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A joint normalcy index to evaluate patients with gait pathologies in the functional aspects of joint mobility †

Ki-Young Shin[1], Yong Hoon Rim[1], Youn Soo Kim[2], Hyo Shin Kim[1], Jae Woong Han[1], Chang Hyun Choi[1], Kyung Suk Lee[3] and Joung Hwan Mun[1,*]

[1]*Department of Biomechatronic Engineering, Sungkyunkwan University, Suwon, 440-746, Korea*
[2]*Department of orthopedic surgery, Bucheon St. Mary's hospital, The Catholic university of Korea, Bucheon, 420-717, Korea*
[3]*National Academy of Agricultural Science, Rural development administration, Suwon, 441-857, Korea*

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Abstract

Gait analysis using 3D motion capture systems provides joint kinematic and kinetic analysis results such as joint relative angles and moments that can be use used to evaluate the degrees of pathological gait patterns. However, the complex data produced using these 3D motion capture systems can only analyzed by experts, because the gait analysis is highly coupled to the kinematics of each joint. Therefore, severalSeveral previous studies using gait analysis have relied on the data compression technique to represent gait deviation from the average normal profiles as a single value. Even though it is important to evaluate gait pathologies at the joint level, all these previous studies have just used a single value to evaluate the pathological gait pattern. Using just one variable for evaluation of a gait is limited in terms of determining which joint movement patterns are getting better during rehabilitation. Therefore, in this study, a method suitable for evaluating gait deviation during a gait was developed to provide three indices for the hip, knee and ankle joints. In addition, to validate the proposed method in clinical cases, experimental tests were conducted on thirty thirty-six normal walkers and six patients with cerebral palsy. Furthermore, to validate the proposed method in regards to rehabilitation, experimental tests were conducted on three classified walking groups with imposed ankle equinus constraints. The JNI for the hip joint, knee joint and ankle were 8.78 (±3.70), 2.92 (±3.25) and 8.79 (±4.38), respectively, in the normal walking group. However, these values were significantly different for the pathological walking group with cerebral palsy. The JNI of the hip joint, knee joint and ankle joint were 203.73 (±171.59), 81.23 (±52.13) and 248.39 (±149.99), respectively, for this group. There were also differences between any two of the three classified groups with imposed ankle equinus constraints. In particular, the JNI of the ankle joint was statistically different at the $p<0.01$ level, and this parameter clearly increased as the degree of the imposed ankle equinus was increased. These results demonstrate that the proposed JNI can be used as a scalar factor to evaluate the angular deviation of each joint in normal and patient groups. In addition, this approach can be adapted to evaluate rehabilitation and pre/post surgery.

Keywords: Gait analysis; Joint Normalcy Index (JNI); Multivariate analysis; Cerebral palsy; Rehabilitation

1. Introduction

Observational gait analysis has long been used to evaluate the pathological gait pattern in patients with cerebral palsy. However, it is difficult to evaluate the pathological gait pattern just using observational techniques, since several internal factors are used for this analysis such as joint relative angles, forces, moments and power. Therefore, gait analysis based on a 3-D motion capture system has been widely used for quantitative analysis of human gait [1-4]. Even though gait analysis using motion capture systems can provide important quantitative information including joint kinematic and kinetic information, gait analysis using this approach is too complex to be objectively interpreted. This complexity arises from the fact thatbecause the kinematic and kinetic results of each lower-body joint are highly coupled; thus, objective evaluation of the degree of pathological gait still remains one of the most difficult problems in the field of clinical gait analysis.

Therefore, several previous studies have focused on comparing only a limited number of specific gait characteristics [5-9] or obtaining reduced variables using multivariate statistic techniques [10] to evaluate gait pathologies more objectively [11-17]. In particular, these indices have been shown to be clinically meaningful indicators not only for a more general representation of a subject's overall gait pathologies but also for more objective gait analysis. However, by only comparing

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*Corresponding author. Tel.: +82 31 299 4820, Fax: +82 31 299 4825
E-mail address: jmun@skku.edu

a limited number of specific gait characteristics, the highly coupled kinematic and kinetic results of each lower-body joint are ignored.

