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Understanding gait characteristics of Japanese elderly men through joint angle and angular velocity parameters

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ABSTRACT

Studies investigating the walking patterns of elderly men are well documented, however, there has been no investigation of the gait parameters that specifically reflect the walking motion of elderly men. This study aimed to identify reliable gait parameters to represent the walking motion of elderly Japanese men. 33 elderly men (65 to 74.9 years old) and 20 very elderly men (≥ 75 years old) participated. A 3-dimensional motion analysis system was used to collect kinematic data and 52 gait parameters were analyzed namely; spatiotemporal gait, joint angle, and angular velocity parameters (peak value and peak timing at the hip, knee, and ankle joints. Our results showed that walking speed, cadence, walk ratio, gait cycle, peak joint angle timing, and angular velocity parameters significantly differ between elderly men and very elderly men. Delayed peak timing in the joint angle occurred during the terminal stance phase and pre-swing phase. The accurate parameters for walking motion in old Japanese men as they age may result from the peak timing of joint angle parameters and the peak value of angular velocity parameters.

INTRODUCTION

In Japan, the proportion of older people has been increasing dramatically. In 2020, D'Ambrogio reported that 28.7% of the total population was 65 years old or over, and it is indicating that the aging society in Japan is progressing quite rapidly (Statistics Bureau of Japan, 2021). Additionally, the life expectancy of the Japanese people has increased over the past few decades since the average life of Japanese women reaches 87.5 years and that of Japanese men is 81.41 years. (Statistics Bureau of Japan, 2021).

In advanced age, human activity could be affected by aging, including walking as the most common of all human movements. According to Afiah et al. (2016), it is important to assess the gait characteristics to avert walking ability decline as people age. Many previous studies have investigated the age-related changes in gait variability. The majority of studies pointed out the gait characteristics in older adults compared to the younger, or elderly women (Grabiner et al., 2001; Kang & Dingwell, 2008; Mills & Barrett, 2001; Moyer et al., 2006; Schulz, 2012; Vieira et al., 2015).

Furthermore, research into the walking patterns of elderly men is extensively documented (Judge et al., 1996; Kirtley et al., 1985; Murray et al., 1969; Watanabe et al., 2015; Watelain et al., 2000). Murray et al. (1969) and Kirtley et al. (1985). Their findings proved that as people got older, their walking speed and stride length reduced and that an interrelation existed between cadence and knee flexion throughout the stance and swing phases

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Additionally, based on spatial-temporal parameters and muscle power, Watelain et al. (2000) grouped a gait pattern They inferred that for elderly men, the peak muscle power in the hip, knee, and ankle joints is lower than in other age groups. Watanabe et al. (2015) also suggested that during one gait cycle, as a result of little rectus femoris muscle activity, lateness occurred on the toe-off timing in elderly men during their preferred walking speed. As far as research is concerned, no research has been carried out on the gait parameters that specifically characterize the walking motion of older men in 2 categories: elderly and very elderly men. The present study examined the gait characteristics of 2 categories of elderly Japanese men. This study intended to determine accurate gait parameters that might be utilized to depict the walking motion of elderly Japanese men. Consequently, this study examined the influence of aging on gait parameters for old Japanese men to determine the parameters that indicate the walking motion upon aging in the Japanese population.

METHODS

Participants

In this study, fifty-three healthy elderly Japanese men who were selected to participate were separated into two groups. Group 1 consisted of 33 elderly men aged between 65 – 74.9 years and group 2 included 20 very elderly men aged ≥75 years. Each group had one left-leg-dominant individual, while the other subjects were all right-leg-dominant. The list of participant characteristics is displayed in Table 1.

Before the measurement, to ensure that the entire participants did not have any major orthopedic in the lower leg and were capable of walking without the use of any assistive equipment, they were checked using a medical questionnaire. The Ethics Committee of Kyushu University's Faculty of Design approved this study, and written consent was acquired.

Procedures

This study utilized a 3D motion analysis system and a Cortex software program (Motion Analysis Corporation, Santa Rosa, CA, USA) to conduct the experiment and collect kinematic data. Participants were asked to wear clothes that were in firm contact with the skin. Thirty-one trajectory markers were attached to the main segment of each participant's body, namely, head, upper limb, leg along the superior iliac spine, greater trochanter, lateral joint line of the knee, lateral malleolus, and toe.

