MATERIALS

The Characteristics of Fast Speed Walking in Old Men from the Viewpoint of the Ground Reaction Forces

Kazuo MAIE¹⁾, Tadatoshi YAMADA²⁾, Shiro KONDO¹⁾ and
Hideyuki TANAKA¹⁾

1) *The Institute of Human Living Sciences,
Otsuma Women's University*

2) *Bridgestone Corp., Sports Research Division*

Abstract Characteristics of the fast speed walking in old men, primarily from the viewpoint of the ground reaction forces, were investigated in comparison with those during the ordinary speed walking. As a result, the following were recognized as the characteristics of fast speed walking in old men; (1) the walking speed, step length, and brake impulse as well as acceleration impulse began to decrease pronouncedly from the age group in their 60s, (2) the walking of subjects in their 60s and 70s were hastened from the ordinary speed level with almost the same ratios as in the younger subjects, (3) increase of the step length during the fast speed walking, against those during the ordinary speed walking, was smaller in subjects in their 70s than in the younger, (4) increase of the brake impulse during the fast speed walking, against those during the ordinary speed walking, began to decrease from the age-group in their 60s, while (5) that of the acceleration impulse remained unchanged with age. The principal component analysis revealed that (6) the contents of the fast speed walking are almost identical in ages between 20s and 50s, suggesting that they begin to change at one's 60s.

Key Words Fast speed walking, Step length, Ground reaction forces, Old men, Principal component analysis

Introduction

A number of studies have reported on the characteristics of walking in the elderly. For instance, MURRAY *et al.* (1969) summarized their previous studies (MURRAY *et al.*, 1964, 1966a, 1966b, 1967) that the old men walked with shorter stride, broader step breadth, lower cadence, less swing-to-stance phase duration, and

less movement of several body segments. They also reported that the walking in old men beyond 65 years old were widely different from that in the younger. YAMADA *et al.* (1988) reported, primarily from the viewpoint of the ground reaction forces, that the characteristics of ordinary speed walking in old men were as follows; 1) the impulses of brake and acceleration decreased in the age-groups of 60s and 70s, 2) the transverse

peak force (outward) and its impulse increased in 60s and 70s, 3) the 1st and 2nd peaks of the vertical force decreased and its minimum force increased in 60s and 70s, 4) the step length and the walking speed decreased in 60s and 70s, and 5) from the principal component analysis, the contents of the 1st, 2nd, and 3rd principal components remained almost unchanged from 20s to 40s, but altered according to age-groups from 50s to 70s, suggesting that the ordinary speed walking begins to change at one's 50s.

With respect to the walking at higher speeds, however, studies seems to be scarce for the elderly. The maximum speed walking is regarded as a useful measure of physical fitness (ITO *et al.*, 1989), but it is not always suitable for the elderly. We thought that the fast speed walking could be one of the indices of physical fitness, especially for the elderly, in place of the maximum speed walking. Besides, information on the biomechanical features of the fast speed walking would be useful for the shoe construction.

The purpose of this study is to clarify, primarily from the viewpoint of the ground reaction forces, the characteristics of fast speed walking in old men, in comparison with the ordinary speed walking. The data of ordinary speed walking are just the same as those used in our previous paper (YAMADA *et al.*, 1988).

Subjects and Methods

The subjects were 66 male Japanese living around Tokyo, aged from 23 to 78 years, who were the same subjects examined in our previous paper (YAMADA *et al.*, 1988). They were divided into six age groups; 20s, 30s, 40s, 50s, 60s, and 70s. The subjects in their 70s were the members of a gate-ball sports club. The physical characteristics of the subjects are listed in Table 1.

The subjects were asked to walk barefoot at their own fast speeds for several times, on the level indoor track of ten meters long. The instruction given to the subjects was only "Please walk naturally at your fast speed". The characteristics of walking, as have been noticed frequently, depend on the walking speed (KIMURA, 1985). But we did not control their walking speed by showing the speed or cadence indicator, in order to avoid the awkwardness of gait caused by the speed or cadence control. The walking speed was measured by analyzing video images, and the step length was measured from the foot prints marked by white powder.

