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ORIGINAL

Gait Stability in K-pop Professional Dancers

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Objective: The purpose of this study was to provide data on gait characteristics of K-pop professional dancers.

Method: Participants were divided into four groups: male dancers (n=10, age: 28.2 ± 3.4 years, height: 175 ± 6 cm, weight: 68.9 ± 5.6 kg), female dancers (n=10, age: 26.7 ± 3.1 years, height: 162 ± 4 cm, weight: 52.1 ± 3.7 kg), non-dancer males (n=10, age: 25.2 ± 2.6 years, height: 171 ± 6 cm, weight: 66.4 ± 5.3 kg), or non-dancer females (n=10, age: 26.2 ± 3.0 years, height: 161 ± 5 cm, weight: 56.4 ± 6.7 kg). Twelve infrared cameras (Qualisys, Oqus 500, Sweden, 150 Hz.) were used to capture three-dimensional motion data. Gait motion data of professional dancers and ordinary persons were obtained.

Results: K-pop dancers' dynamic stability during the female toe off event and the male heel contact event was better compared with that of ordinary persons in the front-rear direction. In addition, the results showed a significant difference in the margin of stability (MoS). However, the medial-lateral direction of both female and male dancers during heel contact and the toe off event was more stable compared with ordinary person, who exhibited an increased MoS than did the dancers.

Conclusion: This study aimed to investigate the gait characteristics of K-pop professional dancers in comparison with ordinary persons using gait parameters and MoS. The stability of K-pop professional dancers' dynamic gait in the front-rear direction was better than that in the medial-lateral direction. Therefore, further studies in which the dance movements of K-pop dancers are sub-divided and analyzed will be necessary to reduce related injury.

Keywords: Margin of stability, Dance, Stability, Gait, K-pop

INTRODUCTION

Gait is the most common and natural form of human movements and is the most complicated and fully integrated movement that cannot be learned without risk of injuries (Winter, 1991). In addition, correct gait movements may result in health promotion by replacing the lack of exercises to some extent, while incorrect gait can cause unbalances in joints, muscles, brain, and physical structures, thereby causing diseases (Scott, Winter, 1990). Individual gait patterns differ across people. Thus, lifestyle habits associated with concerned social characteristics, musculoskeletal differences due to genetic factors, and psychological characteristics based on individual personality can be major factors for evaluating gait analyses (Chung, Shin, Seo, Eun & In, 2001).

Because motion analyses are mostly based on results that were obtained under static conditions, there are some problems in evaluating dynamic stability, such as gait with motion analysis (Chang & Yoon, 2010). Therefore, the dynamic stability of gait is used as an important factor for determining exercise performance in locomotor movements in humans (Ryu, 2008). In order to evaluate the dynamic stability of gait, the margin of stability (MoS), which comprises gait speed, the base of support, the center of mass, and leg length, has been proposed for dynamic motion analysis studies (Hof, van Bockel, Schoppen & Postema, 2007). Such analyses of gait stability can serve as an important factor in preventing injuries.

The lower limb movements of K-pop dancers consist mainly of rotation, jumping, and continuous dynamic movements of knee flexion and extension movements. Meanwhile, the key factors for these movements include balance to maintain the center of mass in dynamic situations and stability as resistance to balancing hindrance factors. Therefore, MoS in dynamic situations is used to assess gait characteristics of K-pop dancer groups. Furthermore, the cadence, step length, step width, swing time, double limb support time, and speed are also important mediators of the basic characteristics of gait.

Previous studies on dancers have been mostly qualitative in nature and have focused on modern dance and ballet that mostly express emotions. Meanwhile, a limited number of biomechanical studies that collect and analyze quantitative data have been conducted (Laws, Sugano & Swope, 2002). Studies on K-pop dancers are scarce, despite South Korea being the birthplace of K-pop, which prompts researchers to proactively provide relevant biomechanical information (Jang, Hong &

Kim, 2016). Therefore, the present study sought to investigate differences in gait stability between K-pop professional dancers as well as ordinary persons and, thus, to evaluate gait stability in professional dancers.

