velocity of the younger is less than that of the elderly although their mean speed is almost the same. As a result, the elderly subjects can use less time to arrive the terminal, as shown in Fig. 15.

In summary, with the help of the walking aid, the elderly people can have the similar walking speed, step length, step period as the younger people. In the obtained gait parameters that can describe the walking ability, there are three indicators in which the difference exists:

- maximum instantaneous walking velocity,
- mean value of the forward acceleration,

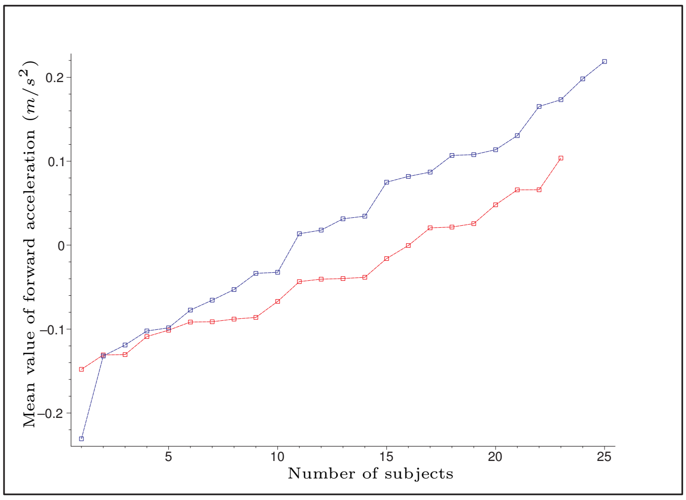

Figure 14: Mean value of forward acceleration, where the color blue denotes the elderly subjects and the red denotes the young subjects. The results of every group of subjects are sorted into ascending order.

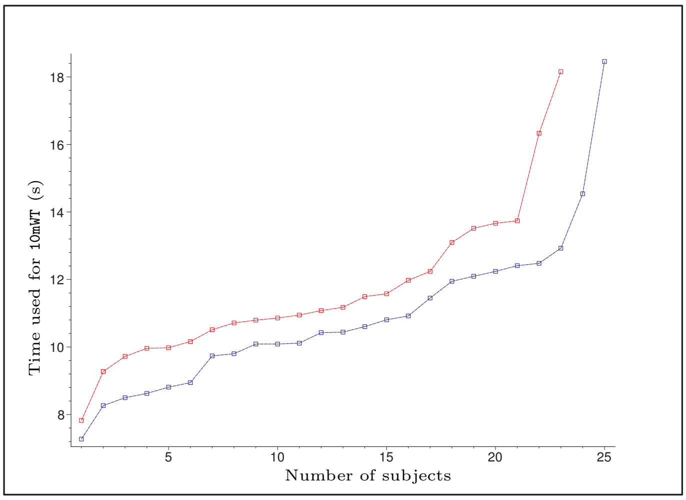

Figure 15: Time used for `10mWT`, where the color blue denotes the elderly subjects and the red denotes the young subjects. The results of every group of subjects are sorted into ascending order.

- time used for the total test.

4.3. Comparison of the walking stability

Gait variability is an index of gait stability and complexity. The increased variability of gait parameters corresponds to decreased gait stability, complexity and increased risk of falling. Gait variability is defined as changes in gait parameters from one stride to the next. It can be characterized by the coefficient of variance (CV) of kinematic gait parameters [32], [19]. The coefficient of variation (CV) is defined as the ratio of the standard deviation (SD) to the mean, i.e., for a set of gait parameter A, it's CV is:

