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Trajectory of Walking Function in Late-Stage Older Individuals Managed with a Regular Exercise Program: A 5-Year Longitudinal Tracking with an IoT Gait Analysis System Using Accelerometers

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Abstract

Purpose: This study focused on maintaining and improving the walking function of late-stage older individuals while longitudinally tracking the effects of regular exercise programs in a day-care service specialized for preventive care over 5 years, using detailed gait function measurements with an accelerometer-based system. Methods: Seventy individuals (17 male and 53 female) of a daycare service in Tokyo participated in a weekly exercise program, meeting 1 - 2 times. The average age of the participants at the start of the program was 81.4 years. Gait function, including gait speed, stride length, root mean square (RMS) of acceleration, gait cycle time and its standard deviation, and left-right difference in stance time, was evaluated every 6 months. Results: Gait speed and stride length improved considerably within six months of starting the exercise program, confirming an initial improvement in gait function. This suggests that regular exercise programs can maintain or improve gait function even age groups that predictably have a gradual decline in gait ability due to enhanced age. In the long term, many indicators tended to approach baseline values. However, the exercise program seemingly counteracts age-related changes in gait function and maintains a certain level of function. Conclusions: While a decline in gait ability with aging is inevitable, establishing appropriate exercise habits in late-stage older individuals may contribute to long-term maintenance of gait function.

Keywords

Late-Stage Elderly, Exercise, Gait Function, Accelerometer, IoT-Based Gait Analysis Device

1. Introduction

Gait is an important function in the activities of daily living (ADL), and a decline in gait ability leads to a decrease in ADL levels. Gait ability decreases with age, and gait speed starts to rapidly decline around the age of 60 years [1] [2]. Individuals in their 70s - 80s have markedly slower gait speeds than other age groups, with a more rapid decline observed at the age of 70 onwards [3]. Gait speed in older adults is known to be a predictor of overall daily function, fall risk, depression, and decline in ADL, institutionalization, or mortality [4] [5] [6]. Slow gait speed is an important risk factor for falls [7] and is used as an evaluation criterion for frailty [8], which is closely related to the decline in the functional abilities of older adults. Faster gait speed is correlated with maintaining daily living functions and longer life expectancy [6] [9]; thus, conserving gait speed is important for older adults' quality of life (QOL).

In addition to gait speed, other parameters, such as decreased step length [2] as a major factor in the decline of gait speed [10], increased variability in gait cycle time in fallers compared to non-fallers [11], and use of the root mean square (RMS) of acceleration as an indicator of body sway [12] [13], have also been emphasized, suggest the need for a comprehensive evaluation of gait.

Exercise is important for maintaining gait function in late-stage older individuals. Physical activity not only prolongs life but also promotes the extension of healthy life expectancy and survival rates [14]; therefore, regular exercise habits are essential. Although various studies have been conducted on the effects of exercise on physical function and gait [15]-[23], these exercises should be continued for as long as possible. It is necessary to track any changes when exercise can be continued for a longer period.

Long-term continuation of exercise is extremely challenging, and approximately 50% of people dropout 3 - 6 months after starting to exercise [24]. The Long-Term Care Insurance (LTCI) system within Japan was introduced in 2000 as a mechanism to solve the problem of an aging population [25], and a system of daycare services specialized in preventive care was implemented. In this system, older adults living in the community performed exercise programs managed by physical therapists and other exercise providers 1 - 2 times a week. Many (a percentage would be nice) older individuals have succeeded in continuing these exercises, which is believed to have contributed to maintaining a certain level of physical function; however, objective examinations have been insufficient. In particular, no previous research has longitudinally tracked the gait function of late-stage older individuals who have continued to perform such exercises for five years, demonstrating the trajectory of gait function and the effects of exercise.

The purpose of this study was to longitudinally measure the gait function of late-stage older individuals who were able to continue a regular exercise program with a certain level of management in a daycare service for 5 years using an accelerometer-based gait analysis system and to examine the effects of this exercise program on gait function. Furthermore, in this study, we employed an Internet of Things (IoT) gait analysis device equipped with an accelerometer to conduct a simple yet detailed gait analysis.

