THE INFLUENCE OF WALKING SPEED ON SYMMETRY FOR TEMPORAL-SPATIAL AND GRF PARAMETERS IN BACKWARD WALKING

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In general, changes in walking speed are known to influence many biomechanical characteristics of human locomotion. Backward walking (BW) is one of the unique strategies of human locomotion, but there is a little information in BW. The purpose of this study was to investigate whether or not walking speed influences on symmetry for temporal-spatial parameters and GRF in BW. Ten healthy subjects were asked to walk on a walk-way with force platform at three times on three speed conditions. The influence of walking speed on temporal-spatial parameters and GRF parameters were founded, and some gait parameters showed asymmetry. And also the calculated SI were showing asymmetry, so the characteristics of backward walking would be influenced walking speed and have possibility of exist some asymmetrical movements in lower leg.

KEY WORDS: backward walking, asymmetry, GRF, symmetry index

INTRODUCTION: BW, the reverse from forward walking, is one of the important strategies of human locomotion, and it is actually performed on several sports, examples soccer, basketball, kendo, and so on, and moreover, it's gained popularity as one part of a program to rehabilitate for patients with disorder on lower leg in clinical setting. In a field of BW training and/or rehabilitation, have been recommended to assess or improve the motor control of hemiplegic patients and reported to decrease patellofemoral joint compressive forces and eccentric loading of the knee extensors. To date, however, there is a little information in BW compared to forward walking, so these information will led to understanding at important locomotor's mechanisms for human. The presence of symmetry between the left and right legs of a normal individual during walking is a common assumption in both clinical and research fields. Examples in research domain, lower leg symmetry is a key consideration in many biomechanical studies as the ability to assume symmetry allows a reduction in the amount of data collection and analysis, so gait symmetry was not tested in many of these investigations. In able-bodied gait, however, differences between the left and right legs have been reported frequently. Furthermore, it is founded that changes in walking speed have a substantial effect on the biomechanical characteristics of forward walking, but it has not yet determined if a similar relationship exist in BW. The purpose of this study was to investigate whether or not walking speed influenced on symmetry for temporal-spatial parameters and GRF at BW.

METHODS: One able-bodied female and nine males with mean (SD) height 174.2 (4.67) cm, weight 68.6 (7.20) kg, age 21.8 (1.33) yrs., were participated in this study, and each subject was asked to walk three different speeds after adequate practice. They gave informed consent before taking all part in the experiment. Subjects were required to walk barefoot on an organized walk-way followed these instructions on speed were specified as follows: (1) "Walk slowly as if you were waiting at a bus stop." (2) "Walk at a normal, comfortable speed." (3) "Walk as fast as you can without running." A total of 9 trials were accepted for the data analysis for each subject. All walking data were assessed with seven video cameras (V-133, Nac Inc., Tokyo, Japan, frame rate 60 Hz) based on VICON motion analysis system (Oxford Metrics Limited, Oxford, UK) synchronized with force platform (Kistlar, sampling frequency 600 Hz). Six markers (heel, lateral malleolus, and fifth metatarsal head) were put on each foot to measure the temporal-spatial parameters. Opposite foot off, opposite foot contact, and foot off were normalized to walking cycle, and stride length and step length were normalized to