$$CV(A) = \frac{SD(A)}{mean(A)}. \tag{7}$$

Since CV shows the extent of variability in relation to mean of the population. Generally, if the difference among the subjects is not very large, its value should less than 1 (100%). Here the CV of step length, step period and walking speed are compared between two groups. The results are given in Fig. 16– Fig. 18 and detailed information are given in Table A.2 at Appendix. Fig. 16 shows that the individual difference of the younger people is not very large. About 87% of the younger people(20 of 23) has the CV of step length between 0.4 and 0.6. On the contrary, the values of elderly people have a wider distribution and only about 52% (13 of 25) of results is between 0.4 and 0.6. The comparison of the CV of step period illustrates the same characteristic. As shown in Fig. 17, 91% of the younger people(21 of 23) has the CV of step period between 0.3 and 0.6 while only 56% of the elderly people(14 of 25) is in this domain. Next let's look at the CV of walking speed shown in Fig. 18. To our surprise, for 95% of younger subjects (22 of 23) and 84% of elderly subjects (21 of 25) the CV of walking speed are less than 0.3. In addition, The results of the younger people are a little larger than that of the elderly except some separate subjects. This is consistent with the result shown in Fig. 10, which illustrates the maximum instantaneous walking velocity of the younger people are a little larger than that of the elderly people.

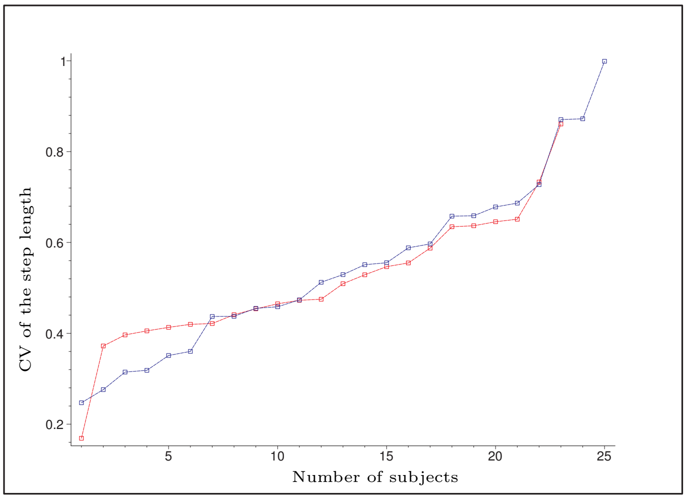

Figure 16: Coefficient of variance for the step length, where the color blue denotes the elderly subjects and the red denotes the young subjects. The results of every group of subjects are sorted into ascending order.

By using our instrumented walker, other information about the pressure on the handles can e used to analyze the walking stability. In the coordinate system fixed at the walker, supposing the forward direction in the horizontal plane is denoted by X and the lateral direction is denoted by Y. When leaning forward to push the walker will induce a clock-wise rotation around Y axis and when leaning on the right (left) handle a rotation around X axis should be observed. Accordingly we have considered the angular velocity

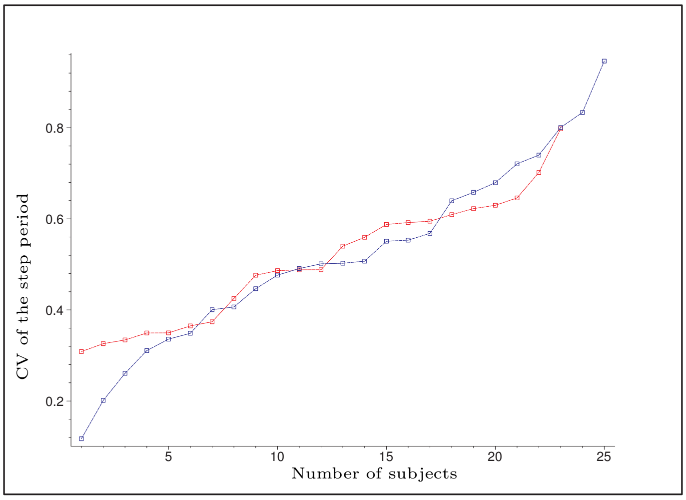

Figure 17: Coefficient of variance for the step period, where the color blue denotes the elderly subjects and the red denotes the young subjects. The results of every group of subjects are sorted into ascending order.