MATERIALS AND METHODS

1. Participants

The present study involved a total of 40 subjects, consisting of 10 male and 10 female professional choreographers aged in their 20's~30's who had neither orthopedic disease nor surgery in the previous three years and had more than 10 years of dancing experience, and 10 non-dancer males and 10 non-dancer females aged in their 20's~30's who had no dancing experience (Table 1).

2. Measurements

All subjects were informed of the purpose, methods, and procedures of the present study before the experiment and provided consent to participate in the present study. After receiving consent from the subjects, the present study was conducted. Twelve infrared cameras (Oqus-5, Qualisys, Sweden) were used to analyze gait movement-related data. Human coordinates were set according to the marker set of Visual 3D, and three-dimensional (3D) images were obtained. In order to acquire data on the usual gait motions of 20 ordinary persons and 20 professional dancers, they were asked to walk three times along a 9-m-long runway at a self- preferred speed without controlling gait speed.

Table 1. Characteristics of subjects (mean ± SD)

Section	Age (y)	Height (cm)	Body weights (kg)
Female dancer (n=10)	26.7 ± 3.1	162 ± 4	52.1 ± 3.7
Male dancer (n=10)	28.2 ± 3.4	175 ± 6	68.9 ± 0.6
Female (n=10)	26.2 ± 3.0	161 ± 5	56.4 ± 6.7
Male (n=10)	25.2 ± 2.6	171 ± 6	66.4 ± 0.3

3. Data processing

2D planar data that were acquired using QTM program were converted into 3D spatial data by the NLT (nonlinear transformation). After human body modeling was performed using Visual 3D (C-motion Inc., USA), an application program, variables were derived. In order to evaluate gait stability in the subjects, data on the base of support (BoS) in gait motion, the position of the center of mass (PCoM), the velocity of the center of mass (VCoM), extrapolated center of mass (XCoM) and the margin of stability (MoS) were used (Figure 1). Gait para meters (cadence: number of steps per min, step length: length from the heel of the back foot to the heel of the front foot, step width: right and left length of the right foot and left foot, swing time: swing phase time, double limb support time, speed: gait speed) were compared between the groups. The result values for gait stability were calculated using the following formula (Marone, Patel, Hurt & Grabiner, 2014):

$$\mathbf{MoS} = \mathbf{BoS} - \mathbf{XCoM}$$

$$\mathbf{XCoM} = \mathbf{PCoM} + \frac{\boldsymbol{VCoM}}{\omega_0}$$

$$\omega_0 = \sqrt{\frac{g}{l}}, \quad \text{where} \quad l = CoM_z - Ankle_z \text{ (equivalent pendulum length)}$$

