原　著

転倒しやすい高齢者の歩行解析
－第７回三重県旧宮川村検診結果より－

Gait Analyzer-mediated Determination of Risk Factors for Falls in the Elderly

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キー・ワード：epidemiology, falling, gait analysis
疫学，転倒，歩行解析

〔要旨〕　本研究の目的は転倒に関連があるとされる歩行速度低下の中で，どの因子が影響を与えているかを調べることである．旧宮川村（三重県）の65歳以上の男女で，2009年の検診に参加した296例を対象とした．転倒評価は骨折の既往を有するものを骨折群（n＝26），骨折の既往がなかったもののうち，過去２年間で１回でも転倒した群を転倒群（n＝58），転倒しなかった群を非転倒群（n＝212）として比較検討した．歩行検査は通常歩行（自由歩行かつ定常歩行）をさせ，圧力分布装置で歩幅・歩隔・つま先開き角度と立脚期・遊脚期・両脚支持期の時間を測定し，比較検討した．年齢・身長を調整因子として統計を行うと，歩幅は有意に転倒群の方が小さく，立脚期の時間の比率は転倒群が長かった．易転倒性高齢者は下肢筋力低下のため，歩幅が小さくなり，バランス能の低下のため，相対的な立脚期の時間が長くなっているものと推測された．

はじめに

日本は2007年より65歳以上人口が21％以上である超高齢社会を迎え，約780万～1,100万人が骨粗鬆症に罹患していると推測されている[1]．また，転倒の約10％が大腿骨近位部骨折などの重篤な外傷を引き起こすとも報告されており[2]，2007年の国民生活基礎調査では要支援・要介護者の原因の9.3％が転倒・骨折によるものであるとされている．一方，転倒しやすい高齢者（以下，易転倒性高齢者）はその歩行速度に低下が認められるという報告があり，歩行と転倒の関連が示唆されている[3]．しかし，易転倒性高齢者の歩行のどの要素が転倒に関連するのかを検討した報告は少ない．本研究の目的は歩行解析計を用いて，歩行のどの要素が転倒に関連するのかを検討することである．

対象および方法

1．対　象

三重県旧宮川村に在住する65歳以上の男女を対象とした旧宮川村検診（1997年より２年毎に実施している検診）のうち，2009年の第７回検診に参加し，歩行解析が可能（杖を使用せず裸足で6m以上歩行が可能）であった296名（男性101名，女性195名）を対象とした．旧宮川村は林野率が96％の林業を主産業とした山村である．全人口は2010年で3,490人であり，今回対象となる65歳以上の高齢者は1,553人であった．高齢者における本研究への参加率は19.1％であった．

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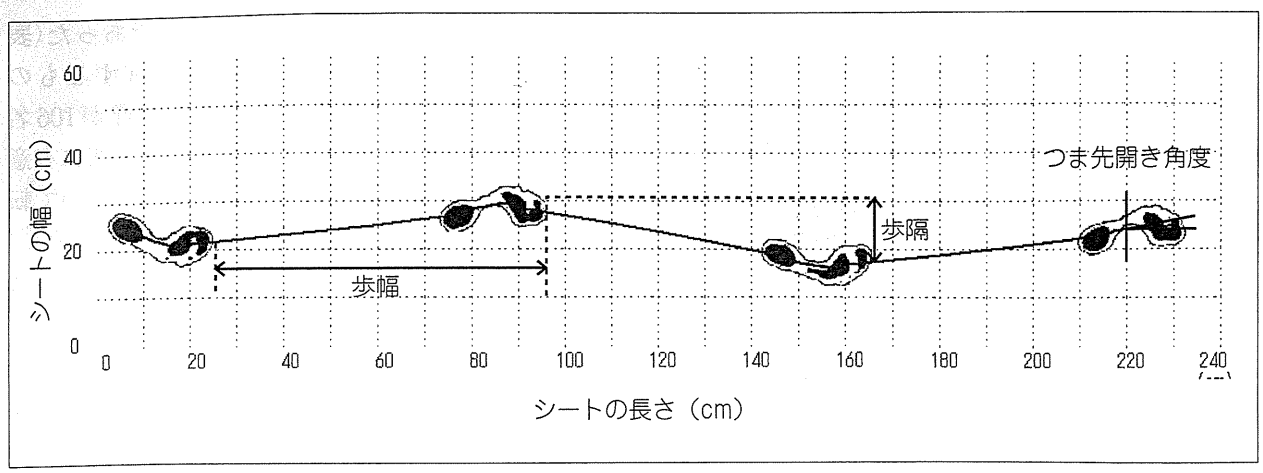

図1a　転倒群・非転倒群と歩行の距離
縦軸が荷重歩行計のシートの幅(cm)，横軸がシートの長さ(cm)になっており，歩行してできたfoot printより歩幅，歩隔，つま先開き角度(踵部の中央と前足部の中央を結んだ線が進行方向の線となす角度)を算出した．

2．検診方法

問診票を郵送し，検診時に問診票を持参の上，受診させた．問診票には氏名，生年月日，年齢，性別などの基本情報を記載してもらうほか，過去２年間の転倒の有無，骨折既往の有無も記載させた．検診日には身長，体重，血圧などの測定と歩行解析を行った．また，膝関節は膝立位単純X線撮影を行い，変形性膝関節症の有無についても評価を行った．変形性膝関節症(膝OA)はどちらかの膝が一方でもKellgren & Lawrence分類でgrade Ⅱ以上のものを膝OAと定義した．直接検診は約１ヵ月の間に週末を利用して計４回行った．

3．歩行解析

歩行解析は6mの長さを通常速度歩行(自由歩行)[3]させ，その中間部に長さ2.4mの圧力分布センサーシートを設置し，シート式下肢荷重計(Walk way MW 1000：アニマ社)を用いて解析を行い，距離因子である歩幅，歩隔とつま先開き角度(**図1a**)および時間因子である立脚期・遊脚期・両脚支持期の時間(**図1b**)を測定した．時間因子では１歩行周期に対する相対値(%)でも検討を行った．

4．検討項目

過去２年間で１回でも転倒したことがあると答えた参加者と，１回も転倒しなかったと答えた参加者の骨折があった頻度を算出し，比較した．骨折の既往があったものを骨折群，骨折がなく転倒があったものを転倒群，骨折がなく転倒がなかった群を非転倒群とし，歩行解析ではこれら３群で，歩幅，歩隔とつま先開き角度および１歩行周期における立脚期・遊脚期・両脚支持期の割合(%)を比較した．

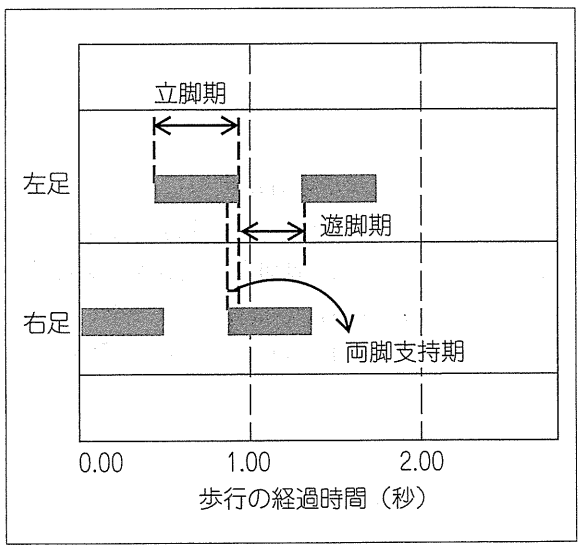

図1b　転倒群・非転倒群と時間因子
横軸が経過時間(秒)を示しており，立脚期・遊脚期・両脚支持期の時間を算出した．

5．統計解析

転倒の有無と骨折の関連はχ^2検定で解析を行った．３群の背景は一元配置分散分析で検定し，群間比較はScheffe法のPost hoc testで行った．歩行解析では参加者背景で年齢・身長に有意差を認めたため，年齢・身長を調整因子とし，転倒群をベースカテゴリーとした多項ロジスティック回帰分析で解析を行った．歩行の時間因子は相対値で比較検討した．$p<0.05$を有意差ありとし，歩行解析ではオッズ比も算出した．統計

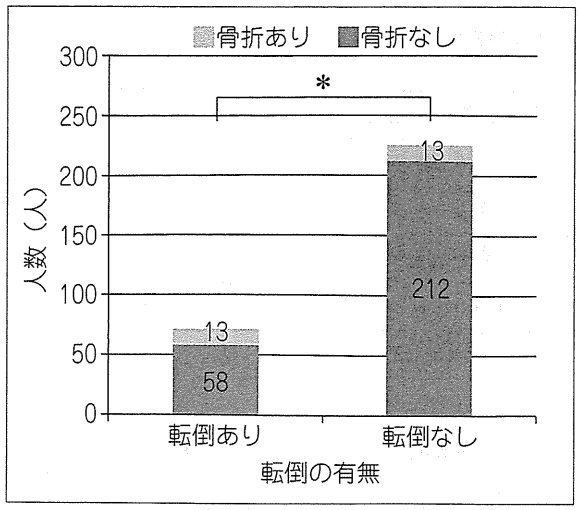

図2　転倒の有無と骨折の関連
＊p＜0.05，χ^2検定.