2. Participants and Methods

The participants included 70 long-term individuals (17 male and 53 female) in a daycare service in Tokyo who continued the exercise program. The average age at the start of the exercise program was 81.4 ± 6.9 years, the average height was 155.0 ± 9.7 cm, and the average weight was 55.3 ± 12.6 kg. While users of this program can be considered in a certain state of frailty due to the long-term care insurance system, the fact that they have been able to continue using the service also indicates that they have been able to maintain their general daily life with some assistance; therefore, it is possible to observe a course close to normal aging. Prior to the experiment, informed consent was obtained from the participants and their families, both verbally and in writing.

The exercise program in which the subjects participated was set up by exercise providers, such as care staff, and was performed once or twice a week. The program was conducted for 2 - 3 hours per session, with sufficient rest breaks. The content included learning about health and healthcare, stretching and exercises in sitting or standing positions, strength training using machines, light-load aerobic exercises using an ergometer, and functional exercises using suspension cords targeting the whole body with a variety of menus divided into time slots to avoid bias. Vital signs and the participants' physical conditions were checked before each exercise session, and the amount, time, and content of the exercise were adjusted as needed.

Gait function was measured using a 3-axis accelerometer (IoT-based gait analysis device, AYUMI EYE [26]; Waseda Elderly Health Association Co., Ltd.). The accelerometer had a sampling frequency of 31.25 Hz. The accelerometer had three axes (X, Y, and Z) corresponding to the vertical (up-down), lateral (side-to-side), and anteroposterior (front-to-back) acceleration components, respectively. The accelerometer was attached to the third lumbar spine. The participants performed the 10-meter walk test (10 MWT) while wearing their shoes. Sufficient practice trials were conducted, and the average of the two trials was calculated for each parameter. The 10 MWT is a well-established assessment method that has been validated in numerous previous studies [27], including those using accelerometers [26].

The analyzed items included basic gait ability (gait speed and stride length), spatial stability of gait (root mean square; RMS) [12], regularity of gait (mean and standard deviation of gait cycle time), and left-right symmetry (difference in stance time). Furthermore, the RMS was normalized by dividing the mean square of the acceleration by the square of the walking velocity. RMS values were calculated for each axis and averaged. For the gait cycle time, complete gait cycles were extracted after excluding the beginning and end of the analysis period. Gait data were collected every six months for five years. The Friedman test was used to examine whether there were statistically significant differences at each time. If significant differences were found, the Wilcoxon test with Holm correction was used for multiple comparisons to compare each time point with the baseline. The significance level was set at 5% for all statistical analyses. This process aimed to provide an overview of the changes in mean gait parameters over time and identify the time points that showed significant differences compared to the baseline.

3. Results

The trajectory of each gait parameter over the 5 years is shown in **Table 1**. Gait speed markedly increased at 6 months compared to baseline. Subsequently, it gradually decreased, returning to baseline at 12 months, and remained above baseline until 48 months but fell below baseline at 54 months. Stride length showed a trajectory similar to that of gait speed, reaching a maximum at 6 months and then declining, with a considerable difference from baseline only at 54 months. The RMS decreased from the baseline, reached a minimum at 12 months, and then increased, with a remarkable difference only at 6 months. The gait cycle time decreased from baseline, reached a minimum at 12 months, and then increased, showing a bimodal trend, with marked differences from baseline between 6 and 18 months. The standard deviation of the gait cycle time generally showed an upward trend, with notable differences from the baseline at most time points, except at 12 months. The left-right difference in stance time increased extensively at 6 months, remained relatively stable until 48 months, and then increased sharply again at 54 months, with marked differences from baseline at most time points, except at 18, 24, and 36 months.

4. Discussion

In older adults, continuing appropriate exercise and physical activity is beneficial for maintaining and improving physical function [15], and the effectiveness of corresponding preventive care programs in Japan has been demonstrated prior [16]. Effective exercises for preventive care have been reported to include strength, balance, and gait practice [19] [20] [21] [22]. Regarding the frequency and intensity of effective exercise in preventive care, it has been shown that even low-intensity exercise can be effective for preventive care if an exercise time of approximately 300 min per week can be secured [23]. It has also been suggested that adults aged 65 years and older should perform approximately 150 min of moderate exercise per week and that strength training is effective and should be undertaken; however, strength training should be better started together with aerobic exercises such as walking [17]. The American College of Sports Medicine recommends that older adults engage in regular physical activity and exercise, as they can improve physical function and independent living and reduce the risk and severity of falls [18]. The exercise program used in this study also comprehensively

Table 1. Trends in gait parameters over 5 years and statistical analysis results for each period compared to baseline.