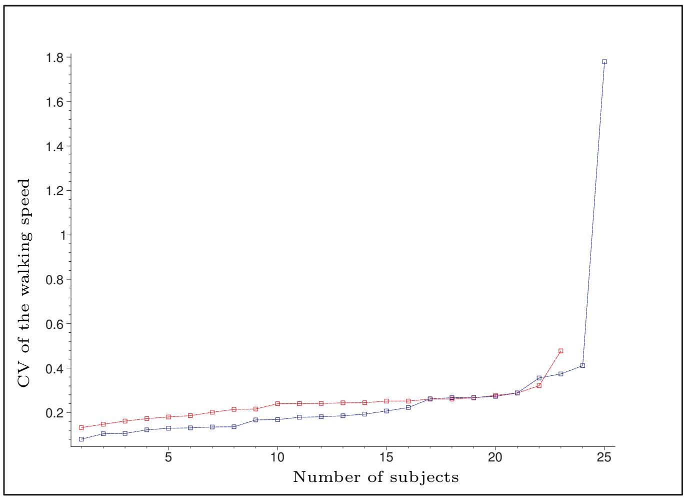

Figure 18: Coefficient of variance for the walking speed, where the color blue denotes the elderly subjects and the red denotes the young subjects. The results of every group of subjects are sorted into ascending order.

measurements around X and Y as provided by the gyrometer. We were wondering if these measurements were sensitive enough to estimate changes in the forward/backward support force (change on the angular velocity around Y) and on the left/right support force (change on the angular velocity around X).

It appears that indeed the measurements data has allowed us to determine the respective percentage of forward/backward and left/right support with a reasonable accuracy without any force sensors in the handles [44]. Fig. 19 and Fig. 20 show the percentage of forward support and right support respectively. It is interesting that in both two figures the results of the younger people are much farther away from 50% than that of the elderly people. That means for younger people the difference between forward and backward support, left and right support are larger. It appears that the younger adults are leaning significantly more on the aid than the elderly people.

Based on the analysis above, the following three indicators are more interesting to be researched in the future, they are:

- variability of walking speed,
- percentage of forward/backward support,
- percentage of right/left support.

5. Conclusions

We This paper proposed a gait analysis method by using an instrumented walker. In the help of walker, the results of a 10 m straight line test for 23

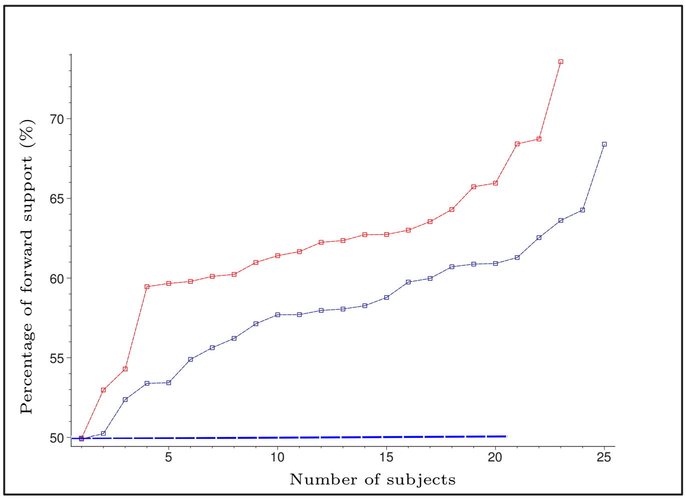

Figure 19: Percentage of the forward support, where the color blue denotes the elderly subjects and the red denotes the young subjects. The results of every group of subjects are sorted into ascending order.

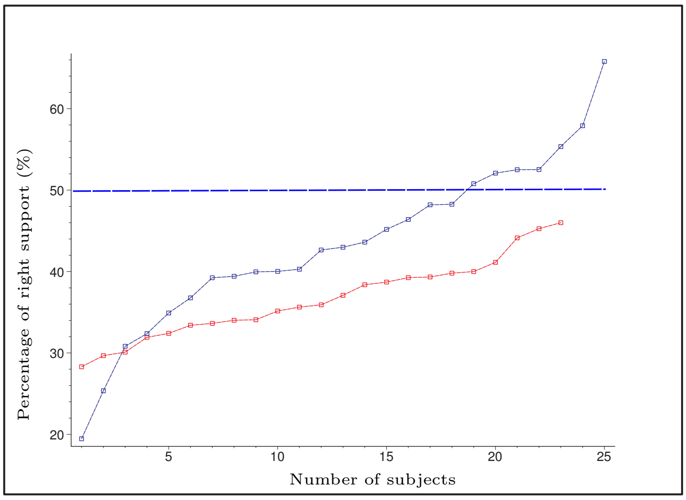

Figure 20: Percentage of the right support,, where the color blue denotes the elderly subjects and the red denotes the young subjects. The results of every group of subjects are sorted into ascending order.