ソフトはPASW Statics 18を使用した.

結　果

1．転倒の有無と骨折の関連

参加者296名中，転倒ありと答えた参加者は71名，転倒なしと答えた参加者は225名であった．転倒ありの参加者13名(18.3%)，転倒なしの参加者の13名(5.8%)に骨折の既往があり(**図2**)，転倒ありの参加者は転倒なしの参加者に比べ有意に多く骨折していた($p<0.05$)．骨折の詳細は転倒ありの参加者が胸腰椎4例，手関節5例，肋骨3例，膝関節1例，肩関節1例，足部・足関節1例，股関節1例であり，転倒なしの参加者が手関節4例，膝関節1例，胸腰椎4例，足部・足関節2例，股関節2例であった．骨折の既往がなく転倒のある転倒群と，転倒のない非転倒群および骨折の既往をもつ骨折群の3群に分けると，転倒群58名，非転倒群212名，骨折群26名であった(**表1**)．これら3群のうち，膝OAを有するものは，転倒群が25名(43.1%)，非転倒群が106名(50.0%)，骨折群が13名(50.0%)で各群間に有意な差は認められなかった．3群の背景において転倒群は非転倒群に比べ高齢であった($p<0.05$)．また，非転倒群は骨折群に比べ身長が高かった($p<0.05$)．

2．歩行解析結果

距離因子の比較検討(**表2**)では歩幅において転倒群は非転倒群に比べ有意に短かった($p<0.05$：オッズ比1.033)．時間因子の相対値の比較検討では立脚期において転倒群が非転倒群に比べ長く，遊脚期において転倒群が非転倒群に比べ短かった($p<0.05$；オッズ比0.925および1.081)．オッズ比をみると，歩幅が1cm減少すると3.3%の確率で転倒率が上昇し，歩行周期における立脚期の比率が1%上昇すると転倒する確率が7.5%上昇，遊脚期の比率が1%上昇すると転倒する確率が8.1%減少すると考えられた.

考　察

転倒はなんらかの障害物につまずくなどして，バランスを崩して発生し，その結果，骨折などの外傷を受傷して，ADLの低下，要介護へと至る．高齢者の転倒のしやすさをスクリーニングするため，様々な運動機能検査が行われている[3~7]．坂田[4]は高齢者自身で評価できる転倒予防法の指標としてバランス能力を反映する開眼片脚起立時間が有効であると報告している．北ほか[5]は開眼片脚起立時間とtimed up & go testが有用であり，開眼片脚起立時間15秒未満，timed up & go test 11秒以上が運動器不安定症の基準

表1　検診参加者背景
数値は平均値±標準偏差.
検定は一元配置分散分析の後，群間比較はScheffe法のPost hoc test.
*$p<0.05$：非転倒群との比較.

	転倒群	非転倒群	骨折群
性別(名)	男22，女36	男74，女138	男5，女21
年齢(歳)	*77.2±6.8	75.0±6.0	77.0±5.4
身長(cm)	151.4±8.1	152.0±8.1	*147.6±7.2
体重(kg)	53.3±9.3	54.4±9.6	50.8±9.6
BMI (kg/m^2)	23.2±3.1	23.5±3.5	23.3±3.8

表２　転倒群・非転倒群と歩行の距離・時間因子
検定は年齢・身長を調整したロジスティック回帰分析.
*p<0.05：非転倒群との比較.

	転倒群(n＝58)	非転倒群(n＝212)	骨折群(n＝26)
歩幅(cm)	*51.0±10.5	54.6±9.2	49.8±10.3
歩隔(cm)	9.2±4.4	8.5±3.6	8.4±3.3
つま先角度(°)	11.1±7.2	9.2±5.0	10.4±5.3
立脚期(秒)	0.66±0.14	0.60±0.09	0.62±0.12
遊脚期(秒)	0.38±0.07	0.39±0.07	0.40±0.05
両脚支持期(秒)	0.13±0.06	0.11±0.03	0.11±0.04
立脚期率(%)	*62.9±5.4	60.9±4.7	60.7±2.1
遊脚期率(%)	*37.1±5.4	39.1±4.7	39.3±2.1
両脚支持期率(%)	11.7±3.7	11.0±2.3	10.9±1.8

となると報告している．我々の先行研究において５回椅子立ち上がり，開眼片脚立位時間，通常速度歩行，最大速度歩行などの運動機能訓練のなかで，転倒群は非転倒群に比べて通常歩行速度が遅いこと，その歩幅が小さいことが示唆された．このため，本研究では通常速度歩行のどの因子が転倒に影響を与えているかを検討した．その結果，転倒群が非転倒群に比べ，歩幅が小さく，相対的に立脚期が長く，遊脚期が短いという結果が得られた．遊脚期は片脚を挙げた状態，つまり片脚立位となっている状態であるため，バランス能力の低下が影響したと考えられる．一方で，歩幅の減少には下肢筋力の低下が影響する[8]ことから，下肢を振り出す股関節屈曲筋群の筋力低下が影響を及ぼしていると考えられた．日本整形外科学会では，主に加齢による運動器障害のために，移動能力の低下を来し，要介護になっていたり，要介護になる危険が高い状態をロコモティブシンドロームと定義し，その予防に開眼片脚立ちとスクワットをロコモーショントレーニング(ロコトレ)として行うことを推奨している[9]．開眼片脚立ちはバランス能の向上に，そしてスクワットは筋力の向上に重点をおいたトレーニングである．本研究では，これら筋力・バランス能の向上が有効であることを支持する結果が得られた．

本研究の限界は対象が296名と少数であること，旧宮川村という山村の限られた地域住民を対象としていること，性差についても背景で両群の有意差はでていないものの，分けて比較検討するほどの総数が得られず，性別での判断は困難であったことが挙げられる．

今後，どの筋がどの程度転倒に影響を与えているかを評価し，地域高齢者に介入して実際に転倒・骨折を予防できるかを検討していく必要があると考えられた．

結　論

- 地域住民を対象として転倒に歩行のどの因子が影響を及ぼしているかを調査した．
- 転倒群は非転倒群に比べ，骨折の既往が多かった．
- 転倒群は非転倒群に比べ，歩幅が小さく，立脚時間が長かった．
- 高齢者の下肢筋力低下，バランス能の低下を反映して，歩幅の減少と相対的な立脚期の時間の増大と遊脚期の時間の減少が起こっていると考えられた．

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Gait Analyzer-mediated Determination of Risk Factors for Falls in the Elderly

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Key words：epidemiology, falling, gait analysis

〔Abstract〕 Falls, which are closely related to unstable gait, can cause fatal fractures in the elderly. Hence, we determined the factors associated with trip-related falls using a gait analyzer. In 2009, we examined 296 inhabitants (male, 101；female, 195；age, >65 years) of Miyagawa village and compared the fall frequencies over the last 2 years among the subjects who experienced fractures (group X, n=26), those who fell without group X (group F, n=58) and those who did not fall without group X (group N, n=212). The average weight and body mass index were not significantly different between the 3 groups. The gait-related factors, i.e., step length, step width, foot angle, the relative time during the stance phase of the gait cycle (STANCE) and the relative time during the swing phase of the gait cycle (SWING), were measured using a gait analyzer (Walk way MW 1000；Anima, Tokyo, Japan). $p<0.05$ was considered significant (age and height-adjusted logistic analysis). The step length of group F was significantly lower than those of group N. The STANCE of group F was significantly longer than that of group N and the SWING of group F was significantly shorter than that of group N. Narrow step length and long stance phase were the risk factors for falls.