Measurements

The participants were instructed to walk barefooted along 10 meters of a flat surface at a speed convenient for them. Before the measurement, they were requested to practice barefooted walking as well. Every participant had three self-selected speed measures marked.

Gait Parameters

Gait parameters of the elderly Japanese men were analyzed using KineAnalyzer software (Kissei Comtec, Nagano, Japan). In total, 52 gait parameters were analyzed in this present study; 9 spatiotemporal gait parameters (walking speed, step length, stride length, cadence, walk ratio, duration of swing and stance phase, percentage of single and double supports), 21 joint angle parameters at the hip, knee, and ankle joints (peak extension and flexion angles, peak plantarflexion and dorsiflexion angles, timing of peak values, timing of peak values, and maximal angle), and also 22 angular velocity parameters at the hip, knee, and ankle joints (peak extension and flexion angular velocities, peak plantarflexion and dorsiflexion angular velocities, and timing of peak values).

Statistical Analysis

IBM SPSS version 23.0 for Windows was employed for statistical analysis (Chicago, IL, USA). Means and standard deviations were applied to present the descriptive results. The analysis of the differences in characteristics and gait parameters between elderly and very elderly Japanese men was carried out using an unpaired t-test. The significance threshold was set at 0.05.

RESULTS AND DISCUSSION

Participants

In terms of the age of the participants, the very elderly men in Group 2 were substantially older than the elderly men in Group 1 ($p<0.01$). Nevertheless, in the matter of body height, weight, or lower-limb length, both groups showed no significant differences (Table 1).

Spatiotemporal Gait Parameters

Table 2 shows the results of the entire spatiotemporal gait parameters. Group 2 exhibited slower walking speed and cadences than Group 1 (<0.05 and $p<0.01$) without any detection of significant differences in step length, stride length, and walk ratio. Meanwhile, in terms of the duration of one gait cycle (swing and stance phases), the result of Group 2 was considerably greater than that of Group 1 ($p<0.05$ and $p<0.01$). Furthermore, although the swing phase percentage and single support percentage of Group 2 showed significantly lower values than those of Group 1 ($p<0.05$), the percentage of the stance phase and the double support percentage of Group 2 were significantly higher than those of Group 1 ($p<0.05$).

Numerous preceding studies of gait motion have indicated that the elderly participants exhibit slower walking speed and cadence changes (Anderson & Madigan, 2014; Andriacchi et al., 1977; Cho et al., 2004; Friedman, 1988; Jerome et al., 2015; Kirtley et al., 1985; Prince et al., 1997; Watelain et al., 2000). The finding of this study revealed that the slower cadence and shorter stride length of very elderly men became the primary factor affecting slower walking speed, despite the insignificant differences between the two groups in terms of the stride length. Furthermore, this finding is comparable to the study by Winter et al. (1990) which reported that the characteristics of gait in the elderly are slower walking speed, lower cadence, and shorter stride length.

In the comparison between elderly men and very elderly men, this study also showed that there were significant findings for the single support percentage and double support percentage. In this respect, very elderly men exhibited a lower single support percentage but a higher double support percentage than elderly men. The single support phase was correlated to the swing phase of the other limb (Ayyappa, 1997), while the double support phase comprised the time when both feet come into contact with the ground (Demura et al., 2012). The center of mass of the body shifts forward from the supporting limb to the predicted landing position of the swing limb (Frank & Patla, 2003). Amid single limb support, the condition of the body is inherently unstable (Prince et al., 1997), and elderly adults decrease the concentric energy output of trunk muscles to dwindle the energy delivered to the trunk as a result of lack of stability during the single support phase (McGibbon & Krebs, 2001).

Table 1. Characteristics of the participants

	Group 1 (Elderly Men)	Group 2 (Very Elderly Men)	*p-value*
Age *(years)*	70.2 ± 2.7	77.1 ± 1.8	< 0.01
Body Height *(cm)*	164.8 ± 5.4	163.4 ± 4.8	NS
Body Weight *(kg)*	62.4 ± 6.4	61.5 ± 7.7	NS
Lower-Limb Length *(cm)*	74.2 ± 3.8	73.5 ± 3.9	NS

NS: Not significant. All values are presented as mean +/- standard deviation.