In regards to the gait indexing technique, Schutte et al. [13] applied principal component analysis (PCA) to calculate the proposed gait normalcy index (NI) with 16 discrete gait variables and Romei et al. [17] and Assi et al [18] used the NI to verify the reliability and to ascertain the usefulness of this method under different experimental conditions. In particular, Romei et al. concluded that the NI is a meaningful indicator of gait pathology for independent ambulators and is a useful element in the evaluation of subjects with movement disorders [17]. However, although it is important to evaluate gait pathologies at the joint level, all these previous studies have only considered a single value for evaluating a pathological gait pattern. In addition, these studies just compared the differences in NI magnitudes between normal and pathological walking groups.

In fact, the human lower-body consists of three joints; : the hip, knee and ankle joints. In addition, the kinematic and kinetic patterns among the lower-body joints are coupled in pathological gait patterns. Therefore, there are limitations in using just one variable to evaluate which joint movement pattern is getting better during rehabilitation. Thus, there is a clear need to develop methods that provide indices for each lower-body joint that are capable of evaluating the degree of a pathological gait.

Children with cerebral palsy may have a number of bone, joint and muscle problems that make their pathological gait pattern more complex [19, 20]. Therefore, in this clinical case, the evaluation of movement pathologies for each joint is more important than other more simple clinical cases. As a result, there is a need to validate whether this method is applicable to the patient rehabilitation procedure, since most patients with cerebral palsy require rehabilitation procedures or surgeries to improve their gait normality.

The objectives of this study were: (1) to provide a method to calculate the Joint joint Normalcy normalcy Index index (JNI) based on a multivariate statistic technique, (2) to validate the method in clinical cases by comparing the differences in JNI between normal and pathological walking groups, and (3) to validate the method in a rehabilitation setting by comparing the differences in JNI among three classified pathological walking groups with different degrees of imposed ankle equinus. In addition, a visualization technique to present the JNI more effectively was introduced.

2. Methodology

2.1 Gait analysis

All subjects walked barefoot at a self-selected speed on a 10m walkway. The first and second groups were composed of a normal walking group and a patient group with cerebral palsy to compare the differences in JNI between the two groups. The first group, which consisted of thirty thirty-six normal walkers (mean ± standard deviation, age, 24.4 ± 3.7year; height, 174.1 ± 3.7cm; mass, 71.4 ± 8.2kg), walked normally with the first heel and ankle rockers. The second group consisted of six patients with cerebral palsy (age, 7.7± 2.7year; height, 109.8 ± 15.2cm; mass, 21.7 ± 7.8kg). To validate the JNI in a rehabilitation setting, three pathological walking groups were selected based on the degrees of imposed ankle equinus using the proposed taping method [21, 22]. In this case study, six normal walkers (age, 23.6± 0.5year; height, 174.9 ± 2.2cm; mass, 68.7 ± 2.8kg) participated. During these tests, two clinicians from the Catholic University of Korea participated in the observational gait analysis. As shown in Fig. 1 and Table 1, the classified pathological walking groups were the normal/mild group, moderate group and severe group. To compare the joint kinematic data of the pathological walking group with those of the normal walking group, the RMS difference, which is the correlation and the maximum difference from the average of the normal walking kinematic patterns, were was used. The JNI of each group was then compared.

Table 1. Definition of the test groups.

Test Group	Definition
Normal/Mild	- Normal and flat-foot walking - Heel–Toe walking
Moderate	- Heel lifting angle in stance at 5°-20° level - Occasionally heel-toe walking
Severe	- Maximum plantar flexion group - Toe-Toe walking

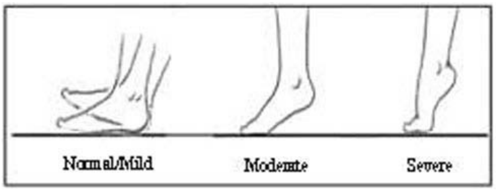

Fig. 1. Ankle movement patterns in the test groups.

An optic motion analysis system with six cameras (Vicon 460) was used to collect video data. During walking, the sample frequency of the camera motion system was 60 Hz. The motion data was then filtered using a fourth-order Butterworth, zero-lag, low-pass filter with a cut-off frequency of 7Hz [23]. SWING BANK. Inc., SB Gait was used to calculate the joint kinematic and kinetic analysis results using the displacement of skin markers and the ground reaction forces. Table 2 provides a description of the equipments used in this study.