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ORIGINAL ARTICLE: EPIDEMIOLOGY, CLINICAL PRACTICE AND HEALTH

Spatiotemporal components of the 3-D gait analysis of community-dwelling middle-aged and elderly Japanese: Age- and sex-related differences

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Aim: To describe age- and sex-related differences in gait patterns of community-living men and women using 3-D gait analysis.

Methods: Subjects (n = 2006) aged 40–84 years participated in the National Institute for Longevity Sciences-Longitudinal Study of Aging (NILS-LSA). Spatiotemporal components, including velocity, step length, step frequency, and double support time during a gait cycle, were calculated from 3-D coordinates and vertical force data. Velocity, step length and step frequency were normalized by leg length and acceleration due to gravity, and double support time was normalized to gait cycle duration.

Results: Spatiotemporal walking variables of brisk velocity and step length were significantly greater in men than in women, while comfortable velocity and comfortable and brisk step frequencies and double support times were greater in women than in men. Age-related changes were marked at 70–84 years in most spatiotemporal variables in both sexes during comfortable walking. During brisk walking, age-related changes were observed from a younger age than during comfortable walking, and there were sex-related differences.

Conclusion: The age-related gait alteration was obvious among those aged 70 years and older, and it accelerated markedly in women's brisk walking intensity. **Geriatr Gerontol Int 2011; 11: 39–49.**

Keywords: aging, gait, sex, velocity, walking.

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Author contributions: W. D. designed the study, obtained the funding, analyzed data and drafted the original article; R. K. interpreted data and advised on revising the article; K. H. Y. supervised data processing and prepared the article; and F. A. and H. S. originated the study, created the gait analysis program, supervised all aspects of its implementations, and contributed to obtaining the funding and revising the article. All authors conducted epidemiological studies on geriatric disease and human aging in Obu, Aichi, Japan, and read and approved the manuscript.

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Introduction

Age-related impairment of ambulatory ability is a critical component for inhibiting activities of daily living (ADL). For instance, decreased gait velocity observed in elderly is an indicator of common distinct diseases[1,2] and falls,[3–6] which lead to functional dependence[7–11] or death.[12] The prevalence and incidence of gait disorders increase with age in elderly persons.[13,14] The early presence of dynamic postural stability may provide more essential information for preserving adequate mobility, delaying the onset of functional decline and encouraging early appropriate lifestyle changes to promote active healthy aging.[6,8,10,11,15]

Previous studies examined age-related changes in spatiotemporal gait parameters including velocity, step length, step frequency (cadence) and selected stride time variables (single and double support time and swing time).[7,8,10,16–21] These performance-based gait variables were often measured by a 3-D gait system that computes the motions of the body center of mass (COM) and each segment, which can accurately evaluate the control of dynamic balance during walking.[22,23] The COM velocity on the 3-D gait system identified the effect of age on older gait in limited comparison between young and older groups.[24–26] It showed that the 3-D analyses conducted have not determined from which age group the accelerated decline of gait started. The collection of data using a large sample size with a broad age range could resolve the issue.

Age-related gait studies have recruited either men or women, or both sexes have been analyzed together: a few studies previously focused on sex-related changes on gait pattern with advancing age. Callisaya *et al.*[8] revealed the effects of sex and age on gait velocity in elderly men and women aged 60–86 years. The results of other studies of various age ranges and groups[17,19,27] to determine which sex shows an earlier age of accelerated gait velocity decrease have differed. The conflicts may partly depend on the sampling and subject characteristics.

Therefore, to understand the aging process in gait measures across the adult lifespan, a large sample size ranging from young or middle-aged to elderly men and women should be warranted. We decided to reinvestigate the previous findings. In the present study, the gait of elderly subjects was investigated based on comfortable and brisk spatiotemporal gait parameters with a 3-D gait analysis system; a large number of subjects were recruited. We found the age-related changes in gait by sex among middle-aged and elderly men and women in Japan. This may contribute to a beneficial effect on assessing gait in elderly people and making an adequate walking exercise program suitable for targeted age groups.

Methods

Study sampling

The present gait analysis is part of the third phase of the National Institute for Longevity Sciences Longitudinal Study of Aging (NILS-LSA); this study includes medical, physiological, nutritional and psychological examinations. The study began in November 1997 (the first phase), and the third phase lasted from May 2002 to May 2004. The subjects were age- and sex-stratified random samples of the population, aged 40–84 years, who lived in Obu-shi and Higashiura-cho, Aichi, Japan. These participants were chosen from the residents registered with local governments. All subjects lived or had lived at their home in the community and had Japanese nationality.[28] The NILS-LSA was approved by the Ethics Committee of the National Center for Geriatrics and Gerontology. Details of the NILS-LSA have been previously published.[28,29]

Of 2378 men and women aged 40–84 years in the third phase examination, 1017 men and 989 women (84.2% of all participants, Table 1) completed the walking tests and were included in the present analysis. The participants also completed a structured questionnaire dealing with their socioeconomic characteristics, cardiovascular risk factors and medical history.[28,29] Exclusion criteria included a current medical history of arthritis[6,8] and fractures (musculoskeletal disorders),[30] stroke[1] and Parkinson's disease (neurological disorders),[8,31] and ischemic heart disease and chronic bronchitis (Table 1).[32,33] These diseases were checked and excluded as the possible cause of gait disorders or spatiotemporal gait parameter changes by a physician before the walking tests. One participant who was diagnosed with dementia was excluded because she had a limited ability to comprehend or execute the test, which was judged by a physician. The existence of walking difficulty in activities of daily living (ADL)[11,15] was also excluded (Table 1). The participants who met the above-mentioned requirements and could walk 10 m independently without a walking aid were included in the current gait analysis and therefore 372 participants of the third phase examination were totally excluded.

Protocol

All participants wore short-sleeved T-shirts and shorts for testing. Shoes were made from the same material that had a vinylon/polyester and cotton blended upper part and a urethane foam outsole (Moonstar, Fukuoka, Japan), and were selected to exactly fit each participant's feet. Ten 2.5-cm diameter optical markers were placed on the participants' left and right sides on the fifth metatarsal heads, the lateral malleoli, the lateral epicondyles, and one-third of the way along the straight lines from the greater trochanters to the anterior

Table 1 Inclusion/exclusion characteristics of 2378 participants in the third wave examination of the National Institute for Longevity Sciences-Longitudinal Study of Aging (NILS-LSA), 2002–2004

Characteristics	Men	Women
Inclusion ($n = 2006$)		
Total (n (%))	1017 (50.7)	989 (49.3)
Age group (n (%))†		
40s	250 (12.5)	279 (13.9)
50s	302 (15.1)	265 (13.2)
60s	250 (12.5)	242 (12.1)
≥70	215 (10.7)	203 (10.1)
Exclusion ($n = 372$)		
Total (n (%))	187 (50.3)	185 (49.7)
Prevalence of disease (n (%))		
Stroke	42 (22.5)	23 (12.4)
Ischemic heart disease	41 (21.9)	41 (22.2)
Chronic bronchitis	7 (3.7)	3 (1.6)
Arthritis	26 (13.9)	56 (30.3)
Fracture	5 (2.7)	6 (3.2)
Dementia	–	1 (0.5)
Parkinson's disease	3 (1.6)	–
Walking difficulties in ADL (n (%))	50 (26.7)	54 (29.2)
Not completed walking test (n (%))	55 (29.4)	53 (28.6)

†χ^2-Test test examines significance among each age group and sex. Values are numbers (% of total at each inclusion/exclusion category) of samples. ADL, activities of daily living.