	Baseline	6 months	12 months	18 months	24 months	30 months	36 months	42 months	48 months	54 months	60 months
Gait speed (m/s)	1.08 ± 0.27	1.17 ± 0.35**	1.15 ± 0.29	1.13 ± 0.28	1.12 ± 0.30	1.09 ± 0.29	1.05 ± 0.32	1.03 ± 0.30	1.00 ± 0.31	0.95 ± 0.30*	0.94 ± 0.34**
Stride length (cm)	57.99 ± 8.67	60.22 ± 13.83	58.87 ± 12.47	58.29 ± 12.81	58.51 ± 13.82	57.02 ± 12.86	55.92 ± 14.11	54.50 ± 13.73	52.70 ± 14.77	51.18 ± 14.49*	50.49 ± 15.51**
RMS (1/m)	2.23 ± 1.06	2.15 ± 0.92*	2.13 ± 0.79	2.28 ± 1.25	2.35 ± 1.55	2.33 ± 1.45	2.60 ± 2.05	2.67 ± 2.15	2.75 ± 1.97	3.11 ± 3.25	3.00 ± 2.23
Stride time (s)	1.04 ± 0.12	1.00 ± 0.13**	0.98 ± 0.11**	0.99 ± 0.11**	1.03 ± 0.20	1.01 ± 0.15	1.04 ± 0.21	1.03 ± 0.16	1.02 ± 0.20	1.04 ± 0.20	1.06 ± 0.25
SD of Stride time (s)	0.03 ± 0.01	0.03 ± 0.02*	0.03 ± 0.02	0.04 ± 0.02*	0.04 ± 0.02**	0.04 ± 0.02*	0.05 ± 0.07**	0.05 ± 0.04**	0.05 ± 0.05**	0.05 ± 0.06**	0.06 ± 0.05**
Asymmetry in stance time (s)	0.02 ± 0.02	0.03 ± 0.03**	0.03 ± 0.03**	0.03 ± 0.03	0.03 ± 0.04	0.03 ± 0.03*	0.03 ± 0.03	0.03 ± 0.03*	0.03 ± 0.03*	0.05 ± 0.14*	0.03 ± 0.03**

RMS: Root Mean Square, SD: Standard Deviation, *: $p < 0.05$, **: $p < 0.01$.

addressed flexibility, strength, and physical fitness of the whole body, while paying close attention to the safety of older participants.

Establishing a regular exercise habit in older adults and reliably confirming that it has been implemented is difficult. There are reports that the exercise implementation rate decreases when the intervention frequency is two or fewer times per week [28] and that approximately half of adults aged 50 years and over perceive strength training as an undesirable strenuous exercise [29]. There are also reports that psychological counseling interventions for community-dwelling older adults considerably increase their amount of exercise and improve their physical function [30], suggesting that psychological factors are deeply involved in the continuation of exercise. Therefore, exercise for older adults should be easy and safe to perform and easily incorporated into daily life. In addition, selecting exercises tailored to each individual's physical function can lead to a sense of enjoyment and continuation of exercise. The participants in this study were able to continue exercising under the LTCI system [25], which is an advantageous environment for maintaining the physical function of older adults. The ability to regularly and reliably sample gait function using the gait analysis system in the same exercise conditions is not only a powerful condition control for the study of the long-term effects of habitual exercise intervention but may also have contributed to the suppression of motivational decline in exercise continuation for older individuals and early detection of risks of gait function decline. The findings of this study are particularly valuable in regions where LTCI systems [25] do not exist. The authors suggested that regular exercise interventions and gait function assessments could have long-term effects on the walking ability of older adults, even in the absence of LTCI support.