Table 2. Comparison of the spatiotemporal gait parameters between elderly men and very elderly men

Parameters	**Group 1 (Elderly Men)**	**Group 2 (Very Elderly Men)**	***p-value***
Walking speed *(m/min)*	73.9 ± 8.9	67.9 ± 10.1	<0.05
Step lengths (cm)	62.7 ± 5.8	61.1 ± 7.5	NS
Stride length (cm)	125 ± 11.5	122.2 ± 15.2	NS
Cadence *(steps/min)*	117.6 ± 6.8	111.4 ± 7.8	<0.01
Walk ratio	0.53 ± 0.05	0.55 ± 0.07	NS
Duration of swing phase (sec)	0.40 ± 0.02	0.43 ± 0.03	< 0.05
Duration of stance phase (sec)	0.62 ± 0.05	0.66 ± 0.05	< 0.01
Single support percentage (%)	79.0 ± 2.6	77.4 ± 2.8	< 0.05
Double support percentage (%)	21.0 ± 2.6	22.6 ± 2.8	< 0.05

Due to the instability during single limb support, very elderly men may exhibit a lower single support percentage. Furthermore, the effects of prolonged duration of the stance phase result in a smaller single support percentage in very elderly men during one gait cycle. A higher percentage value, however, occurred in very elderly men throughout the double support phase when compared to elderly men. More double limb support follows gait changes in elderly adults (Alexander, 1996; Liu et al., 2006). A previous study conducted by McGibbon and Krebs (2001) discovered that to manage energy transfer during the double limb support phase, elderly adults depend more upon eccentric control of low-back muscles. Furthermore, when compared to elderly men in this study, very elderly men displayed shorter swing phase duration. As a result, the higher percentage of the double support phase in this study revealed that very elderly men spent more time with both feet on the floor to prolong walking stability following complete swing limb advancement than elderly men did.

Joint Angle Parameters

Table 3 shows the results of all joint angle parameters. Peak extension timing at the hip joint and peak extension timing at the knee joint ($p<0.05$) were the only ones showing significant differences. In the comparison of the peak extension timing at the hip and knee joints, Group 2 was significantly slower than Group 1 ($p<0.05$). For ankle joint parameters, however, the differences between Group 1 and Group 2 were not significant.

To obtain a better understanding of the gait patterns of elderly Japanese men, an investigation of the peak value and peak time of joint angle data was carried out. The results indicated that there were no significant differences in the peak values of any joint angle between elderly and very elderly men. Moreover, the differences were significant merely on the peak timings of joint angle parameters, namely peak extension timing at the hip and knee joints.

During the analysis of the timing of joint angles, it was discovered that delayed peak timing started at around 40% of the gait cycle. The comparison between very elderly men and elderly men revealed a delay in the peak extension timing at the hip joint which occurred during the terminal stance phase (31 percent to 50% of the gait cycle) when the hip joint transitioned from a flexed to an extended state. The occurrence of peak timing at the knee joint was during the terminal stance phase (31% to 50% of the gait cycle), while the occurrence of peak timing at the hip joint was during the pre-swing phase (50% to 62% of the gait cycle) when the joints transitioned from flexed to the extended position.

Heel rise is the beginning of the terminal stance phase which resumes until the other foot hits the ground (Perry & Burnfield, 2010). Throughout this phase, the body is driven forward until the pre-swing begins (Rueterbories et al., 2010). In general, knee joint dynamics are linked to neuromuscular activation patterns while walking, such as decreased range of knee motion or moderate knee osteoarthritis (Astephen Wilson et al., 2011; Mundermann et al., 2005). Moreover, Kerrigan et al., (1998) found that as a result of the shift in dynamic stiffness during walking, knee extension strength of elderly people decreased during the stance phase and they also lowered their ankle plantar flexion to maintain more foot–floor contact during the terminal stance phase. To gain greater propulsion energy for forceful joint extension, elderly people made more deliberate efforts. Furthermore, the shift in the medial-to-lateral distribution of proximal tibial bone mineral density was influenced by the knee adduction moment during the terminal stance phase, and variability of knee joint motions during the terminal stance phase becomes one of the crucial parameters when walking (Thorp et al., 2006). Furthermore, reduction of the gait speed resulted in a decrease in muscle activities during the terminal stance phase such as the in thin tibialis anterior, bicep femoris, medial hamstring, and vastus lateralis (Schmitz et al., 2009). Consequently, the very elderly men in the current study may have exerted more effort to transfer the knee joint from the flexed to the extended position on account of reduced knee extension strength, smaller bone mineral density, and smaller muscle power during the terminal stance phase, resulting in delayed peak timing during knee joint extension during the terminal stance phase. In addition, unhurried walking speed influences delayed peak timing of very elderly men more than elderly men during this phase.