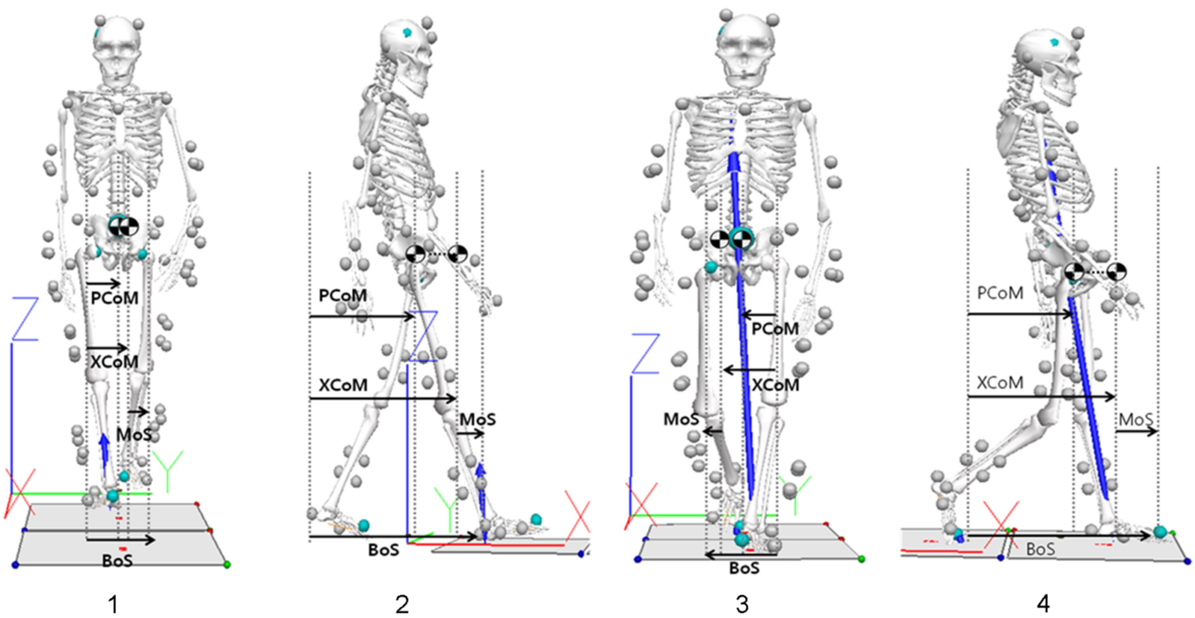

Figure 1. MoS heel contact event (panels 1 and 2) and toe off event (panels 3 and 4)

Table 2. MoS results at heel contact in dancer and ordinary subjects

		Female dancers	Male dancers	Females	Males	F (p)	Post-hoc
A-P	BoS (cm)	59.33 ± 0.22	60.01 ± 6.11	59.06 ± 5.35	59.55 ± 5.18	0.488 (0.693)	
	PcoM (cm)	22.44 ± 3.08	21.63 ± 0.17	22.23 ± 2.27	22.36 ± 2.82	1.208 (0.307)	
	VcoM (m/s)	1.13 ± 0.14	1.13 ± 0.14	1.17 ± 0.22	1.17 ± 0.16	1.492 (0.216)	
	XcoM (cm)	55.51 ± 6.18	55.86 ± 7.73	56.26 ± 7.50	57.35 ± 7.24	1.104 (0.347)	
	MoS (cm)	3.83 ± 4.49	4.15 ± 3.96	2.81 ± 5.03	2.21 ± 3.15	4.076 (0.007)*	male dancer>female dancer>female>male
M-L	BoS (cm)	15.51 ± 3.52	20.48 ± 3.54	18.60 ± 3.10	23.11 ± 3.98	73.043 (0.000)*	male>male dancer>female>female dancer
	PCoM (cm)	7.33 ± 1.79	9.98 ± 1.83	8.53 ± 1.51	11.06 ± 1.93	76.847 (0.000)*	male>male dancer>female>female dancer
	VCoM (m/s)	0.06 ± 0.04	0.08 ± 0.04	0.08 ± 0.03	0.11 ± 0.05	23.914 (0.000)*	male>male dancer>female>female dancer
	XCoM (cm)	8.02 ± 3.43	12.51 ± 2.91	10.88 ± 2.57	14.31 ± 3.17	69.756 (0.000)*	male>male dancer>female>female dancer
	MoS (cm)	6.50 ± 1.26	7.65 ± 1.32	7.97 ± 1.80	8.80 ± 1.44	37.500 (0.000)*	male>male dancer>female>female dancer

$p<.05$

4. Statistical analysis

Data analyses were performed using SPSS 21.0(IBM, USA). A one-way ANOVA was used to compare mean differences between the four groups (female dancer, male dancer, male, and female groups), and a post-hoc analysis was performed to determine differences within a certain group. All statistical significance levels were set at $p<0.05$.

RESULTS

1. Comparison of gait stability at heel contact between dancers and ordinary persons

The results at heel contact in dancers and ordinary subjects are shown in (Table 2).

BOS in the anterior-posterior (A-P) direction was the greatest in male dancers, but it was not statistically significant. PCoM was the smallest in male dancers, but it was not statistically significant. There was no statistically significant difference in mean VCoM and XCoM between the four groups, but mean VCoM and XCoM were greater in ordinary subjects than in dancers. There was a statistically significant difference in MoS between the four groups ($p=.007$), and the mean MOS was the greatest in dancers, i.e., male dancers (2.21 ± 3.15 cm) > female dancers (3.83 ± 4.49 cm) > females (2.81 ± 5.03 cm) > males (2.21 ± 3.15 cm).