body height. A fourth-order zero-lag Butterworth filter was applied to reduce the noise in the three-dimensional coordinates (cut-off frequency: 6Hz and 60 Hz). Three orthogonal GRF components were recorded: vertical force (Fz), medial-lateral force (Fx), and anterior-posterior force (Fy). In the vertical GRF versus time graph the first peak (foot flat or loading response) was defined as Fz1, the through (mid-stance) as Fz2, and second peak (toe lift or terminal stance) asFz3. Similarly we defined Fy1 (maximum braking), Fy2 (mid-stance), and Fy3 (maximum propulsion) in the anterior-posterior GRF, and Fx1 (maximum pronation), Fx2 (foot flat), and Fx3 (maximum supination) in the medial-lateral GRF. The forces were normalized to bodyweight and represented as a percentage of the subject's bodyweight (% bw). The corresponding time parameters were defined as Tz1, Tz2, Tz3 (vertical direction), Ty1, Ty2, Ty3 (anterior-posterior direction), and Tx1, Tx2, Tx3 (medial-lateral direction). The time of initial foot contact was identified by the rise (>5 N) in vertical GRF while the lateral malleolus marker measured the position at the corresponding time. Similarly, the end of foot contact was identified when the vertical GRF returned to within 5 N. Separate 3x2 analyses of variance with repeated measures were used to identify the significant differences in each parameter. All data were analyzed using STATISTICA 5.1 software. Statistical significance was set at a level of $p<0.05$ for all analysis. The asymmetries of GRF patterns were also examined using the magnitude of the symmetry index derived by Herzog et al. (1989).

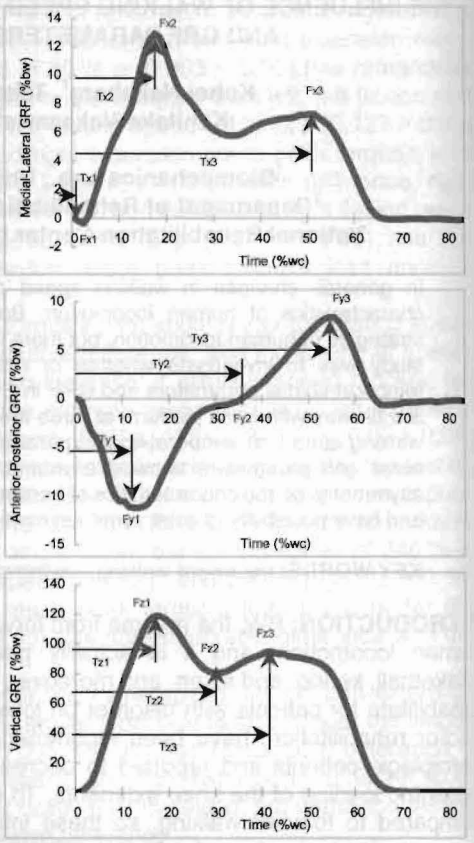

Figure 1. Selected force platform graphs with normal gait. The discrete force (Fx, Fy, Fz) and temporal (Tx, Ty, Tz) values used in the subsequent analysis are indicated.
Upper: Medial-Lateral GRF. Middle: Anterior-Posterior GRF. Bottom: Vertical GRF.

$$SI = \frac{2(X_R - X_L)}{X_R + X_L} \times 100\%$$

X_R and X_L were gait variables for the right and left leg respectively. Perfect symmetry required SI=0, and an acceptable degree of symmetry for this type of parameter symmetry was considered to have a SI between 10% and –10%. Acceptable degree of right asymmetry was considered to have a SI of more than 10% and left asymmetry was less than 10%.

RESULTS AND DISCUSSION: The mean (SD) walking speeds calculated across all individuals in this study were 0.43 (0.111) m/s for slow speed condition, 0.92 (0.114) m/s for normal speed condition, and 1.68 (0.201) m/s for fast speed condition. The mean walking speed at normal condition was similar to previous findings on backward walking of healthy human (Grasso et al., 1998). The overall mean (SD) for temporal-spatial and GRF parameters were summarized in Table 1, Table 2 and Table 3, respectively. All temporal-spatial parameters except opposite foot contact were significant effect on walking speed, and opposite foot off was only significant effect on leg at slow walking speed (right leg 19.3 %wc vs left leg 18.1 %wc). Cadences, stride length, and step length were showing tendency to increase with increasing walking speed, on the other hand, stride time, step time, opposite foot off, foot off, single support, and double support were decreased with decreasing walking