During the pre-swing phase (50 percent to 62 percent of the gait cycle), there was additional evidence of delayed peak joint angle timing. During this phase, a delay in timing was noticed when the hip joint transitioned from the flexed to the extended position. The extra effort necessitated to move the hip joint position, poor hip flexor power for push-off, and a reduction in the range of extension may all contribute to the delayed peak joint angle timing at the hip joint during this phase (Afiah et al., 2016).

Regarding elderly Japanese men, delayed peak timing during the previous gait phase may alter the delayed peak timing as well. Nevertheless, delayed peak timing did not manifest until 64% of the gait cycle (Fig.1). The observed delayed peak timing would be mainly reflected by the unique joint angle behavior during the gait phase in very elderly men.

Table 3. Comparison of the joint angle parameters between elderly men and very elderly men

Parameters	Group 1 (Elderly Men)	Group 2 (Very Elderly Men)	*p-value*
Hip Joint			
Peak extension angle *(deg)*	17.6 ± 5.8	18.8 ± 4.9	NS
Peak extension timing *(%)*	53.5 ± 1.1	54.3 ± 1.2	< 0.05
Peak flexion angle *(deg)*	-26.8 ± 5.3	-24.6 ± 4.8	NS
Peak flexion timing *(%)*	88.0 ± 1.7	88.1 ± 2.1	NS
Maximal angle range *(deg)*	44.4 ± 4.1	43.5 ± 5.9	NS
Knee Joint			
Peak extension angle *(deg)*	171.5 ± 6.3	173.0 ± 6.2	NS
Peak extension timing *(%)*	40.3 ± 2.6	42.5 ± 4.1	< 0.05
First peak flexion angle *(deg)*	155.8 ± 7.1	157.0 ± 7.3	NS
First peak flexion timing *(%)*	13.0 ± 1.0	13.1 ± 2.0	NS
Second peak flexion angle *(deg)*	114.0 ± 7.1	116.5 ± 7.0	NS
Second peak flexion timing *(%)*	72.7 ± 2.3	73.1 ± 2.7	NS
Maximal angle range *(deg)*	57.5 ± 4.1	58.7 ± 5.0	NS
Ankle Joint			
First peak plantarflexion angle *(deg)*	103.0 ± 3.0	103.3 ± 3.2	NS

Parameters	**Group 1 (Elderly Men)**	**Group 2 (Very Elderly Men)**	***p-value***
First peak plantarflexion timing *(%)*	5.8 ± 1.2	5.5 ± 1.1	NS
Second peak plantarflexion angle *(deg)*	111.0 ± 4.8	108.4 ± 6.1	NS
Second peak plantarflexion timing *(%)*	64.7 ± 1.7	65.4 ± 2.7	NS
First peak dorsiflexion angle *(deg)*	86.0 ± 3.3	85.2 ± 4.6	NS
First peak dorsiflexion timing *(%)*	45.2 ± 5.0	45.8 ± 5.8	NS
Second peak dorsiflexion angle *(deg)*	94.9 ± 3.3	93.0 ± 4.7	NS
Second peak dorsiflexion timing *(%)*	84.9 ± 2.6	84.2 ± 2.5	NS
Maximal angle range *(deg)*	25.0 ± 3.8	23.2 ± 3.6	NS

Angular Velocity Parameters

The findings of all angular velocity parameters are displayed in Table 4. In the present study, the differences were proven to be significant only for the first and second peaks of the plantarflexion angular velocity at the ankle joint ($p<0.05$). The comparison of the first peak plantarflexion angular velocity showed that Group 2 had a significantly lower value than Group 1 ($p<0.05$), while on the comparison of the second peak plantarflexion angular velocity, Group 2 had a significantly greater value than Group 1 ($p<0.05$). Other angular velocity metrics of the hip and knee joints, however, showed no significant changes.

The results of this study reveal that there are considerable differences in the peak values of angular velocity at the ankle joint of elderly Japanese men. Several earlier studies have shown several important results related to angular velocity in the gait of the elderly (Leung et al., 2014; Mills & Barrett, 2001; Silder et al., 2008; Van Iersel et al., 2007). Van Iersel et al. (2007), for instance, discovered that a higher angular velocity was correlated with a higher risk of falling. Due to the minimal variability in preferred gait velocity and stride length, Mills and Barrett (2001) discovered no significant variations in the peak value of angular velocity between younger and older people. Therefore, this study can complement previous research by combining the insights of the peak value of angular velocity with the phase of the gait cycle when the peak value of each joint arises despite no significant differences in peak timing parameters.