There was a statistically significant difference in BoS in the medial-lateral (M-L) direction between the groups ($p=.000$), and the BoS in the M-L direction, with the male group (23.11 ± 3.98 cm) > male dancer group (20.48 ± 3.54 cm) > female group (18.60 ± 3.10 cm) > female dancer group (15.51 ± 3.52 cm). We detected a statistically significant difference in mean PCoM between the four groups ($p=.000$), with males (11.06 ± 1.93 cm) > male dancers (9.98 ± 1.83 cm) > females (8.53 ± 1.51 cm) > female dancers (7.33 ± 1.79 cm). Similarly, we measured a statistically significant difference in VCoM ($p=.000$) between the groups, with males (0.11 ± 0.05 cm) > male dancers (0.08 ± 0.04 cm) > females (0.08 ± 0.03 cm) > female dancers (0.06 ± 0.04 cm). There was also a statistically significant difference in XCoM ($p=.007$) between the groups, with males (14.31 ± 3.17 cm) > male dancers (12.51 ± 2.91 cm) > females (10.88 ± 2.57 cm) > female dancers (8.02 ± 3.43 cm). Finally, we also measured a statistically significant difference in MoS between the groups ($p<.05$), with males (8.80 ± 1.44 cm) > male dancers (7.97 ± 1.80 cm) > females (7.65 ± 1.32 cm) > female dancers (6.50 ± 1.26 cm).

2. Gait stability at toe off in dancers and ordinary subjects

The results of gait stability at toe off in dancers and ordinary persons are shown in (Table 3).

The mean BoS in the A-P direction was the smallest in females, but there was no significant difference between the groups. The mean PCoM was the smallest in males, but there was no significant group difference. The mean VCoM was the greatest in females, but there was no statistically significant group difference. XCoM was the smallest in female dancers, but there was no statistically significant group difference. There was a statistically significant difference in mean MoS between the four groups ($p=.004$), with female dancers (-5.32 ± 3.80 cm) > male dancers (-5.77 ± 2.85 cm) > males (-6.31 ± 3.78 cm) > females (-7.13 ± 3.29 cm) in terms of mean MoS.

There was a statistically significant difference in BoS in the M-L direction between the four groups ($p=.000$), with males (21.73 ± 3.49 cm)

Table 3. MoS results at toe off event in dancers and ordinary subjects

		Female dancer	Male dancer	Female	Male	F (p)	Post-hoc
A-P	BoS (cm)	58.52 ± 6.02	58.69 ± 5.62	57.55 ± 4.37	58.19 ± 5.26	0.794 (0.498)	
	PCoM (cm)	29.84 ± 3.87	29.23 ± 3.24	29.67 ± 3.10	28.83 ± 3.60	1.557 (0.199)	
	VCoM (m/s)	1.17 ± 0.15	1.16 ± 0.12	1.2 ± 0.17	1.19 ± 0.15	1.538 (0.204)	
	XCoM (cm)	63.84 ± 7.65	64.46 ± 6.26	64.69 ± 6.39	64.49 ± 7.51	0.249 (0.862)	
	MoS (cm)	-5.32 ± 3.80	-5.77 ± 2.85	-7.13 ± 3.29	-6.31 ± 3.78	4.601 (0.004)*	female dancer>male dancer>male>female
M-L	BoS (cm)	16.70 ± 4.04	20.01 ± 4.54	18.94 ± 3.12	21.73 ± 3.49	27.051 (0.000)*	male>male dancer> female.>female dancer
	PCoM (cm)	8.62 ± 2.45	9.83 ± 2.87	9.77 ± 1.87	10.71 ± 2.19	11.823 (0.000)*	male>male dancer> female>female dancer
	VCoM (m/s)	0.09 ± 0.05	0.09 ± 0.06	0.10 ± 0.04	0.09 ± 0.005	0.777 (0.507)	
	XCoM (cm)	11.13 ± 3.80	12.45 ± 4.20	12.56 ± 3.06	13.49 ± 3.35	6.446 (0.000)*	male>female>male dancer>female dancer
	MoS (cm)	5.57 ± 1.21	7.56 ± 1.49	6.38 ± 0.97	8.24 ± 1.21	83.842 (0.000)*	male>male dancer> female>female dancer