Table 1. Mean values of temporal-special parameters during backward wall

parameter	unit	leg		Walking speed Fast	Normal	Slow	main effect	F-value	p-value		Leg	HSD
Cadence	steps /min	R	Mean	145.4	105.9	69.5	Speed	#####	0.000	**	R	F>N>S
			SD	11.26	9.39	11.06					L	F>N>S
		L	Mean	145.5	105.5	69.6	Leg	0.45	0.518			
			SD	11.53	9.74	10.60						
Stride Time	s	R	Mean	0.83	1.14	1.77	Speed	86.61	0.000	**	R	F<N<S
			SD	0.063	0.104	0.298					L	F<N<S
		L	Mean	0.83	1.15	1.77	Leg	0.00	0.978			
			SD	0.066	0.111	0.274						
Step Time	s	R	Mean	0.41	0.58	0.86	Speed	92.61	0.000	**	R	F<N<S
			SD	0.038	0.058	0.145					L	F<N<S
		L	Mean	0.42	0.57	0.90	Leg	2.24	0.169			
			SD	0.033	0.056	0.154						
Opposite Foot Off	%wc	R	**Mean**	**10.3**	**13.3**	**19.3**	**Speed**	**24.75**	**0.000**	**	R	F<N<S
			SD	**2.78**	**2.65**	**5.39**					L	F<N<S
		L	**Mean**	**9.3**	**13.1**	**18.1**	**Leg**	**10.70**	**0.010**	*		SR>SL
			SD	**2.39**	**2.21**	**4.94**						
Opposite Foot Contact	%wc	R	Mean	50.6	49.7	50.5	Speed	0.81	0.459		R	
			SD	1.86	1.75	2.47					L	
		L	Mean	49.4	50.3	49.1	Leg	1.95	0.196			
			SD	1.53	1.75	3.08						
Foot Off	%wc	R	Mean	59.8	62.9	68.5	Speed	28.97	0.000	**	R	F<N<S
			SD	2.44	2.33	4.50					L	F<N<S
		L	Mean	59.7	63.8	69.4	Leg	5.91	0.038	*		
			SD	2.27	2.87	5.53						
Single Support	s	R	Mean	0.33	0.41	0.55	Speed	24.03	0.000	**	R	F<N<S
			SD	0.031	0.033	0.150					L	F<N<S
		L	Mean	0.33	0.43	0.54	Leg	0.61	0.454			
			SD	0.028	0.037	0.111						
Double Support	s	R	Mean	0.16	0.31	0.67	Speed	37.62	0.000	**	R	F<N<S
			SD	0.046	0.069	0.238					L	F<N<S
		L	Mean	0.16	0.31	0.68	Leg	0.36	0.561			
			SD	0.036	0.070	0.238						
Stride Length	% bh	R	Mean	81.8	59.7	44.2	Speed	42.84	0.000	**	R	F>N>S
			SD	10.28	5.70	11.65					L	F>N>S
		L	Mean	82.0	59.8	43.4	Leg	0.08	0.788			
			SD	9.44	5.93	12.00						
Step Length	% bh	R	Mean	41.0	29.6	21.7	Speed	45.49	0.000	**	R	F>N>S
			SD	5.42	3.70	5.71					L	F>N>S
		L	Mean	40.9	29.7	21.6	Leg	0.24	0.639			
			SD	4.97	3.10	6.53						

*: indicates the significant differences at p<0.05. **: indicates the significant differences at p<0.01.
Bold text indicates the interaction between the two.(speed x leg)
R: right leg. L: left leg. F: fast walking speed. N: normal walking speed. S: slow walking speed.

Table 2. Mean values of all subjects GRF during backward walking trials.