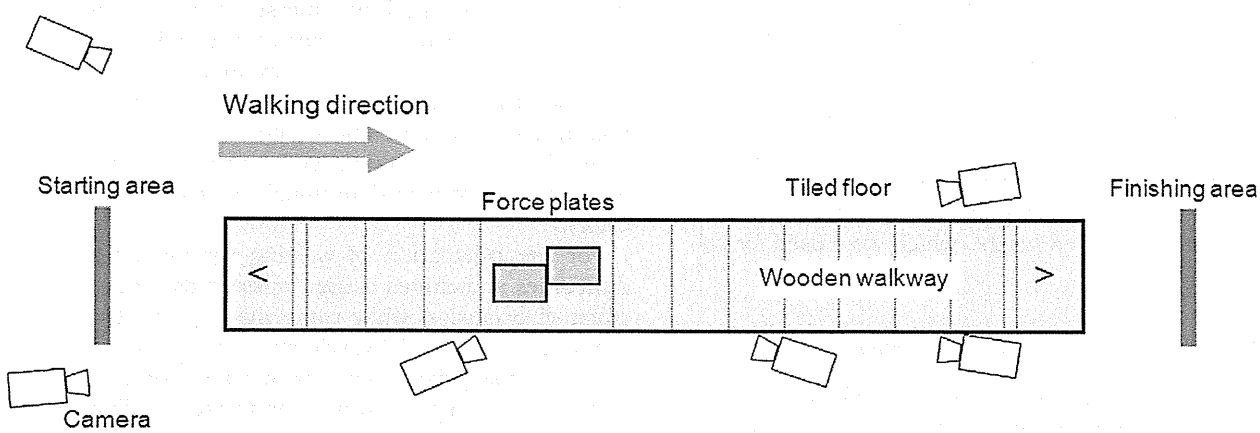

Figure 1 Setup of 3-D gait system: the 10-m walkway consisted of a wooden walkway. Six cameras were placed at various positions and two force platforms were embedded in the center of the walkway. Double support time in pre-swing phase of right foot was measured in this setting.

superior iliac spines and the acromions.[34] The subjects walked on a 10-m walkway at two speeds: (i) at a self-selected pace (comfortable walking); and (ii) as fast as possible without running (brisk walking). Each pace was repeated approximately twice on average. The walkway consisted of a tiled floor and a wooden walkway along the corridor (Fig. 1). The surface of the wooden walkway was covered with gray-colored, thin, stiff rubber, which measured 0.036 m in height from the tile floor surface of the corridor. Force platforms (0.6 m × 0.4 m) (9286; Kistler Instrumente AG, Winterthur, Switzerland), with surface colors similar to those of the walkways, were embedded in the center of the wooden walkway. The starting point for each trial was

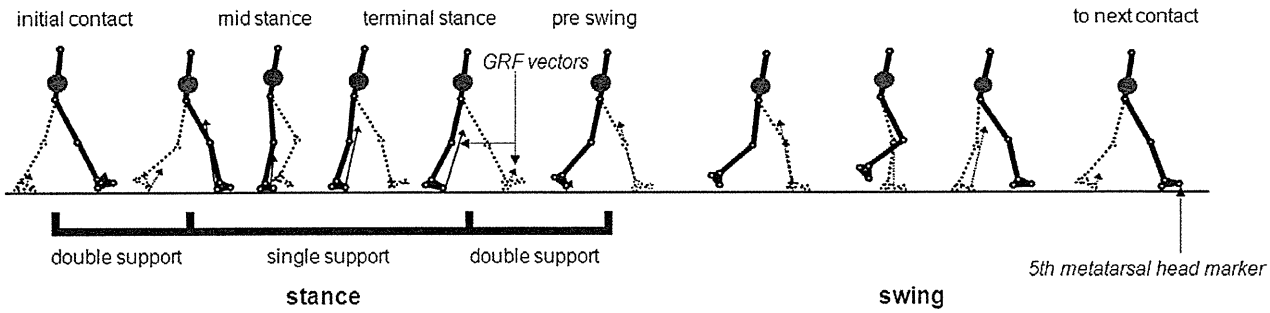

Figure 2 Definition of gait cycle using ground reaction force (GRF) and the fifth metatarsal head marker.

selected in relation to the foot contacts on the force platforms. The distance from each starting and departure point to the force platforms was approximately 3.5–4.5 m. One trial each of comfortable and brisk walking was used in the data analysis. The trials used were those that lacked the least data.

The Vicon 370 system (Oxford Metrics Ltd, Oxford, UK), which consisted of six cameras, was used to obtain the 3-D coordinates of the trunk, thighs, shins and feet. The calibration residual at each camera was set below 1.0 mm. The data were processed using a custom routine that was programmed by the Clinical Gait Analysis Forum of Japan.[34] The raw coordinate data at 60 Hz were digitally filtered with a fourth-order, zero-lag, Butterworth filter[22] with a cut-off at 5 Hz, and the raw ground reaction force data at 1200 Hz were digitally filtered with a cut-off at 10 Hz. The force data were interpolated to correspond with the coordinate data to synchronize the datasets. Smoothed coordinates of the lower extremities were used to construct a rigid link-segment model.[22] Segment masses and inertial properties were determined using previously reports[35] and the participants' mass and height, which were used for calculating COM.

Gait cycle and walking variable calculation

SAS ver. 9.1.3.[36] was used to automatically identify gait event times and each phase of the gait cycle based on kinematic and kinetic gait data. The divisions of the gait cycle are shown in Figure 2.[30] The gait event times for initial contacts and toe off were determined using vertical force data and the vertical motion of the optical marker on the fifth metatarsal head. The period from the first right initial contact to ipsilateral second initial contact was one gait cycle.[30]

Both the right and left leg motions were captured, and primarily the right stride was analyzed. Left leg motion was used for calculating the step length and double support times. The mean COM velocities, step lengths, step frequencies and double support times during a gait cycle were also automatically computed by SAS. The double support time was defined as the duration of time during which each foot was on the ground in the pre-swing phase. The mean COM velocity, step length, and step frequency were normalized as proposed by Hof[37] as follows:

$$\text{Normalized COM velocity, } \hat{v} = \frac{v}{\sqrt{g l_0}},$$

$$\text{Normalized step length, } \hat{l} = \frac{l}{l_0},$$

$$\text{Normalized step frequency, } \hat{f} = \frac{f}{\sqrt{g/l_0}},$$

where v is actual mean COM velocity, l_0 is the leg length of each subject, l is the actual step length, f is the actual step frequency and g is the acceleration due to gravity (9.81 m/s^2). Leg length was measured from the ground to the greater trochanter during quiet standing. Patients with arthritis and fracture were excluded (Table 1), and no case of limited knee extension was observed in the present study. The double support time was also normalized by each subject's cycle duration, from right initial contact to next right initial contact (over one gait cycle).

For the calculation of walking variables, technical difficulties sometimes caused missing data due to the effect of occlusion while capturing motion. Thus, for example, the mean COM velocity over the gait cycle was calculated using data from 1716 men and women (85.5% of the total sample) during comfortable walking and using data from 1614 men and women during brisk walking (80.4%). To demonstrate the lack (or presence) of bias with respect to velocity data loss, the Student's t-test was used to compare the velocity between the group with all available data and that with data available only in the velocity category. The results showed that the velocities were not significantly different between the two groups, and this was confirmed for all walking variables.

Statistical analyses

All analyses were performed using SAS ver. 9.1.3. Sex differences were examined using the Student's t-test. For analysis of age differences, participants were divided

into eight groups based on sex and age (40–49, 50–59, 60–69 and 70–84 years for each sex). Trends in differences across all age groups in the walking variables were tested using the General Linear Model (GLM), and differences by age group were tested using the Tukey–Kramer method for each sex. $P < 0.05$ was considered statistically significant.

Results

The proportion of the sample drawn from each age group and each sex group was the same (χ^2-test, $P > 0.05$). The mean ± standard deviation age was 58.1 ± 11.4 years in men and 58.7 ± 11.4 years in women, which was not significant ($P > 0.05$).