A force platform (Kistler Co.) of 60 cm long and 40 cm wide was set in the middle of the track. The three dimensional ground reaction forces, sagittal (Fs), transverse (Ft), and vertical (Fv) were led to the microcomputer and sampled at 100 Hz. The force parameters used in this study are shown in Fig. 1. To diminish the effect of the absolute body weight, each parameter was

Table 1. Physical characteristics of the subjects

Age group	Subject's number	Age (yrs.)		Stature (cm)		Foot lgth. (cm)		Grip strgth. (kg)	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
70s	11	74.3	2.28	157.8	5.76	23.49	0.66	34.8	5.30
60s	10	67.3	1.57	162.8	4.75	24.37	1.06	37.5	6.10
50s	10	51.8	1.40	167.0	4.79	25.17	0.84	49.0	6.84
40s	10	43.2	2.30	164.7	5.38	24.41	0.79	46.0	6.98
30s	13	34.2	2.94	169.2	6.13	24.78	0.86	48.3	5.43
20s	12	26.2	1.85	170.8	6.47	25.12	0.89	50.0	7.58

Fig. 1. The ground reaction force parameters used in the analysis: 1) F_{to} and 2) $\int F_{to} \cdot dt$ in the transverse force mean the outwards peak value and the outwards impulse, respectively; 3) $\int F_b \cdot dt$ and 4) $\int F_a \cdot dt$ in the sagittal force mean the impulses of brake and acceleration, respectively; 5) F_{v1} , 6) F_{vm} , and 7) F_{v2} in the vertical force mean the first peak value, the minimum value, and the second peak value, respectively; 8) $\int F_v \cdot dt$ in the vertical force means the vertical impulse. The eight items were normalized by the body weight (W) or the product of the body weight multiplied by the stance phase duration (WT).

normalized by the body weight (W) or the product of the body weight multiplied by the stance phase duration (WT). The ground reaction forces of the right foot in the most natural trial were used as the data.

The Principal Component Analysis (PCA) was applied to the ground reaction force items. In the preliminary analysis, the items with low contribution coefficients, such as the maximum F_t at heel contact, and one of two items showing high linear correlation coefficients, such as the braking component of the sagittal force (F_b) and

its impulse, were omitted. Finally, the following eight items of the ground reaction forces were chosen for the PCA; 1) the normalized outward peak force of F_t at toe kick-off; F_{to}/W , 2) the normalized outward impulse of F_t ; $\int F_{to} \cdot dt / WT$, 3) the normalized impulse of F_b ; $\int F_b \cdot dt / WT$, 4) the normalized impulse of the accelerating component of the sagittal force (F_a); $\int F_a \cdot dt / WT$, 5) the normalized 1st peak force of F_v ; F_{v1}/W , 6) the normalized 2nd peak force of F_v ; F_{v2}/W , 7) the normalized minimum force of F_v ; F_{vm}/W , and 8) the normalized impulse of F_v ; $\int F_v \cdot dt / WT$. In addition to those items, the step length, walking speed, and grip strength as indices of physical fitness were included for the PCA. The PCA with varimax rotation was performed for each age group as well as for the whole subjects.

Results and Discussion

The mean and standard deviation of the walking speed, step length, step length relative to the stature, and eight items of the ground reaction forces during the fast speed walking are listed for each age group in Table 2, in comparison with those during the ordinary speed walking.

Fig. 2 illustrates the results for the walking speed, which decrease like a stair or sawtooth pattern at one's 40s and 60s, both for ordinary and fast speed walking. The mean walking speeds of fast speed walking in 60s and 70s were lower than those of the ordinary speed walking in 20s and 30s. MURRAY *et al.* (1969) reported a similar trend for the mean walking speed; it decreased like a stair pattern at the age group of 67–73, during both ordinary and fast speed walking. However, their mean speeds of the fast speed walking in three age groups over 67–73 were not lower than those during the ordinary speed walking in the age group of 20–25.