younger people and 25 elderly people are compared comprehensively. The comparison includes the relative information about the walking accuracy, ability and stability. Several important indicators in which there are obvious difference between two groups are obtained. For example, the maximum lateral deviations between the real and reference trajectory, the area and the Manhattan distance between the real and reference trajectory. The results of them for the elderly people are much larger than that of the young people, that means the elderly people has a lower walking accuracy.

However, for the gait parameters describing the walking ability, it is found that there is no obvious difference in step length, step period, walking speed between two groups. Since the trajectory of the walker can be obtained, the instantaneous walking velocity are obtained and we found that the maximum instantaneous walking velocity of the younger people is a little larger than that of the elderly people. In addition, when we tried to use the variability of gait parameters to analyze the walking stability, there are the same results for the variability of step length and step period while for the younger subjects the variability of the walking speed is larger. Moreover, we also found that the younger adults are leaning significantly more on the aid than the elderly people. Is that means the influence of the walker on the younger people is larger? In order to answer this question, in the nest step we will analyze the gait of the younger people with and without walking aid. Besides of this, another walking test with a returning trajectory for two groups people will be studied. We also want to examine if a learning process may be implemented in order to characterize the walking pattern at a given time and customize the walking analysis software in order to better determine future trends.

Appendix A. Original results

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Results of the elderly (1--25) and young subjects (26--48)