The results of the GLM and Tukey–Kramer tests revealed age-related changes in each age and sex group. Descriptive statistics for all values are shown in Tables 2 and 3 and Figure 3. Mean COM velocities during comfortable and brisk walking significantly decreased with age in both sexes ($P < 0.001$). Age-related changes in the comfortable COM velocity were marked in the 70–84-year group compared with other age groups. Similar changes were found in the brisk COM velocity. The step lengths and frequencies followed these COM velocity patterns in both sexes during both comfortable and brisk walking.

These age-related changes occurred earlier in the middle-aged group. Earlier patterns involving brisk gait parameters were more apparent in women: for example, the brisk COM velocity decreased at 60–69 years in men and at 50–59 years in women, then the decrease accelerated at 70–84 years (Tables 2,3, Fig. 3). The step length and frequency followed these COM velocity patterns. The double support time during pre-swing was significantly increased with age only at the women's comfortable walking pace; it was significantly longer in the 70–84-year group compared to other age groups (Table 3, Fig. 3). The men's double support times showed no significant age-related differences among age groups (P for trend >0.05, Fig. 3).

Descriptive statistics and the results of sex differences for gait parameters are depicted in Table 4. The results of mean COM velocity differed according to walking pace: the comfortable COM velocity was significantly faster in women than in men ($P < 0.001$), and the brisk COM velocity was significantly faster in men than in women. Step length pattern was similar to COM velocity pattern: the brisk step length was longer in men than in women ($P < 0.001$), but the comfortable step length was not significantly different. On the other hand, women had a higher step frequency during both walking paces ($P < 0.001$). The results of the pre-swing double support time were equal to the step frequency.

Discussion

Mobility is essential for independence in the elderly. A better understanding of age-related changes in gait provides useful information for appropriate intervention programs targeting specific age groups.[8] The present cross-sectional, descriptive study showed spatiotemporal components of gait over one gait cycle among community-living middle-aged and elderly Japanese subjects. The sample of 1017 men and 989 women was large enough to allow analysis by age group,[17] and, to the best of our knowledge, the sample size is the largest to be published in which gait characteristics have been analyzed using a 3-D gait system. There was no disproportionate lack of gait data caused by difficulties in capturing the 3-D coordinates.

Mean COM velocities decreased with age, which is in almost complete agreement with previous results, despite the use of different measurement equipment and instrumentation.[16–21,25,29] The age-related decreases in the normalized COM velocities accelerated at 70 years and over were noted at a relatively later age compared with the previous reports: they showed the accelerated decline occurred in 50–59- and 60–69-year age groups,[17] at 62 years,[19] between 60- and 70-year age groups,[20] and at 65 years and in the 67–73-year age group.[18] The differences in age of accelerated decline among the previous and the present findings were likely due to the differences in method and data characteristics.

The brisk COM velocity decreases advancing with age were earlier compared with the comfortable walking. Some previous studies showed the age-related decrease was independent of walking pace,[18–20] while another reported that the decrease depended on the pace.[7] In a report by Bohannon on the comfortable and maximum walking speeds of adults aged 20–79 years,[7] walking speed was found to be influenced by the interaction of pace and age. This result matched our present findings that the age-related decrease was clearer during brisk walking than during comfortable walking. Moreover, these earlier age-related declines in the brisk COM velocities were apparent in women. Some studies reported that the critical age for marked velocity decrease did not differ by sex,[16,19] while another found the critical age to be earlier in men.[17] However, Callisaya *et al.*[8] showed women's walking velocity to be an earlier age-related change compared to men's parameters during the preferred speed of walking among the subjects aged 60 years and older. These results are in agreement with our own, though our data was particularly strong in the brisk parameters across middle-aged and elderly persons. The brisk walking task required greater forward momentum and increased demands in muscle activity[24,38–40] and aerobic capacity[33,41] might alter the spatiotemporal gait parameters accompanying aging.

Table 2 Men's normalized mean COM velocities, step lengths and frequencies and double support times during comfortable and brisk walking in each age group

Men: walking parameters by age group	Mean COM velocity				Step length				Step frequency				Double support times (pre-swing)			
	N	Mean	SD	95% CI	N	Mean	SD	95% CI	N	Mean	SD	95% CI	N	Mean	SD	95% CI
Comfortable walking																
40s	211	0.524	0.053	0.517–0.531	240	0.892	0.065	0.884–0.900	207	0.587	0.043	0.582–0.593	208	14.8	1.5	14.6–15.0
50s	266	0.527	0.059	0.520–0.534	289	0.897	0.076	0.888–0.906	259	0.590	0.042	0.585–0.595	249	14.8	1.5	14.6–14.9
60s	218	0.523	0.067	0.514–0.532	240	0.901	0.089	0.890–0.913	215	0.583	0.046	0.577–0.589	205	14.5	1.6	14.3–14.7
70–	186	0.485	0.070	0.475–0.495	213	0.859	0.096	0.846–0.872	185	0.569	0.047	0.562–0.576	177	15.2	2.0	14.9–15.5
P for trend†	<0.001				<0.001				<0.001				NS			
(Tukey–Kramer test)‡	40s, 50s, 60s >70–				40s, 50s, 60s >70–				40s, 50s, 60s >70–				NA			
Brisk walking																
40s	190	0.705	0.078	0.694–0.716	229	0.998	0.074	0.989–1.008	180	0.707	0.070	0.696–0.717	173	13.3	6.0	12.4–14.2
50s	235	0.699	0.082	0.688–0.709	272	0.998	0.088	0.987–1.008	214	0.697	0.064	0.688–0.705	209	13.3	5.6	12.6–14.1
60s	191	0.678	0.079	0.667–0.690	237	1.000	0.094	0.988–1.012	185	0.685	0.066	0.676–0.695	180	13.4	5.0	12.6–14.1
70–	182	0.618	0.092	0.605–0.631	203	0.946	0.100	0.932–0.960	177	0.657	0.066	0.647–0.667	169	14.1	2.1	13.8–14.4
P for trend†	<0.001				<0.001				<0.001				NS			
(Tukey–Kramer test)‡	40s > 60s > 70–., 50s > 70–				40s, 50s, 60s >70–				40s > 60s > 70–., 50s > 70–				NA			

†Trend tests examine main effects of age in each gait parameter. ‡Tukey–Kramer tests examine the significant difference among each age group. '>' indicates the significant difference between the age groups, with *P*-value is less than 0.5. Values are numbers of samples (N), means (Mean), standard deviations (SD) and 95% confidence intervals (95% CI) at each variable. Age group: 40s, 40–49 years age group; 50s, 50–59 years age group; 60s, 60–69 years age group; 70–, 70–84 years age group. COM, center of mass; NS, not significant; NA, not applicable.

Table 3 Women's normalized mean COM velocities, step lengths and frequencies and double support times during comfortable and brisk walking in each age group

Women: walking parameters by age group	Mean COM velocity				Step length				Step frequency				Double support times (pre-swing)			
	N	Mean	SD	95% CI	N	Mean	SD	95% CI	N	Mean	SD	95% CI	N	Mean	SD	95% CI
Comfortable walking																
40s	228	0.542	0.060	0.535–0.550	267	0.905	0.072	0.896–0.913	223	0.602	0.044	0.596–0.608	212	14.9	1.7	14.7–15.2
50s	224	0.547	0.066	0.538–0.556	252	0.902	0.082	0.891–0.912	219	0.607	0.051	0.600–0.614	214	14.9	1.7	14.7–15.1
60s	210	0.536	0.064	0.527–0.544	236	0.890	0.079	0.880–0.900	207	0.602	0.045	0.596–0.608	189	15.0	1.9	14.8–15.3
70–	173	0.472	0.071	0.461–0.483	189	0.833	0.093	0.820–0.847	169	0.570	0.051	0.562–0.578	148	15.8	1.9	15.5–16.1
P for trend†	<0.001				<0.001				<0.001				<0.001			
(Tukey–Kramer test)‡	40s, 50s, 60s >70–				40s, 50s, 60s >70–				40s, 50s, 60s >70–				70– > 60s, 50s, 40s			
Brisk walking																
40s	216	0.702	0.072	0.692–0.711	269	0.972	0.070	0.963–0.980	210	0.728	0.071	0.719–0.738	201	13.9	1.6	13.7–14.2
50s	215	0.675	0.080	0.665–0.686	252	0.960	0.087	0.950–0.971	212	0.706	0.073	0.696–0.715	209	14.2	1.7	13.9–14.4
60s	212	0.653	0.072	0.643–0.662	230	0.941	0.085	0.929–0.952	209	0.696	0.072	0.687–0.706	199	14.2	1.8	14.0–14.5
70–	173	0.577	0.084	0.565–0.590	187	0.890	0.109	0.875–0.906	163	0.651	0.064	0.562–0.578	157	14.3	8.8	12.9–15.7
P for trend†	<0.001				<0.001				<0.001				NS			
(Tukey–Kramer test)‡	40s > 50s > 60s > 70–				40s > 60s > 70–., 50s > 70–				40s > 50s, 60s > 70–				NA			

†Trend tests examine main effects of age in each gait parameter. ‡Tukey–Kramer tests examine the significant difference among each age group. '>' indicates the significant difference between the age groups, with $P < 0.05$. Values are numbers of samples (N), means, standard deviations (SD) and 95% confidence intervals (95% CI) at each variable. Age group: 40s, 40–49 years age group; 50s, 50–59 years age group; 60s, 60–69 years age group; 70–, 70–84 years age group. COM, center of mass; NS, not significant; NA, not applicable.