Fig. 3 compares the step length between the

Table 2. Walking characteristics of the ordinary speed walking and fast speed walking in each age group

	20s		30s		40s		50s		60s		70s	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
<i>Ordinary speed walking</i>												
Walking speed (km/h)	4.33	0.35	4.54	0.57	3.42	0.60	3.56	0.50	2.68	0.39	2.51	0.47
Step length (cm)	65.40	6.25	67.60	6.40	63.70	5.11	63.90	5.25	57.90	6.02	55.27	4.98
Step length/Stature (%)	38.32	3.12	39.91	3.42	38.71	3.00	38.32	3.22	35.63	3.30	35.30	2.74
Fto/W (%)	3.50	1.20	4.20	0.91	3.80	0.82	5.51	1.80	4.83	1.31	4.60	1.22
Fto-dt/WT (%)	2.11	0.70	2.11	0.60	2.10	0.62	2.60	0.84	2.43	0.61	2.50	1.00
Fb-dt/WT (%)	4.51	0.61	4.82	0.83	4.30	0.90	3.91	0.82	3.42	0.80	3.52	0.63
Fa-dt/WT (%)	4.52	0.52	4.73	0.60	4.71	0.44	4.51	0.70	3.72	0.60	4.12	0.62
Fv1/W (%)	109.81	5.52	114.00	9.54	107.43	6.22	104.63	8.50	101.82	6.71	100.00	5.83
Fvm/W (%)	78.22	5.91	76.52	6.33	80.80	4.21	81.00	6.54	85.22	5.84	84.54	4.91
Fv2/W (%)	109.44	5.71	110.71	5.33	106.60	5.22	110.32	4.61	107.91	7.32	107.31	7.11
Fv-dt/WT (%)	80.62	2.00	81.84	2.00	81.63	0.91	81.22	1.61	80.54	2.22	80.33	2.81
<i>Fast speed walking</i>												
Walking speed (km/h)	6.10	0.58	6.28	0.40	4.96	0.55	5.03	0.75	3.83	0.66	3.66	0.68
Step length (cm)	78.74	7.54	80.22	4.61	74.75	8.26	76.61	9.07	67.15	6.17	63.29	5.98
Step length/Stature (%)	46.10	4.31	47.32	1.94	45.82	5.32	45.93	5.84	41.41	3.00	39.50	4.44
Fto/W (%)	3.62	1.97	3.95	1.38	3.18	1.18	4.54	1.61	4.56	1.57	4.54	1.27
Fto-dt/WT (%)	2.33	0.87	2.50	0.90	2.17	0.93	2.58	1.04	2.43	0.94	2.62	1.01
Fb-dt/WT (%)	6.31	0.96	6.90	0.91	6.06	1.69	5.82	1.39	3.78	0.93	4.42	1.10
Fa-dt/WT (%)	5.37	0.67	5.64	0.67	5.42	0.70	5.16	0.93	4.38	1.04	5.02	0.60
Fv1/W (%)	130.36	12.15	140.91	10.86	135.53	19.49	121.37	23.80	111.66	14.98	119.35	14.56
Fvm/W (%)	60.86	9.15	58.13	9.05	63.26	10.40	67.24	10.69	73.68	10.42	70.75	11.14
Fv2/W (%)	112.33	8.47	112.04	10.33	103.53	8.55	108.65	8.48	106.23	10.25	104.30	7.59
Fv-dt/WT (%)	82.14	1.93	83.28	2.39	82.25	3.02	81.86	2.65	80.15	3.11	82.34	2.11

Fig. 2. The mean walking speed in each age group. Vertical bars indicate +1SD.

Fig. 3. The mean step length in each age group. Vertical bars indicate +1SD.

Fig. 4. The mean normalized impulse of brake in each age group. Vertical bars indicate +1SD.

Fig. 5. The mean normalized impulse of acceleration in each age group. Vertical bars indicate +1SD.

Fig. 6. Schematic patterns of the normalized vertical force (Fv/W) in each age group. The numbers in parentheses show, from left to right, the mean value and the standard deviation for Fv1/W, Fvm/W, and Fv2/W, respectively.

ordinary and fast speed walking in each age group. The step length also decreased according to the age, with a stair pattern at 60s.

Figs. 4 and 5 show the age-related change of the brake and acceleration impulses, respectively, during the ordinary and fast speed walking. For the fast speed walking, both impulses show a pronounced decrease at 60s. Those on 70s were a little higher than those in 60s, but it depended on the subjects in their 70s, who were the members of a gate-ball sport club.