According to the measurement during the pre-swing phase in this study, the first peak plantarflexion angular velocity at the ankle joint of very elderly men is substantially lower than that of elderly men. For the ankle joint, the pre-swing phase becomes a very intricate element of the gait cycle since ankle motions are related to progression, and body weight is quickly shifted from the trailing limb to the forward limb (Perry & Burnfield, 2010). The role of plantar flexors is vital in mobility, while the triceps surae muscle architecture and Achilles tendon stiffness are correlated with improved mobility performance (Stenroth et al., 2015). Norris et al. (2007) found that the decrease in walking speed was influenced by a lack of power in the ankle plantar flexor. Lower strength and ankle plasticity also resulted in declined plantarflexion muscle force in older individuals (Hortobágyi et al., 2016). In addition, there was less isometric strength in the ankle plantarflexion of elderly people (Graham et al., 2015), and the effects of variability in ankle plantarflexion occur on gait velocity, step length, and cadence for healthy elderly people (Leung et al., 2014). As a result, decreased ankle plantar flexor power and low plantarflexion muscle activity during the pre-swing phase may contribute to lower peak plantarflexion angular velocity at the ankle joint. Moreover, slower cadence has a significant impact on lower peak plantarflexion angular velocity in very elderly men compared to elderly men.

In the comparison of the second peak plantarflexion angular velocity at the ankle joint, however, very elderly men showed greater value than the elderly men. The occurrence of the peak value was during the terminal swing phase which is known as e final phase of one gait cycle. Amid this phase, an increase in the pretibial muscle action occurs to guarantee that the ankle remains neutral so that optimum heel contact takes place throughout the next phase (Perry & Burnfield, 2010). A simulation of ankle mechanical impedance in humans was carried out by Endo and Herr (2014) by utilizing time-varying ankle parameters. The results revealed that the tibialis anterior raised during the terminal swing phase before heel-strike suggesting that before the loading response phase, intensified impedance before heel-stride might pare the body for shock absorption. Furthermore, the ankle joint is an indispensable joint for propulsion and shock absorption at the maximum plantarflexion moment (Lee et al., 2013).

As a result, enhanced muscle strength for shock absorption during the terminal swing phase and the effort to relocate the ankle joint from the dorsiflexed to the plantarflexed position may affect higher peak plantarflexion angular velocity in very elderly men.

Table 4. Comparison of the angular velocity parameters between elderly men and very elderly men

Parameters	Group 1 (Elderly Men)	Group 2 (Very Elderly Men)	*p-value*
Hip Joint			
First peak extension angular velocity *(deg/s)*	126.7 ± 18.9	117.4 ± 20.8	NS
First peak extension timing *(%)*	22.2 ± 3.4	21.9 ± 5.7	NS
Second peak extension angular velocity *(deg/s)*	42.4 ± 18.7	36.0 ± 15.7	NS
Second peak extension timing *(%)*	93.2 ± 1.4	92.8 ± 2.0	NS
Peak flexion angular velocity *(deg/s)*	-211.8 ± 28.1	-195.3 ± 27.4	<0.1
Peak flexion timing *(%)*	65.2 ± 1.4	65.8 ± 1.5	NS
Knee Joint			
First peak extension angular velocity *(deg/s)*	91.9 ± 23.5	82.8 ± 28.6	NS
First peak extension timing *(%)*	23.9 ± 2.6	23.4 ± 4.2	NS
Second peak extension angular velocity *(deg/s)*	386.6 ± 49.4	374.9 ± 54.7	NS
Second peak extension timing *(%)*	89.0 ± 2.5	89.4 ± 1.1	NS
First peak flexion angular velocity *(deg/s)*	-183.0 ± 44.8	-190.6 ± 49.0	NS
First peak flexion timing *(%)*	5.2 ± 1.0	5.0 ± 0.9	NS
Second peak flexion angular velocity *(deg/s)*	-379.1 ± 42.2	-355.0 ± 44.9	<0.1
Second peak flexion timing *(%)*	62.1 ± 1.6	63.0 ± 3.3	NS
Ankle Joint			
First peak plantarflexion angular velocity *(deg/s)*	257.0 ± 34.4	235.6 ± 34.8	<0.05
First peak plantarflexion timing *(%)*	57.8 ± 1.8	58.3 ± 2.3	NS
Second peak plantarflexion angular velocity *(deg/s)*	58.9 ± 24.3	76.7 ± 25.7	<0.05
Second peak plantarflexion timing *(%)*	91.6 ± 3.3	91.1 ± 2.1	NS
First peak dorsiflexion angular velocity *(deg/s)*	-95.8 ± 16.9	-96.7 ± 21.6	NS
First peak dorsiflexion timing *(%)*	12.1 ± 4.0	12.9 ± 5.1	NS
Second peak dorsiflexion angular velocity *(deg/s)*	-125.7 ± 33.4	-120.1 ± 19.7	NS
Second peak dorsiflexion timing *(%)*	71.6 ± 2.0	72.4 ± 2.1	NS