Gait analysis can provide a wealth of information, and research on central nervous system disorders, orthopedic diseases, dementia, older adults, and falls has suggested that the characteristics of gait change with physical condition [31]-[37]; therefore, the significance of conducting periodic gait analysis in older adults is profound. A decline in walking ability with age has been widely reported, encompassing a broad range of parameters beyond those utilized in the current study. These include reductions in step length, cadence, and velocity [2], as well as increases in double support time [2] [38], stride width [2], toe-out angle [39], and decreases in toe clearance during the swing phase of the gait cycle [2]. Additionally, decreases in the hip abduction angle [40], knee flexion angle during the swing phase [40], reduced vertical and lateral trunk motion [40], decreased pelvic rotation [40], and diminished forward shoulder sway and backward elbow extension [40] have been observed, among others.

In this study, gait speed and RMS improved within approximately 6 months of starting the exercise program. Gait cycle time was the shortest at 12 months. Stride length also tended to increase at six months, although no significant differences were observed. This suggests that the regular exercise program may be able to counteract the age-related decline in gait function [1] [2] [3] and maintain or improve gait function in this age group, where a gradual decline in gait ability is a premise. This may be because improved muscle strength and balance ability through exercise [41] [42] leads to improved gait function. It is considered that the establishment of regular exercise habits in participants' daily lives led to a change in their lifestyle habits. After 6 months, gait ability tended to decline, but the downward trend may have been gentler owing to exercise habits. On the other hand, the standard deviation of gait cycle time and the left-right difference in stance time did not show clear improvement with the exercise program, only maintaining a certain level. For these parameters, it may be necessary to devise exercises that specifically optimize gait coordination. Alternatively, previous studies using inertial sensors reported high reliability in the analysis of gait parameters, such as walking speed, step length, and stride time in healthy adults. However, low reliability was observed for the coefficient of variation of the step time [43]. It was suggested that the variability in movement in older adults may be small relative to measurement errors, making it difficult to observe distinguishable signs of improvement.

One limitation of this study is the lack of a control group, which is necessary to establish whether the observed decline is also present in non-exercising participants. However, considering the late-stage older participants, it would be difficult to continue tracking gait ability with the same accelerometer-based system every 6 months for 5 years without the management provided by the LTCI system [25]. However, it should be noted that the exercise amount may differ among individuals, as the participation is adjusted considering the health and age of each participant. In addition, older adults who dropped out of the program because of hospitalization or other reasons could not be tracked. Thus, sampling only individuals who have maintained relatively healthy conditions is an important consideration when interpreting the results.

This study was able to longitudinally track detailed gait function using an accelerometer-based gait analysis system. Although other parameters were not measured in this study, gait speed is the most important and essential ability for independent living in older adults [41] [42], and it is known to be highly correlated with muscle strength and balance, representing the basic motor ability of older adults [41] [42]; hence, despite the various individual circumstances that need to be considered in elderly populations, such as depression, it is thought that this study has contributed to elucidating one aspect of age-related changes.

A decline in walking ability associated with aging is inevitable in older adults. However, it is important to regularly conduct gait assessments to evaluate and understand the walking ability of older adults at an early stage. Presenting feedback on walking ability to older adults potentially contributes to suppressing the decline in motivation for exercise. In the care of older adults, it is crucial to establish a habit of regularly managed exercise, keeping in mind changes in gait characteristics, and to appropriately evaluate its effectiveness. This is deemed incredibly important for maintaining the walking conditions of older adults over the long term and ultimately managing their overall health effectively. In future studies, I aim to collect a larger number of samples, ensuring an equal representation of genders to mitigate any bias arising from gender disparities, and conduct more detailed examinations to further validate the findings and expand my understanding of the subject.

5. Conclusion

This study analyzed in detail the effects of a regular exercise program used by late-stage older individuals at a daycare service specializing in preventive care on their gait function over 5 years. The results suggest that the program was effective in counteracting the gradual decline in gait ability due to aging, with improvements in gait speed and other parameters in the first 6 months. These findings support the importance of establishing appropriate exercise habits and periodically assessing gait ability to maintain gait function in late-stage older individuals.

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Conflicts of Interest

The author Taisuke Ito is affiliated with Waseda Elderly Health Association Co. Ltd.

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