Subject	Total time used(s)	Time used for 10m	Traveled euclidean distance(cm)	Traveled manhattan distance(cm)	Error domaine(cm)	Maximum absolute error(cm)	Mean error (cm)	Standard deviation of error (cm)	Average absolute deviation (cm)	Area between real traj and reference traj(cm^2)	Mean orientation (degree)	Standard deviation of rientation (degree)	Average absolute deviation of orientation (degre)
1	10.113	9.718	1040.686	1069.070	13.863	12.016	-7.620	3.222	2.650	7057.905	-0.274	1.837	1.562
2	10.423	8.934	1166.656	1179.347	5.055	5.055	-2.877	1.483	1.325	3398.169	-0.176	1.024	0.815
3	8.496	8.308	1022.638	1034.198	4.699	3.464	-1.749	1.020	0.908	1768.897	-0.015	0.924	0.743
4	14.537	14.760	984.854	1001.812	7.839	6.907	-2.555	2.292	1.968	2900.350	0.080	1.240	0.989
5	10.088	9.563	1054.914	1082.618	13.866	13.866	-6.384	4.647	4.033	7000.278	-0.154	1.940	1.670
6	11.946	11.898	1004.027	1031.728	13.903	13.903	-8.286	4.213	3.613	8786.815	-0.235	1.973	1.690
7	8.624	8.156	1057.320	1085.517	9.772	9.772	-5.710	2.186	1.767	6258.550	-0.604	1.702	1.351
8	10.601	10.236	1035.678	1068.704	15.968	15.510	-7.343	5.280	4.688	8619.661	0.045	2.287	1.903
9	8.945	8.787	1018.028	1066.260	23.568	22.163	-4.163	6.331	4.844	5955.932	-1.202	2.194	1.831
10	12.239	11.383	1075.235	1092.079	5.783	5.783	-2.944	1.632	1.452	3362.376	-0.252	1.337	1.003
11	9.800	9.314	1052.148	1068.561	6.686	3.702	0.004	2.030	1.788	1880.020	0.120	1.090	0.875
12	18.456	17.242	1070.415	1088.041	6.959	6.628	-3.456	2.606	2.446	4716.062	-0.274	1.373	1.130
13	12.479	12.591	991.120	1031.188	19.880	19.880	-10.213	6.084	5.172	11326.516	-0.079	3.152	2.520
14	12.408	11.700	1060.484	1077.227	7.498	7.072	-3.600	2.477	2.179	3752.420	-0.142	1.379	1.122
15	10.440	10.209	1022.716	1066.890	15.224	15.224	-7.994	3.430	2.701	8868.822	-1.005	2.229	1.866
16	8.264	8.102	1019.958	1047.481	13.614	13.614	-7.761	4.260	3.813	7688.381	-0.506	2.656	2.119
17	12.095	11.587	1043.780	1068.686	11.825	9.238	-2.644	3.933	3.607	3761.081	-0.266	2.169	1.700
18	9.736	9.377	1038.248	1072.650	16.314	16.116	-7.630	5.086	4.674	7935.143	-0.203	2.672	2.186
19	12.927	12.325	1048.851	1067.417	8.315	6.000	-2.460	2.228	1.853	2972.125	0.038	1.558	1.131
20	10.087	9.843	1024.833	1076.353	26.192	26.192	-13.479	8.265	7.312	14619.055	0.079	3.628	3.076
21	7.273	6.997	1039.459	1063.419	8.052	5.319	-1.042	2.249	1.888	2006.372	0.138	1.684	1.389
22	8.810	7.827	1125.638	1147.934	9.124	5.108	0.649	2.930	2.707	2947.763	-0.111	1.688	1.304