	Leg		Walking Speed High	Normal	Low	main effect	F-value	p-value		HSD
Fx1	R	Mean	-0.3	-0.2	-0.5	speed	0.799	0.465	*	
		SD	1.05	0.60	0.64					
	L	Mean	0.3	0.2	0.3	leg	2.414	0.155		
		SD	0.31	0.30	0.23					
Fx2	R	Mean	15.7	13.1	7.5	speed	#####	0.000	**	R F>N>S
		SD	3.01	2.42	2.17					L F>N>S
	L	Mean	-16.1	-12.4	-7.0	leg	0.471	0.510		
		SD	2.50	2.68	1.88					
Fx3	R	Mean	10.7	7.3	5.0	speed	#####	0.000	**	R F>N>S
		SD	3.10	2.14	1.64					L F>N>S
	L	Mean	-10.9	-7.1	-4.7	leg	0.249	0.630		
		SD	3.07	1.64	1.15					
Fy1	R	Mean	-21.8	-11.2	-6.9	speed	#####	0.000	**	R F>N>S
		SD	3.06	3.01	2.82					L F>N>S
	L	Mean	-25.5	-14.0	-7.9	leg	#####	0.000	**	FR<FL
		SD	5.49	3.43	4.52					NR>NL
Fy3	**R**	**Mean**	**15.6**	**8.6**	**4.7**	**speed**	**#####**	**0.000**	**	**R F>N>S**
		SD	**5.46**	**1.85**	**2.67**					**L F>N>S**
	L	**Mean**	**25.9**	**12.2**	**7.2**	**leg**	**#####**	**0.000**	**	**FR<FL**
		SD	**7.15**	**2.50**	**2.92**					**NR<NL**
Fz1	R	Mean	134.0	124.5	101.8	speed	#####	0.000	**	R F>N>S
		SD	13.08	11.34	5.63					L F>N>S
	L	Mean	136.5	128.9	105.9	leg	4.101	0.074		
		SD	17.62	14.60	9.51					
Fz2	R	Mean	61.2	79.3	93.7	speed	#####	0.000	**	R F<N<S
		SD	11.94	7.28	2.38					L F<N<S
	L	Mean	56.3	78.2	92.3	leg	4.539	0.062		
		SD	13.58	7.57	5.14					
Fz3	**R**	**Mean**	**106.7**	**94.2**	**96.6**	speed	#####	**0.001**	**	**R F>N,S**
		SD	**12.91**	**3.17**	**1.46**					**L F>N,S**
	L	**Mean**	**112.0**	**96.6**	**97.4**	leg	#####	**0.000**	**	**FR<FL**
		SD	**12.18**	**2.93**	**1.62**					

*: indicates the significant differences at p<0.05. **: indicates the significant differences at p<0.01.
Bold text indicates the interaction between the two.(speed x leg)

speed. Alternations of both legs related with walking speed were similar to all parameters. In GRF parameters, from the analysis a significant main effect of walking speed was prevalent in all parameters except Fx1, and Fy1 at fast and normal speed, Fy3 at fast and normal speed, Fz3 at fast speed were significant main effect of leg, but none of significant effect of leg at slow walking speed. Moreover, walking speed effect on both legs similarly. On the other hand, in GRF parameters on time components, Tx3, Ty1, Ty2, Ty3, Tz1, Tz2, and Tz3 were significant effect on walking speed, but some different patterns observed were observed to force components. The effect on walking speed were different on both legs, examples Tx3 was effect on walking speed on right leg. There is none of the subjects exhibited perfect walking symmetry and symmetry (see Table 4 and Table 5). However, the mean symmetry indices for Fx2, Fx3 and all vertical GRF ranged 10 % $\leqq$ SI $\geqq$ −10%. These results were reported in previous study intended for forward walking (Herzog, et al. 1989).

Goble et al. (2003) reported the asymmetrical characteristics appear at slow

Table 3. Mean values of all subjects GRF time parameters during backward walking trials.