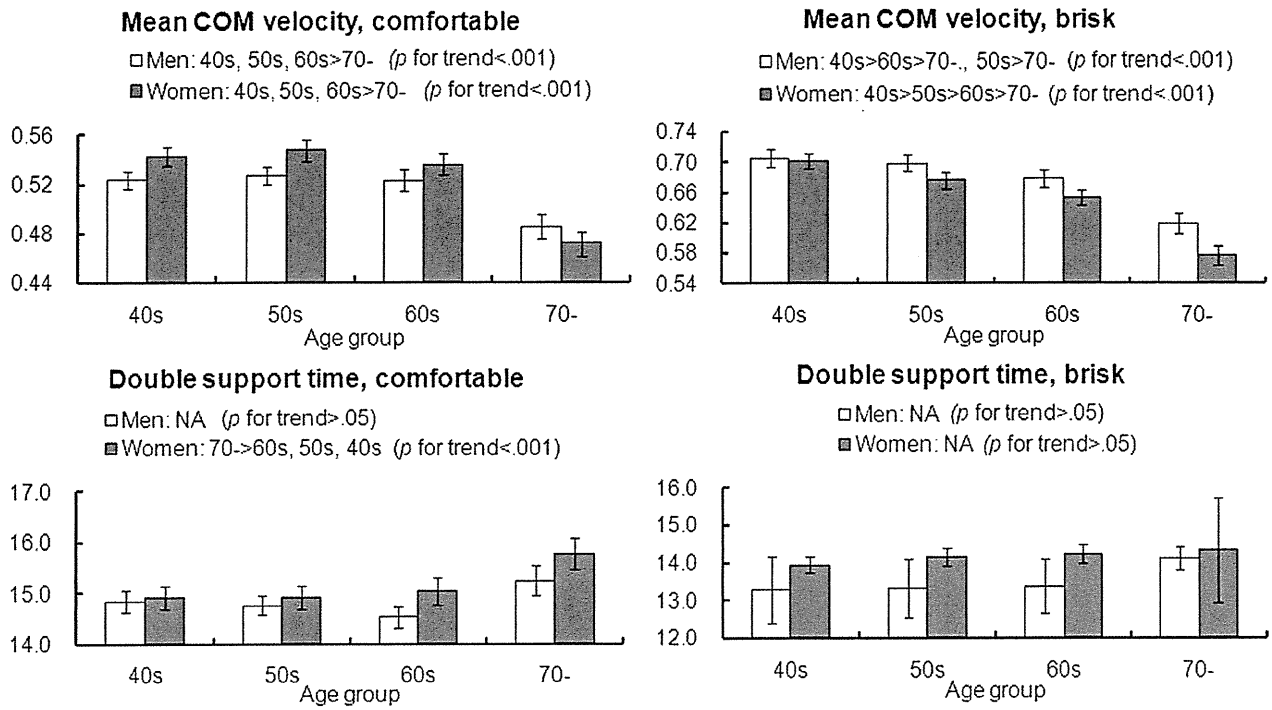

Figure 3 Age-related differences (trend tests and Tukey–Kramer tests); means and 95% confidence intervals of normalized mean center of mass (COM) velocities ($(m/sec)/\sqrt{((m/sec^2)\times m)}$) and double support times (s/s) during comfortable and brisk walking in men and women. Significant differences by age group in men and women are noted on the upper side of each figure. '>' indicates the significant difference between the age groups, with *P*-values of ≤0.05.

Table 4 Normalized mean COM velocities, step lengths and frequencies and double support times during comfortable and brisk walking among men and women

Walking parameters	Men				Women				*P*-value†
	N	Mean	SD	95% CI	N	Mean	SD	95% CI	
Comfortable walking									
Mean COM velocity	881	0.516	0.064	0.512–0.521	835	0.527	0.071	0.523–0.532	<0.001
Step length	982	0.889	0.083	0.883–0.894	944	0.886	0.085	0.881–0.891	NS
Step frequency	866	0.583	0.069	0.580–0.586	818	0.597	0.045	0.593–0.600	<0.001
Double support time (pre-swing)	839	14.8	1.7	14.7–14.9	763	15.1	1.8	15.0–15.2	<0.001
Brisk walking									
Mean COM velocity	798	0.677	0.089	0.671–0.683	816	0.656	0.089	0.650–0.662	<0.001
Step length	941	0.987	0.092	0.981–0.993	938	0.945	0.092	0.939–0.951	<0.001
Step frequency	756	0.687	0.075	0.682–0.692	794	0.698	0.049	0.693–0.703	<0.001
Double support time (pre-swing)	731	13.5	5.0	13.2–13.9	766	14.2	4.3	13.9–14.5	<0.01

†Student *t*-tests examine the sex differences. Values are numbers of samples (N), means, standard deviations (SD) and 95% confidence intervals (95% CI) at each variable. COM, center of mass; NS, not significant.

Further investigation should have discussed the difference between comfortable and brisk walking parameters.[38,42,43]

Age-related step length decreases during comfortable and brisk walking were almost concomitant with the COM velocity decreases, which was similar to the previous findings.[16,20] In brisk walking, however, age-related reduction in the step length seemed to be smaller than that in the step frequency compared with comfortable walking. For example, women's brisk step length decrease was 8.4% across middle-aged and elderly groups compared with their step frequency decrease of 10.7% (Table 3). This was observed also in men's. This may suggest that ambulatory ability observed in the COM velocity may be caused more by the step length during comfortable walking and the step frequency

during brisk walking in the elderly. This was also apparent in middle-aged women. The interpretation was limited qualitatively and should be further explored.

Step frequencies also decreased with age and this decrease was found even in middle-aged women during brisk walking. Previous studies in step frequency reported no age-related changes,[16,17,21] age-related decrease[8,18–20,25] and age-related increase.[26] Moreover, the current age- and sex-related decrease depending on required walking pace was not previously reported.[16,17] One explanation of these conflicts was that degree of the age-related reduction in step frequency was relatively less than that in other gait parameters such as velocity or step length.[8,17,19,20] Therefore, sample size, subject characteristics and measuring instruments may affect the age-related decrease in the step frequency.[16,25] Double support times in the present study did not increase with age, with the exception of women's comfortable data. On the other hand, exploratory analyses of actual values of double support times showed age-related increases in both sexes during both walking paces (data not shown, P for trend <0.001, <0.022). This shows that the double support as a percentage of one gait cycle remained almost constant in middle-aged and elderly subjects. Ferrandez *et al.*[32] found that double support time increased as velocity decreased, and that prolonged double support time was affected more by walking velocity than age.

The present study found brisk COM velocity and step length to be greater in men than in women. By contrast, step frequencies and double support times were greater in women than in men. This is characteristic of sex differences and is supported by previous findings.[8,17,21] Although the comfortable COM velocity was faster in women than in men, this is believed to be a result of the difference in body size as the actual comfortable COM velocity was significantly faster in men than in women (men, 1.46 ± 0.18 m/s; women, 1.43 ± 0.20 m/s; $P < 0.001$). The comfortable step length did not differ significantly between either sex group, perhaps because of the slower men's COM velocity.