The normalized vertical forces during the ordinary and fast speed walking in each age group are shown in Fig. 6, together with the means for the peak values. In all age groups, the 1st peak forces ($Fv1/W$) are enhanced during the fast speed walking than during the ordinary speed walking, while the minimum force (Fvm/W) decreased during the fast speed walking from the ordinary speed walking levels. In contrast, the 2nd peak forces ($Fv2/W$) during the fast speed walking are almost identical with those during the ordinary speed walking in all age groups. Thus, the peaks of the vertical forces even in 60s and 70s seemed to be still sharp during the fast speed walking, as compared with those during the ordinary speed walking which were more dull.

The ratios of walking speed, step length, and brake as well as acceleration impulse during the fast speed walking against those during the ordinary speed walking are listed in Table 3. The

mean ratio of the walking speed ranged from 1.40 in 30s to 1.50 in 40s, including those in 20s and 50s. The mean ratios for 60s and 70s were 1.44 and 1.47, respectively, which fell within the above range. This appears to indicate that old men in their 60s and 70s hastened the walking speeds from ordinary to fast speed in almost the same ratios with those in the younger.

The mean ratios of the step length, from 20s to 50s, were from 1.18 to 1.21, while those in 60s and 70s were 1.17 and 1.13, respectively. There was a significant difference in the ratio between 50s and 70s by the t-test ($p < 0.05$). This means that the old men in their 70s could not increase their step lengths during the fast speed walking as much as the younger.

The mean ratios of the brake impulse from 20s to 50s were from 1.43 to 1.49, while those in 60s and 70s were 1.17 and 1.27, respectively. There was a significant difference in the ratio between 50s and 60s by the t-test ($p < 0.01$). Absolute values of the brake impulse during the fast speed walking also decreased drastically at one's 60s (Fig. 4). Therefore, it may be concluded that the brake impulse during the fast speed walking begins to decrease at one's 60s.

The mean ratio of the acceleration impulse from 20s to 50s were from 1.15 to 1.24, while those in 60s and 70s were 1.21 and 1.23, respectively, which fell within the range from 20s to 50s. Unlike the brake impulse, the accelera-

Table 3. Ratios of the measurement items during the fast speed walking against those during the ordinary speed walking in each age group

Age group	Walking speed		Step length		Brake impulse		Accel. impulse	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
70s	1.47	0.22	1.13	0.10	1.27	0.28	1.23	0.10
60s	1.44	0.14	1.17	0.07	1.17	0.24	1.21	0.12
50s	1.42	0.11	1.20	0.08	1.49	0.21	1.15	0.12
40s	1.50	0.14	1.18	0.08	1.44	0.44	1.16	0.10
30s	1.40	0.15	1.19	0.07	1.48	0.30	1.24	0.18
20s	1.41	0.11	1.21	0.08	1.43	0.29	1.20	0.07

Table 4. Correlation coefficients between the measurement items during the fast speed walking

	1	2	3	4	5	6	7	8	9	10	11	12
1 Age	1.00											
2 Step length	-0.64**	1.00										
3 Grip strength	-0.63**	0.50**	1.00									
4 Walking speed	-0.84**	0.81**	0.59**	1.00								
5 Fto/W	0.23	-0.10	-0.20	-0.19	1.00							
6 $\int$ Fto-dt/WT	0.08	0.02	-0.14	-0.05	0.70**	1.00						
7 $\int$ Fb-dt/WT	-0.62**	0.71**	0.38**	0.73**	-0.17	0.00	1.00					
8 $\int$ Fa-dt/WT	-0.33**	0.43**	0.15	0.48**	-0.05	0.11	0.50**	1.00				
9 Fv1/W	-0.41**	0.44**	0.11	0.57**	-0.25**	0.00	0.67**	0.51**	1.00			
10 Fvm/W	0.44**	-0.51**	-0.23	-0.64**	0.04	-0.06	-0.67**	-0.65**	-0.71**	1.00		
11 Fv2/W	-0.27*	0.19	0.14	0.28*	0.16	0.00	0.26*	0.39**	0.06	-0.45**	1.00	
12 $\int$ Fv-dt/WT	-0.18	0.25*	-0.03	0.27*	-0.17	0.01	0.51**	0.38**	0.50**	-0.32**	0.36**	1.00

** : significant at the 1% level, * : significant at the 5% level

tion impulse in 60s and 70s increased during the fast speed walking with almost the same ratio as those in the younger.