$p<.05$

Table 4. Gait parameters in dancers and ordinary subjects

	Female dancer	Male dancer	Female	Male	F (p)	Post-hoc
L_cadence (steps/min)	107.99 ± 7.10	104.78 ± 5.96	110.48 ± 12.85	108.85 ± 7.88	2.206 (0.091)	
R_cadence (steps/min)	107.92 ± 10.66	106.97 ± 9.61	110.75 ± 12.03	109.00 ± 8.53	0.746 (0.527)	
L _step Length (cm)	120.95 ± 8.70	123.58 ± 8.50	121.45 ± 8.10	122.51 ± 9.28	0.549 (0.650)	
R _step Length (cm)	122.06 ± 9.27	123.30 ± 9.46	122.07 ± 7.62	122.92 ± 9.21	0.146 (0.932)	
Step Width (cm)	6.67 ± 2.73	7.66 ± 2.41	8.93 ± 1.60	10.60 ± 3.10	13.584 (0.000)*	male>female>male dancer>female dancer
L_swing time (s)	0.44 ± 0.03	0.45 ± 0.03	0.43 ± 0.05	0.44 ± 0.04	1.261 (0.291)	
R_swing time (s)	0.44 ± 0.03	0.45 ± 0.04	0.44 ± 0.04	0.45 ± 0.04	0.403 (0.751)	
Double limb support time (s)	0.12 ± 0.02	0.12 ± 0.02	0.11 ± 0.03	0.11 ± 0.02	1.361 (0.258)	
Speed (m/s)	1.1 ± 0.09	1.09 ± 0.10	1.13 ± 0.16	1.12 ± 0.14	0.696 (0.556)	

$p<.05$

> male dancers (20.01 ± 4.54 cm) > females (18.94 ± 3.12 cm) > female dancers (16.70 ± 4.04 cm). There was also a statistically significant difference in PCoM between the groups (p=.000), with males (10.71 ± 2.19 cm) > female dancers (9.83 ± 2.87 cm) > females (9.77 ± 1.87 cm) > female dancers (8.62 ± 2.45 cm). The mean VCoM was the greatest in the female group, but there was no statistically significant difference between the four groups. There was a statistically significant group difference in XCoM (p=.000), with males (13.49 ± 3.35 cm) > females (12.56 ± 3.06 cm) > male dancers (12.45 ± 4.20 cm) > female dancer (11.13 ± 3.80 cm). We measured a statistically significant difference in MoS (p=.000) between the groups with MoS in the order of males (8.24 ± 1.21 cm) > male dancers (7.56 ± 1.49 cm) > females (6.38 ± 0.97 cm) > female dancers (5.57 ± 1.21 cm).

3. Gait parameters in dancers and ordinary subjects

The analysis of gait parameters in dancers and ordinary subjects are shown in (Table 4).

The cadence of the left foot (L cadence) was the highest in the female group and was the lowest in the male dancer group, but there was no statistically significant group difference. The cadence of the right foot (R cadence) was the highest in the female group and was the lowest in the male dancer group, but there was no statistically significant group difference. The mean step length of the left foot was the longest in the male dancer group and was the shortest in the female dancer group, but there was no statistically significant difference. The mean step length of the right foot was the longest in the male dancer group and was the shortest in the female dancer group, but there was no statistically significant difference.

There was a statistically significant difference in mean step width between the four groups (p=.000), with the male group (10.60 ± 3.10 cm) > the female group (8.93 ± 1.60 cm) > the male dancer group (7.66 ± 2.41 cm) > the female dancer group (6.67 ± 2.73 cm).

The mean swing time of the left foot was the largest in the male dancer group and was the smallest in the female group, but it was not statistically significant. The mean swing time of the right foot was the largest in the male dancer group and was the smallest in the female dancer group, but it was not statistically significant.