The present gait data may give some insight into gait assessment and preventive walking exercise programs for older persons as previously reported.[42,44,45] The values for the gait parameters during one gait cycle may be useful to clinicians judging the ambulatory ability of patients from a short indoor walk.[7,42] Patients whose gait parameters are lower than that of their appropriate age group are at increased risk of ADL difficulties.[8,11] Comfortable and brisk walking velocities are predictive of adverse outcomes such as loss of physical function, requirement of caregivers, hospitalization and increased mortality in elderly persons.[8,10–12] Decreased step length and prolonged double support time are correlated with fear of falling and/or future fall risk.[4,5,9] Also, the other gait parameters such as gait velocity,[9,11] stride-to-stride variability[4] and lateral sway[3,5,6,46] are associated with the falling events. We did not directly ascertain whether the participants had a history of falls and/or a fear of falling in our gait parameters. Further work should confirm which gait measure is the best independent predictor for future fall risk in a large sample.

A moderate workload prescription in walking exercise programs should be given by controlling both step length and step frequency during comfortable walking in the elderly. Brisk walking, which is recommended for moderately vigorous endurance training and has a high impact compared to comfortable pace walking, might be considered for middle-aged women and the elderly to improve physical functions such as muscle strength[7,40,43] and/or cardiovascular fitness.[33,41]

This study has some limitations. Some previous gait investigations used the results of several trials or mean values of gait, while we used gait data from one trial of each participant. This was done because of technical difficulties in the automatically computed 3-D gait parameters. Next, the conjunction of our excluding criteria with the potential diseases might overestimate gait disorders: the elderly subjects were more likely to be healthy and physically fit. Moreover, patients with dementia were considered to be less in the present sample. The general comparability of the present gait variables with previously reported data is limited because of the lack of data for young adults in their 20s and 30s. Furthermore, our cross-sectional analysis approach could not demonstrate a cause-and-effect relationship from aging. We are planning longitudinal studies to further determine the effects of aging on gait. The present study included regional limitations such as race, culture, lifestyle, genetics and socioeconomic status which also may be important. However, the findings did permit age- and sex-related differences in gait to be clarified in the elderly.

In conclusion, age- and sex-related gait alterations were apparent in one gait cycle of walking in a large sample of community-dwelling, middle-aged and elderly Japanese men and women, when analyzed by a 3-D gait system. There were marked age-related gait differences in subjects aged 70 years and over compared to subjects aged 40–69 years during comfortable walking, and subtle differences were also observed in subjects aged 40–69 years during brisk walking. The earlier age-related changes were clearer in women than in men. These results may guide the assessment of gait patterns attributed to usual aging and to develop moderate exercise programs for the elderly.

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Impact of Caregiver Burden on Adverse Health Outcomes in Community-Dwelling Dependent Older Care Recipients

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Objective: *To determine whether caregiver burden is associated with subsequent all-cause mortality or hospitalization among dependent community-dwelling older care recipients.* **Methods:** *A prospective cohort study of 1,067 pairs of community-dwelling 65-year-old or older care recipients and their informal caregivers was conducted. The 1,067 pairs completed the baseline assessment including caregiver burden assessed by the Zarit Burden Interview and a 3-year follow-up for all-cause mortality and hospitalization.* **Results:** *During the 3-year follow-up, 268 recipients died and 455 were admitted to hospitals. The multivariate Cox proportional hazards model revealed that the recipients with caregivers with a baseline ZBI score in the highest quartile were 1.54 and 1.51 times more likely to show increased risks of all-cause mortality and hospitalization, respectively, in comparison with those with caregivers in the lowest quartile after adjustment for potential confounders. The highest quartile of caregiver burden was associated with all-cause mortality and hospitalization within nonusers of respite services including day-care services, home-help services, and nursing-home respite stay services. No apparent association was observed within the users of these services except for day-care services, for which users showed a statistically significant association between the highest quartile and the risk of hospitalization.* **Conclusions:** *Heavy caregiver burden is associated with mortality and hospitalization among community-dwelling dependent older adults, even after adjusting for potential confounders. The reduction of caregiver burden and improvement of caregiver well-being may not only prevent the deterioration of caregiver health but also reduce adverse health outcomes for care recipients.* (Am J Geriatr Psychiatry 2011; 19:382–391)

Key Words: Caregiver burden, mortlity, hospitalization, adverse health outcomes of care recipient

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The current trend toward a community-based healthcare system means that when older people require care, much of it is provided at home. Thus, family members are providing care for ill or disabled older relatives. Family caregiving has been intensively studied in the past decade, particularly the impact on caregivers of providing home care to a family member. Caregiver burden has been defined as a negative reaction to the impact of providing care on the caregiver's social, occupational, and personal roles.[1–3] It is well documented that informal care for the disabled elderly places heavy burdens on family caregivers.[1–3] Previous studies demonstrated that caregiver burden is associated with the substantial care needs of seriously ill patients, which are in turn associated with the presence of dementia, behavioral problems, poorer physical functioning, and factors that are not readily modifiable.[4–7] Caregiver burden can lead to a chronic stress response that can worsen caregiver health, contribute to psychiatric morbidity in the form of increased depression,[8] contribute to the risk of health problems such as wound healing impairment, elevated blood pressure, and coronary heart disease risk and immune function impairment,[9–11] and is an independent risk factor for mortality.[12]

Thus, most of the previous studies on caregiver burden have focused on examining its cause(s) and extensively examining caregiver health. However, conversely, much less attention has been paid to the impact of caregiver burden or distress on the health of the partner, the care recipient. In fact, it remains uncertain whether caregiver burden or distress has any influence on the health-related outcomes of care recipients, although the association of caregiver burden with long-term care placement has been well demonstrated.[13,14] In this study, we investigated whether caregiver burden is associated with adverse health outcomes of the care recipients, including all-cause mortality and hospitalization for acute illness, during a 3-year study period. In addition, we examined the effect of community-based respite care services, including day-care, home-help, and nursing-home respite stay services on the adverse outcomes of care recipients.

METHODS

Study Setting and Cohort Participants

In this study, we employed baseline data on the care recipient and caregiver pairs in the Nagoya Longitudinal Study for Frail Elderly (NLS-FE) and data on the mortality and hospitalization of the care recipients during the 3-year follow-up period. Japan introduced a universal-coverage long-term care insurance (LTCI) program in 2000. Under the LTCI program, each applicant's care levels are determined according to eligibility criteria. Eligibility status is classified into six levels ("needs support" and care levels 1–5) by the estimation of care needs based on an assessment of the current physical and mental status of the patient and their use of medical procedures.[15] The NLS-FE was designed to compare the outcomes of different uses of community-based care services provided by the LTCI program.[16,17] The study sample consisted of 1,875 community-dwelling elderly (632 men and 1,243 women, age 65 years or older) with some degree of physical or mental disability. They were eligible for the LTCI program, lived in Nagoya City, Japan, and received various kinds of community-based services from the Nagoya City Health Care Service Foundation for Older People, which has 17 visiting nursing stations associated with care-managing centers. These 1,875 NLS-FE participants and 1,502 caregivers (373 of the 1,875 participants lacked a primary caregiver), who were enrolled between December 1, 2003, and January 31, 2004, were scheduled to undergo comprehensive in-home assessments by trained nurses at the baseline and at 6, 12, and 24 months. At 3-month intervals, data were collected about any important events in the lives of the participants, including mortality and admission to the hospital for acute illness during the 3-year follow-up. Written informed consent for participation was obtained from the participants, care recipients, and caregivers, or, for those with substantial cognitive impairment, from a surrogate (usually the closest relative or legal guardian), according to procedures approved by the Institutional Review Board of Nagoya University Graduate School of Medicine.