	Leg		Walking Speed High	Normal	Low	main effect	F-value	p-value		HSD
Tx1	R	Mean	2.5	2.1	1.8	speed	5.792	0.011	*	
		SD	1.50	1.04	0.40					
	L	Mean	3.1	2.0	1.8	leg	0.280	0.610		
		SD	1.70	0.77	0.60					
Tx2	R	Mean	17.8	16.9	19.8	speed	1.727	0.206		
		SD	1.17	0.70	4.35					
	L	Mean	17.5	17.6	18.7	leg	0.361	0.563		
		SD	1.36	1.85	3.63					
Tx3	R	Mean	49.1	46.1	51.8	speed	14.757	0.000	**	R N<S
		SD	2.02	4.64	2.64					
	L	Mean	49.5	46.8	51.3	leg	0.049	0.830		
		SD	1.63	4.04	2.33					
Ty1	**R**	**Mean**	**10.7**	**11.5**	**18.6**	**speed**	**23.101**	**0.000**	**	**R F,N<S**
		SD	**1.62**	**2.97**	**4.43**					**L F<N<S**
	L	**Mean**	**9.5**	**12.8**	**17.1**	**leg**	**0.461**	**0.514**		
		SD	**1.50**	**3.68**	**3.14**					
Ty2	R	Mean	26.7	35.0	40.7	speed	63.880	0.000	**	R F<N,S
		SD	3.90	4.15	5.66					L F,N<S
	L	Mean	23.1	27.6	34.6	leg	15.922	0.003	**	NR>NL
		SD	2.17	4.36	3.75					SR>SL
Ty3	R	Mean	52.8	54.2	58.2	speed	19.693	0.000	**	R F,N<S
		SD	2.04	1.17	3.52					L F<N<S
	L	Mean	52.2	53.5	57.2	leg	4.573	0.061		
		SD	1.72	1.36	3.28					
Tz1	R	Mean	17.4	17.5	23.1	speed	15.497	0.000	**	R F,N<S
		SD	1.62	2.20	3.91					L F,N<S
	L	Mean	16.7	17.2	21.7	leg	2.070	0.184		
		SD	1.27	1.54	6.07					
Tz2	R	Mean	34.2	30.1	30.2	speed	11.235	0.001	**	R F>N,S
		SD	0.75	1.37	3.54					L F>N,S
	L	Mean	33.5	29.4	28.9	leg	2.981	0.118		
		SD	1.20	1.20	5.11					
Tz3	R	Mean	49.6	41.8	39.1	speed	36.272	0.000	**	R F>N,S
		SD	2.29	2.96	4.59					L F>N>S
	L	Mean	49.8	41.2	37.8	leg	0.756	0.407		
		SD	1.89	3.76	5.64					

*: indicates the significant differences at p<0.05. **: indicates the significant differences at p<0.01.
Bold text indicates the interaction between the two.(speed x leg)

Table 4. Mean SI value of GRF force elements in backward walking at each speed trial.

A

		Mean	SD	Number of subject ≧10%	10%>SI>-10%	-10%≧
Fx	1	17.1	136.21	4	2	4
	2	**-3.3**	**8.16**	**0**	**7**	**3**
	3	**-1.7**	**14.90**	**3**	**3**	**4**
Fy	1	-14.2	12.93	0	3	7
	2	-	-	-	-	-
	3	-50.8	24.86	0	0	10
Fz	**1**	**-1.6**	**4.75**	**0**	**9**	**1**
	2	**9.6**	**14.16**	**3**	**6**	**1**
	3	**-5.1**	**4.82**	**0**	**9**	**1**

B

		Mean	SD	Number of subject ≧10%	10%>SI>-10%	-10%≧
Fx	1	93.3	72.80	9	0	1
	2	**5.8**	**12.52**	**4**	**4**	**2**
	3	**0.8**	**14.18**	**2**	**6**	**2**
Fy	1	-22.9	15.44	0	2	8
	2	-	-	-	-	-
	3	-35.0	13.53	0	0	10
Fz	**1**	**-3.3**	**3.39**	**0**	**10**	**0**
	2	**1.5**	**3.23**	**0**	**10**	**0**
	3	**-2.5**	**1.58**	**0**	**10**	**0**