Double limb support time was greatest in the female dancer group and the male dancer group and was the smallest in the male group, but it was not statistically significant. Mean speed was the highest in the female group and was the lowest in the male dancer group, but it was not statistically significant.

DISCUSSION

The present study sought to investigate differences in gait stability between K-pop professional dancers and ordinary persons and thus to evaluate gait stability in professional dancers. Although most previous studies have been conducted to evaluate gait stability in static situations, the present study analyzed gait using gait stability variables for assessing dynamic stability and basic gait parameters, such that gait stability can be more accurately evaluated.

The results of the present study showed that MoS at heel contact in the anterior-posterior direction was greater in male dancers > female dancers > females > males, while MoS at toe off was greater in female dancers > male dancers > males > females, thereby indicating that professional dancers might walk more stably compared with ordinary persons. However, MoS at heel contact and toe off in the medial-lateral direction was greater in males > male dancers > females> female dancers (p<.05), which can indicate that males walk more stably compared with females. In addition, the step length among gait parameters was found to be the greatest in male dancers with no statistical difference. The step width was greatest in males>females>male dancers>female dancers (p<.05). Gait is the process of repeatedly moving the body forward while maintaining stance phase stability (Perry & Burnfield, 1992). It seems that the MoS at heel contact or with movements to start weight transfer tended to be great in male dancers, whereas the MoS at toe off or with movements to obtain the propulsive force during gait tended to be great in female dancers. Previous studies have shown that moving distance and stride width were generally increased such that gait stability increased (Chang et al., 2010; Bendall, Bassey & Pearson 1989). In the present study, professional dancers exhibited a secured anterior-posterior stability by increasing step length rather than step width. This is thought to be due to the observation that dancers are supposed to practice movement in the anterior-posterior direction by the nature of dancing on stages, where the left and right movement area is limited. Therefore, dancers practice more anterior-posterior movements than do ordinary persons, thereby increasing the anterior-posterior base of support rather than the medial-lateral base of support. The reason for such a remarkable difference in the base of support can be thought to be the maintenance of a small base of support that is fixed among dancers so that they may switch to fast movements while dancing. In addition, such a relatively great step width means that instability was relatively increased in terms of static stability, but the rhythmic movements of the center of the body during every gait cycle means that the stability of movement is secured in terms of dynamic stability (Lee, Kim & Shin, 2010). Therefore, the present study confirmed that professional dancers walked efficiently with a greater step length and a small step width compared with ordinary persons. It was previously reported that achieving a complete gait requires that the center of the body while maintaining stability and balance through coordinated movements of the lower limbs, the pelvis, the trunk and the upper limbs (Chae, 2006). Increased dynamic stability of gait acts as a very important factor for preventing stability-related injuries.

Taken together, the results of the present study found that gait in K-pop professional dancers was more efficient than that in ordinary persons. However, it seems that there is a limit to understanding gait characteristics and stability in K-pop dancers because dance is characterized by a variety of movements that express emotions freely. Therefore, further studies are needed to systemically subdivide and analyze K-pop dancers' movements and investigate their characteristics in depth.

CONCLUSION

The present study sought to investigate the characteristics of gait stability in K-pop professional dancers and ordinary persons by analyzing differences in gait stability with the MoS and gait parameters. There were several results of the present study. First, the MoS at heel contact in the anterior-posterior direction was greater in male dancers > female dancers > females > males, while the MoS at toe off was greater in female dancers > male dancers > males > females (p<.05), thereby indicating that gait in the anterior-posterior direction was more stable in professional dancers than in ordinary persons. Second, the MoS at heel contact and the MoS at toe off in the medial-lateral direction were greater in males > male dancers > females > female dancers (p<.05), which demonstrated that males walked more stably compared with females. Third, step width among gait parameters was greater in males > females > male dancers > female dancers (p<.05). Therefore, it can be seen from the results of the present study that professional dancers walk efficiently. However, there is a limitation in comparing gait stability characteristics in K-pop dancers because K-pop dance movements are varied and free as opposed to dance, ballet and dance sports that practice the same movements consistently. Therefore, in order to analyze the characteristics of K-pop dancers, it is necessary to subdivide and analyze their dance movements based upon the type of movement.

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