The linear correlation coefficients between all pairs of items for the whole subjects and their significance levels are listed in Table 4. The results are almost identical with our previous ones for the ordinary speed walking (YAMADA *et al.*, 1988). Thus, the fundamental relationships between the items appear to be conserved even if the walking speed is hastened.

The results of PCA, for each age group as well as for the whole subjects are listed in Table 5.

For the fast speed walking in the age groups from 20s to 50s, the 1st component (PC1) is mainly characterized by the brake impulse, walking speed, step length, and Fvm, the 2nd one (PC2) by the outward transverse impulse, and the 3rd one (PC3) by the vertical impulse. Thus, each PC is characterized by each impulse of Fb, Ft, and Fv. For 60s and 70s, however, the constitution of each PC was different from those in the age groups from 20s to 50s, and that in 60s was further different from that in 70s. These results suggest that the contents of the fast speed walking begin to change at one's 60s.

YAMADA *et al.* (1988) applied the PCA to the

ordinary speed walking using the same items as in the present study, and reported that the constitutions of the principal components were almost identical from 20s to 40s. That is, PC1 was mainly characterized by the brake impulse (though the acceleration impulse was included in 20s and 30s), PC2 by the outward transverse impulse, PC3 by the vertical impulse, and they were different according to age groups from 50s to 70s. Based on these findings, they concluded that the contents of the ordinary speed walking begin to change at one's 50s.

Comparing the present results with those in YAMADA *et al.* (1988), it may be concluded that the contents of the fast speed walking from 20s to 50s were almost identical with those of the ordinary speed walking. In contrast, the age period was different at which the contents of walking began to change; they began to change at one's 60s in the fast speed walking and at ones 50s in the ordinary speed walking. We should, however, notice here that the data used in our study were not longitudinal according to the age but cross-sectional.

As for the whole subjects, the PC1 is mainly characterized by the age, walking speed, and step length, showing that the contents is identical with

Table 5. Measurement items constituting the principal components for each age group and for whole subjects

Age group	PC 1	PC 2	PC 3
70s	Fvm/W (0.735) speed (-0.724) step length (-0.333) (A.C. = 39.3%)	$\int Fa \cdot dt/WT$ (0.168) $\int Fto \cdot dt/WT$ (-0.227) grip strength (-0.948) (A.C. = 57.1%)	$\int Ft \cdot dt/WT$ (-0.908) Fvm/WT (0.332) speed (-0.220) (A.C. = 67.8%)
60s	$\int Fto \cdot dt/WT$ (-0.435) Fvm/W (0.923) speed (-0.838) (A.C. = 31.1%)	$\int Fb \cdot dt/WT$ (0.098) step length (-0.673) speed (-0.298) (A.C. = 55.4%)	$\int Fto \cdot dt/WT$ (-0.925) step length (0.308) (A.C. = 70.9%)
50s	$\int Fb \cdot dt/WT$ (-0.600) Fvm/W (0.228) step length (-0.888) speed (-0.728) (A.C. = 32.8%)	Fvm/W (0.222) $\int Fto \cdot dt/WT$ (-0.487) (A.C. = 55.6%)	$\int Fv \cdot dt/WT$ (-0.966) $\int Fb \cdot dt/WT$ (-0.536) grip strength (0.217) (A.C. = 72.6%)
40s	$\int Fb \cdot dt/WT$ (-0.730) Fvm/W (0.867) speed (-0.885) (A.C. = 45.2%)	$\int Fto \cdot dt/WT$ (-0.807) grip strength (0.160) (A.C. = 63.7%)	$\int Fv \cdot dt/WT$ (0.121) $\int Fb \cdot dt/WT$ (-0.246) step length (-0.387) (A.C. = 75.4%)
30s	$\int Fv \cdot dt/WT$ (0.151) $\int Fb \cdot dt/WT$ (-0.056) step length (-0.428) (A.C. = 31.4%)	$\int Fto \cdot dt/WT$ (-0.396) speed (0.261) (A.C. = 50.4%)	$\int Fv \cdot dt/WT$ (-0.451) $\int Fa \cdot dt/WT$ (-0.267) step length (0.146) (A.C. = 65.9%)
20s	$\int Fb \cdot dt/WT$ (-0.860) Fvm/W (0.774) speed (-0.613) (A.C. = 34.0%)	$\int Fto \cdot dt/WT$ (-0.955) grip strength (0.426) (A.C. = 56.2%)	$\int Fv \cdot dt/WT$ (0.174) $\int Fb \cdot dt/WT$ (-0.113) speed (0.329) (A.C. = 71.6%)
Whole subjects	age (0.344) Fvm/W (0.267) speed (-0.561) step length (-0.868) $\int Fb \cdot dt/WT$ (-0.597) (A.C. = 43.3%)	grip strength (0.106) $\int Fto \cdot dt/WT$ (-0.949) (A.C. = 58.9%)	speed (0.389) $\int Fb \cdot dt/WT$ (0.533) $\int Fa \cdot dt/WT$ (0.331) Fvm/W (-0.817) (A.C. = 71.0%)