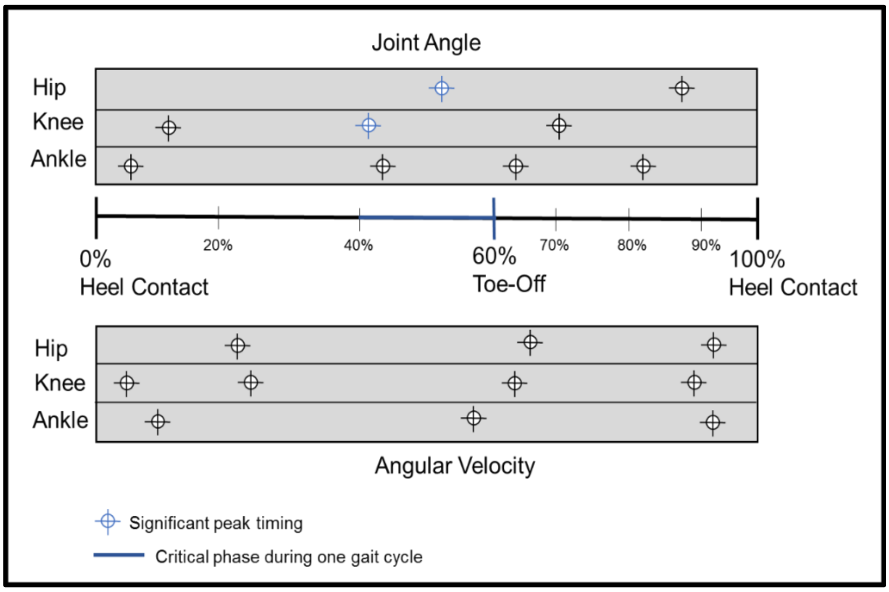

Figure 1. The peak timing of joint angle and angular velocity parameters

Implication, Limitation, and Future Research

The comprehensive analysis of both the joint angle and angular velocity to provide new insight regarding peak value and peak timing parameters is the novel component of this study. Gait parameters that consist of peak value and peak timing in joint angle and angular velocity are the aspects that have significant effects on elderly Japanese men when aging. One constraint of this study is that it only compares the same gender, namely elderly men. The study might generate different results if the participants were from different gender, elderly women and elderly men. On that account, the upcoming research should consider the gait differences between elderly Japanese women and men.

CONCLUSION

According to the result of this study, for basic gait and gait cycle parameters, gait characteristics among elderly men could be identified from the reduction in walking speed, the decrease in cadence, the smaller single support percentage, and the greater double support percentage. Concerning the joint angle and the angular velocity parameters, specific gait characteristics of elderly Japanese men also could be identified from delayed peak extension timing at the hip and knee joint, smaller first peak plantar flexion angular velocity, and greater second peak plantar flexion angular velocity at the ankle joint.

Finally, it is discovered that elderly men and very elderly men have different gait parameters (basic gait, gait cycle, joint angle, and angular velocity). The attested parameters as the indication of walking motion in elderly Japanese men when aging may arise from peak timing of joint angle parameters and peak value of angular velocity parameters.

AUTHOR CONTRIBUTIONS

INA designed the study, performed the experiments, analyzed the data, and wrote the manuscript. HN performed the experiments and contributed to data analysis. PYL contributed to the interpretation of the results. SM designed the study and reviewed the manuscript. All authors read and approved the final manuscript.

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