23	11.448	11.565	989.839	1010.958	9.206	9.197	-5.439	2.309	1.823	5450.687	-0.126	1.539	1.314
24	10.920	10.189	1071.751	1093.331	9.893	9.863	-5.399	2.747	2.443	6111.605	0.086	1.583	1.306
25	10.806	10.492	1029.881	1058.610	14.617	14.617	-9.007	4.354	3.896	9120.989	-0.237	2.153	1.796
26	16.332	16.107	1013.973	1029.073	4.445	4.236	-2.104	1.503	1.413	2406.272	-0.106	1.188	0.955
27	10.793	10.735	1005.426	1019.371	4.469	2.715	0.955	1.337	1.174	1512.369	-0.008	1.051	0.848
28	13.666	13.636	1002.144	1013.737	2.549	2.056	0.559	0.793	0.692	809.319	-0.048	0.910	0.730
29	10.857	10.713	1013.364	1021.897	2.227	2.067	0.826	0.680	0.607	1036.115	-0.082	0.747	0.614
30	11.576	11.624	995.917	1011.723	3.744	3.734	-1.519	1.157	1.054	1896.943	-0.009	1.184	0.905
31	10.511	10.499	1001.144	1013.170	4.569	3.739	1.223	1.413	1.243	1737.640	-0.020	1.003	0.820
32	11.976	11.964	1001.035	1010.207	3.073	2.908	1.141	0.922	0.844	1344.696	0.002	0.738	0.614
33	13.737	13.190	1041.459	1055.006	5.603	5.603	2.913	1.497	1.253	3268.150	0.049	1.024	0.859
34	12.241	11.782	1038.936	1051.297	3.492	2.661	0.896	0.932	0.795	1180.521	0.019	1.016	0.816
35	9.977	9.861	1011.707	1035.818	8.397	8.397	-5.465	2.668	2.304	6003.658	-0.190	1.946	1.582
36	10.944	10.811	1012.325	1033.995	9.874	9.874	-5.492	2.848	2.389	6266.182	0.107	2.171	1.678
37	10.160	9.938	1022.427	1049.399	9.817	9.817	-5.563	2.678	2.180	6165.286	0.102	2.009	1.701
38	11.493	11.558	994.394	1007.535	4.321	3.806	-1.346	1.163	0.967	1538.759	-0.036	1.004	0.787
39	13.517	13.509	1000.582	1014.853	4.727	3.298	-0.956	1.447	1.215	1622.401	0.020	1.154	0.916
40	13.097	13.161	995.136	1007.984	4.731	3.123	0.153	1.276	1.024	1092.119	-0.092	1.000	0.824
41	11.176	11.145	1002.730	1010.248	2.271	1.693	0.726	0.623	0.540	820.150	0.074	0.745	0.599
42	11.079	11.087	999.285	1012.005	3.504	3.168	-1.183	0.974	0.846	1218.985	-0.144	1.116	0.910
43	9.960	9.896	1006.504	1022.513	4.570	2.717	0.252	1.291	1.094	1172.839	-0.132	1.255	1.037
44	9.720	9.738	998.128	1011.245	4.028	3.482	-1.282	1.159	0.973	1534.383	-0.170	1.089	0.887
45	10.711	10.702	1000.886	1012.559	3.662	3.058	-0.790	1.028	0.907	1036.045	-0.023	0.882	0.703
46	9.272	9.191	1008.871	1023.952	4.312	2.755	0.528	0.980	0.775	889.333	0.218	1.563	1.162
47	7.824	7.941	985.252	1003.301	4.927	2.509	-0.210	1.263	1.013	1061.180	-0.059	1.353	1.144
48	18.157	18.204	997.402	1008.961	3.856	3.742	2.071	1.227	1.077	2357.790	-0.126	1.021	0.816