A.C.; accumulated contribution coefficient.
Numbers in parentheses mean eigen values.

that of the ordinary speed walking (YAMADA *et al.*, 1988).

抄 録

床反力値からみた高齢者の速歩きの特徴

真家和生・山田忠利・近藤四郎・田中秀幸

高齢者の体力指標のひとつとして、床反力値からみ

た高齢者の速歩きの特徴を、通常速度での歩行と比較しながら検討した。その結果、(1) 歩行速度、歩幅、制動及び推進の力積は、いずれも60歳台から急速に低下する、(2) 60歳台・70歳台では速歩きの際、より若い世代と同様の比率で通常速度歩行時よりも速度を高めている、(3) 70歳台では、通常速度歩行と比較した歩幅の増大率がより若い世代よりも小さい、(4) 通常速度歩行と比較した前後方向力積の増大率は、制動力積では60歳台から弱まるが、推進力積では年代差がないことがわかった。主成分分析から、(5) 速歩きでは20歳台から50歳台まではほぼ同様の主成分からなっており、60歳台から歩行の様相が変化することが示唆された。

References

- ITO, H., H. NAGASAKI, H. MARUYAMA, K. HASHIZUME and R. NAKAMURA, 1989: Age-related changes of the walking cycle during fastest walking in healthy male subjects. *Jpn. J. Geriatr.*, 26: 347-352. (In Japanese with English summary)
- KIMURA, T., 1985: Bipedal and quadrupedal walking of primates: comparative dynamics. In: KONDO, S. (ed.) *Primate Morphology, Locomotor Analyses and Human Bipedalism*, Univ. of Tokyo Press, Tokyo, pp. 84-104.
- MURRAY, M.P., A.B. DROUGHT and R.C. KORY, 1964: Walking patterns of normal men. *J. Bone and Joint Surg.*, 46-A: 335-360.
- MURRAY, M.P. and B.H. CLARKSON, 1966a: The vertical pathways of the foot during level walking: I. Range of variability in normal men. *J. Amer. Phys. Therapy Assoc.*, 46: 585-589.
- MURRAY, M.P., R.C. KORY, B.H. CLARKSON and S.B. SEPIC, 1966b: A comparison of free and fast speed walking patterns of normal men. *Amer. J. Phys. Med.*, 45: 8-24.
- MURRAY, M.P., S.B. SEPIC and E.J. BARNARD, 1967: Patterns of sagittal rotation of the upper limbs in walking. *J. Amer. Phys. Therapy Assoc.*, 47: 272-284.
- MURRAY, M.P., R.C. KORY and B.H. CLARKSON, 1969: Walking patterns in healthy old men. *J. Geront.*, 24: 169-178.
- YAMADA, T., K. MAIE and S. KONDO, 1988: The characteristics of walking in old men analysed from the ground reaction force. *J. Anthropol. Soc. Nippon*, 96: 7-15.

真 家 和 生

大妻女子大学人間生活科学研究所
〒103 東京都千代田区三番町 12

Kazuo MAIE

Institute of Human Living Sciences
Otsuma Women's University
12 Sanbancho, Chiyoda-ku, Tokyo 102, Japan