C

		Mean	SD	Number of subject ≧10%	10%>SI>-10%	-10%≧
Fx	1	58.1	#####	7	0	3
	2	**4.5**	**14.66**	**4**	**5**	**1**
	3	**4.7**	**9.38**	**3**	**7**	**0**
Fy	1	-11.7	30.66	1	5	4
	2	-	-	-	-	-
	3	-45.5	32.16	1	0	9
Fz	**1**	**-3.9**	**7.65**	**0**	**9**	**1**
	2	**1.7**	**5.80**	**1**	**9**	**0**
	3	**-0.9**	**0.72**	**0**	**10**	**0**

A: high speed walking, B: normal speed walking, and C: low speed walking.
Bold text indicates the force platform variables with an acceptable symmetry index (10%>SI>-10%)

Table 5. Mean SI value of GRF time elements in backward walking at each speed trial.

A

		Mean	SD	Number of subject ≧10%	10%>SI>-10%	-10%≧
Tx	1	-15.8	71.15	4	1	5
	2	**1.8**	**4.55**	**0**	**10**	**0**
	3	**-0.8**	**4.18**	**0**	**10**	**0**
Ty	1	11.9	9.75	4	6	0
	2	13.8	15.12	5	5	0
	3	**1.1**	**3.76**	**0**	**10**	**0**
Tz	1	4.0	6.70	3	7	0
	2	**2.1**	**3.77**	**0**	**10**	**0**
	3	**-0.4**	**4.68**	**0**	**10**	**0**

B

		Mean	SD	Number of subject ≧10%	10%>SI>-10%	-10%≧
Tx	1	2.2	54.91	4	3	3
	2	**-3.6**	**13.76**	**2**	**4**	**4**
	3	**-1.6**	**14.95**	**3**	**4**	**3**
Ty	1	-9.3	32.48	3	2	5
	2	23.7	21.57	7	2	1
	3	**1.3**	**2.63**	**0**	**10**	**0**
Tz	1	1.3	8.17	2	7	1
	2	**2.3**	**3.61**	**0**	**10**	**0**
	3	**1.6**	**4.39**	**0**	**10**	**0**

C

		Mean	SD	Number of subject ≧10%	10%>SI>-10%	-10%≧
Tx	1	2.7	24.44	1	8	1
	2	**5.0**	**10.48**	**4**	**5**	**1**
	3	**0.9**	**6.29**	**0**	**10**	**0**
Ty	1	6.7	15.06	5	3	2
	2	15.6	21.99	8	0	2
	3	**1.7**	**3.43**	**0**	**10**	**0**
Tz	1	8.7	27.45	4	5	1
	2	**5.5**	**18.93**	**1**	**8**	**1**
	3	**4.0**	**14.29**	**3**	**5**	**2**

A: high speed walking, B: normal speed walking, and C: low speed walking.
Bold text indicates the force platform variables with an acceptable symmetry index (10%>SI>-10%)

walking condition in forward walking, and the asymmetries were characterized by larger stance time in the left leg and by larger Fz3 in the right leg. In our study, however, foot off was larger in the left leg, but it was not significant difference. Fz3 was larger in the left leg at slow walking condition (right 96.6 (1.46) vs left 97.4 (1.62)), moreover, it's significant larger in the left leg at fast walking conditions (right 106.7 (12.91) vs left 112.0 (12.18)). These differences would be related the direction of walking, and indicate that each legs would play the difference role between BW and forward walking. Historically, the waveforms of the elevation angles of BW is assumed the mirror image of forward walking, but there are several report that the muscle activities and a region of muscle activated during BW are differ from forward walking. Furthermore, the characteristics of GRF in fast walking are similar image compared to forward walking not mirror image.

CONCLUSION: To our knowledge, this is the first study to report influence of walking speed in backward walking. Human backward walking is asymmetrical according to the definition for "Symmetry Index" used in this study and the results of ANOVA.

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