Table A.1: Result of trajectory for the elderly $(1-25)$ and younger subjects $(26-48)$.

Results of the elderly (1-25) and young subjects (26-48)

Subject	Step number	Mean step length (cm)	Minimum step length (cm)	Maximum step length (cm)	Variation of step length	Mean walking cycle (s)	Minimun walking cycle(s)	Maximum walking cycle(s)	Variation of walking cycle	Mean walking speed(cm/s)	Variation of walking speed	Mean foward acceleration (m/s^2)	Standard deviation of foward acceleration (m/s^2)
1	12	82.921	52.920	202.720	0.551	0.734	0.482	1.692	0.501	112.608	0.129	-0.102	0.208
2	25	42.404	7.022	136.153	0.658	0.389	0.078	1.073	0.553	109.091	0.268	0.031	0.233
3	18	56.293	1.427	101.454	0.555	0.461	0.001	0.818	0.507	217.939	1.780	-0.053	0.385
4	23	45.676	6.320	69.053	0.319	0.610	0.081	1.045	0.349	75.833	0.106	0.219	0.144
5	17	72.040	1.126	235.058	0.872	0.661	0.012	1.974	0.800	107.812	0.135	0.107	0.213
6	20	51.100	20.202	99.100	0.459	0.577	0.200	0.960	0.406	89.776	0.193	0.075	0.120
7	14	74.004	17.926	130.485	0.360	0.581	0.328	1.233	0.400	127.207	0.207	-0.231	0.261
8	19	58.561	27.199	86.262	0.276	0.523	0.339	0.689	0.201	110.614	0.131	0.035	0.198
9	17	59.859	3.074	207.145	0.871	0.504	0.016	1.513	0.740	126.354	0.288	-0.034	0.259
10	21	47.998	2.916	152.318	0.728	0.480	0.028	1.577	0.721	100.605	0.168	0.014	0.189
11	20	51.994	1.416	100.955	0.473	0.465	0.005	0.866	0.447	121.855	0.411	-0.132	0.494
12	31	37.701	0.669	110.098	0.687	0.607	0.049	2.673	0.833	68.111	0.374	0.165	0.199
13	27	40.483	1.137	99.439	0.678	0.451	0.006	1.016	0.658	94.144	0.272	0.108	0.240
14	29	33.312	5.858	97.523	0.588	0.379	0.055	1.006	0.568	90.361	0.167	0.131	0.266
15	18	56.441	9.332	91.475	0.455	0.529	0.079	0.915	0.476	109.992	0.136	0.087	0.224
16	19	48.610	8.972	97.786	0.438	0.401	0.255	0.706	0.311	118.447	0.267	-0.119	0.459
17	20	52.996	1.223	106.687	0.529	0.592	0.006	1.748	0.679	99.928	0.262	0.173	0.173
18	17	62.476	6.570	89.165	0.351	0.545	0.107	0.789	0.336	112.329	0.179	-0.077	0.291
19	24	43.558	15.888	87.297	0.437	0.511	0.174	1.443	0.551	87.792	0.080	0.198	0.191
20	18	60.378	18.027	75.697	0.247	0.548	0.438	0.657	0.117	110.144	0.223	-0.099	0.240
21	17	57.511	6.455	85.754	0.512	0.375	0.041	0.625	0.502	151.234	0.104	0.018	0.198
22	20	57.823	19.110	89.430	0.315	0.432	0.220	0.606	0.261	134.145	0.186	-0.066	0.408
23	17	69.029	20.903	198.043	0.659	0.739	0.234	2.075	0.640	93.700	0.122	0.114	0.195
24	22	51.904	15.072	145.279	0.597	0.487	0.130	1.211	0.491	103.673	0.181	0.082	0.482
25	18	56.484	1.473	221.339	0.999	0.577	0.007	2.124	0.946	103.840	0.356	-0.032	0.197
26	17	63.562	4.135	128.368	0.454	0.786	0.315	2.275	0.630	83.235	0.288	0.022	0.099
27	23	42.397	2.444	128.813	0.861	0.404	0.017	1.104	0.798	108.786	0.277	-0.101	0.285
28	21	44.727	13.856	79.080	0.441	0.500	0.242	0.806	0.326	88.666	0.252	-0.086	0.193
29	24	48.638	6.452	99.169	0.465	0.450	0.045	0.852	0.488	116.145	0.240	0.104	0.317
30	19	65.546	17.305	169.675	0.646	0.668	0.211	1.453	0.592	99.821	0.261	0.026	0.293
31	19	60.559	18.135	110.274	0.421	0.528	0.137	0.947	0.425	117.764	0.173	-0.040	0.269
32	22	48.086	9.139	93.776	0.473	0.472	0.083	1.084	0.559	106.607	0.147	-0.000	0.159
33	21	54.244	7.390	85.969	0.420	0.578	0.073	0.853	0.365	93.539	0.214	-0.038	0.295
34	21	52.800	1.019	78.531	0.405	0.554	0.007	0.764	0.334	97.361	0.244	-0.016	0.244
35	16	71.941	32.556	184.565	0.509	0.655	0.280	1.779	0.540	112.527	0.186	-0.043	0.265
36	16	68.243	46.257	90.528	0.169	0.591	0.375	1.289	0.374	120.280	0.133	-0.092	0.201
37	19	62.723	3.583	109.991	0.413	0.551	0.026	0.935	0.350	114.700	0.201	-0.109	0.336
38	17	56.930	9.549	137.246	0.588	0.610	0.248	1.428	0.486	91.555	0.321	-0.088	0.314
39	20	58.976	13.937	106.636	0.475	0.662	0.173	1.430	0.476	90.444	0.244	0.021	0.271
40	25	40.416	1.155	79.878	0.637	0.482	0.004	1.038	0.588	94.237	0.478	0.048	0.207
41	21	49.478	5.605	126.980	0.733	0.514	0.083	1.248	0.646	95.306	0.266	-0.041	0.227
42	18	58.275	2.376	129.605	0.635	0.524	0.038	1.143	0.622	109.730	0.261	-0.131	0.331
43	19	54.777	7.646	111.694	0.555	0.463	0.056	1.253	0.609	123.488	0.252	-0.067	0.276
44	22	51.677	7.011	79.897	0.397	0.454	0.135	0.747	0.349	112.852	0.241	-0.091	0.363
45	20	54.936	2.875	79.032	0.372	0.478	0.105	0.662	0.309	110.902	0.240	-0.148	0.395
46	22	49.220	2.809	101.165	0.651	0.381	0.017	0.895	0.702	137.518	0.180	0.066	0.384
47	16	64.334	11.461	116.511	0.547	0.479	0.075	1.001	0.595	141.711	0.162	-0.130	0.359
48	27	43.658	9.531	89.937	0.529	0.578	0.141	1.135	0.488	76.389	0.216	0.066	0.208

Table A.2: Result of gait parameters for the elderly $(1-25)$ and younger subjects$(26-48)$.

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