Data Collection

The data were collected at the clients' homes through structured interviews with care recipients or surrogates and caregivers and from care-managing center records taken by trained nurses. The data included each participant's demographic characteristics, general socioeconomic status, living arrangements, subjective economic status, use of medical services, and the utilization of a total of seven community-based services available under LTCI programs, including the day-care service, visiting nurse service, home-help service, visiting bathing service, visiting rehabilitation, assistive device leasing, and nursing-home respite stay (overnight respite, temporary stays at nursing facilities). The data also included depressive symptoms as assessed by the 15-item Geriatric Depression Scale (GDS-15) (range: 0–15, with higher values indicating more depressive symptoms)[18] and a rating for eight basic activities of daily living (bADL) using summary scores ranging from 0 (total disability) to 20 (no disability). The information on the following physician-diagnosed chronic conditions was obtained from care-managing center records: ischemic heart disease, congestive heart failure, cerebrovascular disease, diabetes mellitus, dementia, chronic obstructive pulmonary disease, cancer, hypertension, and other diseases comprising the Charlson Comorbidity Index,[19] which represents a sum of weighted indexes that takes into account the number and seriousness of preexisting comorbid conditions (range: 0–19, with a higher value indicating higher comorbidity).

Data were also obtained from caregivers concerning their own personal demographic characteristics including caregiver relationship to care recipient (spouse or not), and the presence of behavioral disturbance of the care recipient according to the primary assessment dataset of the public LTCI, including wandering, hallucinations, physically aggressive behaviors, verbal aggression, delusions, altered sleep-wake cycles, sexually disinhibited behaviors, aberrant behaviors, abnormal eating behaviors, and resistance to care. Depressive symptoms were assessed by the GDS-15, and the caregiver's subjective burden was assessed by the Japanese version of the Zarit Burden Interview (ZBI), which is a 22-item self-report inventory that examines the burden associated with functional behavioral impairments in the home care situation (range: 0–88, with higher values indicating a greater burden). The primary caregivers were also asked to rate their current overall health in three categories of subjective health status (poor, fair, and good to excellent).

Subjects for the Analysis

Among the original 1,502 pairs at baseline, 276 caregivers could not complete or refused to assess the ZBI, and the data on comorbidity condition or sociodemographic characteristics were lacking for 159 participants. The study sample, therefore, consisted of 1,067 community-dwelling disabled elderly (387 men, 680 women, age range: 65–104 years) and paired caregivers (256 men, 811 women, age range: 31–90 years). There were no statistical differences in mortality and hospitalization rates during the follow-up period between participants with and without caregiver ZBI measurements among the 1,502 participants. Of these 1,067 pairs, 259 care recipients could not complete the GDS-15 because of severe cognitive impairment or communication impairment, and 101 caregivers because of refusal to do the assessment.

Statistical Analysis

The ZBI score was categorized into quartiles (quartile 1: score, 0–15, N = 284; quartile 2: 16–26, N = 253; quartile 3: 27–39, N = 269; quartile 4: 40–84, N = 261). Baseline characteristics of the study participants, including both care recipients and caregivers, were examined using the Jonckheere–Terpstra test or the General Linear Models for trends across the quartiles of the ZBI score. Analysis of variance for multiple comparisons was used to determine differences among the quartiles of the ZBI score for continuous variables, and the Pearson χ^2 test was used to test categorical variables. The end point of this study was defined as the time to all-cause death or hospitalization because of acute illness, whichever occurred first, during follow-up. Cox proportional hazard models and the Kaplan–Meier method (differences between strata of the ZBI score levels determined using log-rank tests) were used to assess the association of quartiles of the ZBI score with those adverse outcomes after enrollment during a 3-year period (3-month intervals). To create an ideal model for a multivariate Cox proportional hazards model, we first evaluated the association between

each covariate and all-cause death or hospitalization, using the univariate Cox proportional hazards model. Covariates included, for the recipient, sociodemographic characteristics, the presence or absence of regular medical checkups, the number of community-based services, economic status, bADL score, the Charlson comorbidity index, and the presence or absence of selected major comorbidities and behavioral problems. Covariates also included, for the caregiver, sociodemographic characteristics, subjective health status, and categorized ZBI score. In the multivariate analysis, the covariates included were variables associated with each event with $p < 0.05$ in univariate analysis. In models considering the quartiles of the caregiver ZBI score, we compared hazard ratios (HRs) with a corresponding 95% confidence interval (CI) in the second, third, and fourth quartiles with those in the first quartile (referent).

Additional analyses stratified by the use or nonuse of community-based respite care services including day-care, home-help, and nursing-home respite stay services were also performed using a consistent set of covariates to examine the data for possible interactions of these variables with the adverse health outcomes of care recipients. Student's *t*-test and analysis of covariance (ANCOVA) were used to compare the caregiver ZBI score according to the service use and nonuse groups. Covariates of ANCOVA included recipient gender, age, bADL score, the Charlson comorbidity index, the presence or absence of dementia and behavior problems, caregiver gender, and caregiver age.

The data were analyzed using the SAS, Release 9.13. Probability value of <0.05 was considered significant.

RESULTS

The baseline distribution of the sociodemographic characteristics of the care recipients and caregivers according to the quartiles of the ZBI score is shown in Table 1. We used analysis of variance or Pearson χ^2 test to evaluate differences among the quartiles of the ZBI score. The bADL score decreased, and the number of community-based services used, the Charlson comorbidity index, and recipient GDS-15 score increased as the level of the ZBI quartile increased. The care recipients whose caregivers' ZBI scores were in higher quartiles were more likely to show a higher prevalence of dementia (χ^2 test: $\chi^2 = 61.09$, degrees of freedom [*df*] = 3, $p < 0.001$; Jonckheere-Terpstra test: *z* statistics, Z value = 7.51, N = 1,067, $p < 0.001$), behavioral problems ($\chi^2 = 14.75$, $df = 3$, $p = 0.002$; Jonckheere-Terpstra test, Z value = 8.58, N = 1,067, $p < 0.001$) and a history of cerebrovascular disease ($\chi^2 = 10.31$, $df = 3$, $p = 0.016$; Jonckheere-Terpstra test, Z value = 2.37, N = 1,067, $p = 0.018$). The caregiver's GDS-15 score increased (General Linear Model, *F* value = 313.48, $df = 1{,}964$, $p < 0.001$), and the prevalence of good to excellent subjective health status of the caregiver decreased with increasing quartiles of the ZBI score (Jonckheere-Terpstra test, Z value = 5.37, N = 1,067, $p < 0.001$). There were no differences in the rate of regular medical checkups (χ^2 test, $\chi^2 = 5.66$, $df = 3$, $p = 0.130$), living arrangements (living alone or with one person versus living with two or more, $\chi^2 = 1.46$, $df = 3$, $p = 0.692$), and three categories of economic status ($\chi^2 = 6.70$, $df = 3$, $p = 0.349$) among the quartiles of the ZBI score.

During the 3-year period, 268 care recipients died and 455 were admitted to hospitals (Table 2). The participants whose caregivers' ZBI scores were in the higher quartiles were more likely to die and be hospitalized during the follow-up period than those whose caregivers' scores were in the lower quartile categories (χ^2 test, $\chi^2 = 9.78$, $df = 3$, $p = 0.020$; $\chi^2 = 11.09$, $df = 3$, $p = 0.007$, respectively).

Kaplan–Meier curves of survival and the cumulative incidence of hospitalization during the 3-year period among care recipients according to the quartile of the caregivers' ZBI scores demonstrated that all-cause mortality and hospitalization increased with higher quartiles of caregiver ZBI at baseline (log-rank χ^2 test, mortality: $\chi^2 = 17.29$, $df = 3$, $p < 0.001$; hospitalization: $\chi^2 = 23.61$, $df = 3$, $p < 0.001$; Fig. 1).

The univariate Cox proportional hazards model revealed that the recipients whose caregivers' ZBI scores were in the highest quartile were 1.93 times and 1.86 times more likely to suffer all-cause mortality and hospitalization, respectively, during the 3-year period than those in the lowest quartile (95% CI: 1.38–2.71, Wald χ^2 test, $\chi^2 = 14.80$, $df = 1$, $p < 0.001$; 95% CI: 1.43–2.42, Wald $\chi^2 = 21.16$, $df = 1$, $p < 0.001$). The GDS-15 score of the care recipients and caregivers was not associated with mortality and hospitalization in univariate analysis (mortality: HR: 1.03; 95% CI: 0.98–1.07, Wald χ^2