2.2 Joint parameters and the calculation of JNI

In this study, 36 of the most representative joint parameters were extracted from the joint kinematic analysis according to a previous study [14]. The extracted joint parameters for each lower body joint are shown in Tables 3, 4 and 5, respectively. As shown in Tables 3, 4 and 5, 14 parameters representing the

Table 2. Specification of gait analysis apparatus.

Equipment	Maker	Model	Specification
Camera	VICON	MCam2	1. User selected frame rates: up to 1,000 fps 2. Pixel of digital CMOS sensor: 1,280 x 1,024 3. Resolution: 1,280 x 1,024 pixels

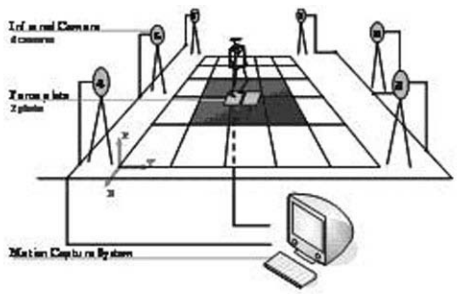

Fig. 2. Schematic diagram of the gait analysis apparatus.

hip joint movement, 4 parameters representing the knee joint movement and 16 parameters representing the ankle joint movement were used to calculate the JNI.

The extracted joint parameters were used to calculate the joint normalcy indices of each joint at a p<0.05 level according to the previously proposed method based on principal component analysis [13]. The required processes were as follows:

(1) Calculate the mean (μ_i) and the standard deviation (σ_j) of the measured hip joint kinematic variables (x_j) from normal subjects (j = 1, 2, 3….14)

(2) Standardize the 1st measured data

$$z_j = (x_j - \mu_j)/\sigma_j \qquad (j = 1,2,3...14)$$

(3) Calculate the covariance matrix (C_{ij}) for the standardized discrete variables (i & j = 1, 2, 3….14)

(4) Calculate the eigenvalue-eigenvector pairs (λ_i - e_i) for the covariance matrix

(5) Define a new set of scaled independent/uncorrelated variables

$$y_i = \left(\frac{1}{\lambda_i}\right)\sum_j^{14} \alpha_j^i z_j \qquad (i = 1,2,3...14)$$

(6) Measure the hip joint kinematic variables ($\tilde{x}_j$) from a given subject (j = 1, 2, 3….14)

(7) Standardize the 6th measured data using the mean (μ_i) and the standard deviation (σ_j) from the normal subjects

$$\tilde{z}_j = (\tilde{x}_j - \mu_j)/\sigma_j \qquad (j = 1,2,3...14)$$

(8) Define a new set of scaled independent/uncorrelated variables

$$\tilde{y}_i = \left(\frac{1}{\lambda_i}\right)\sum_j^{14} \alpha_j^i \tilde{z}_j \qquad (i = 1,2,3...14)$$

(9) Find the square of the Euclidian length for a given subject from the normal mean in the new uncorrelated coordinate system

$$d = \sum_i^{14} \tilde{y}_i^2 \qquad (i = 1,2,3...14)$$

After calculating the hip joint normalcy index, the same process was applied to the knee and ankle joints.

Table 3. 14 gait parameters for hip joint JNI.

	Hip joint	Gait Phase	Unit
1	Maximum flexion-extension angle	Stance/Swing	degrees
2	std* of flexion-extension angle	Swing	degrees
3	Minimum rotational velocity	Stance	degrees
4	Minimum rotational velocity	Terminal-Swing	degrees/min
5	Minimum abduction-adduction velocity	Pre-Swing	degrees/min
6	Mean rotational Velocity	Terminal-Swing	degrees/min
7	Range of rotation angle	Loading-Response	degrees
8	Mean abduction-adduction velocity	Mid-Swing	degrees/min
9	Maximum abduction-adduction velocities	Initial-Swing	degreed/min
10	Minimum abduction-adduction velocity	Stance	degrees/min
11	Range of rotation angle	Swing	degrees
12	Minimum flexion-extension velocity	Mid-Swing	degrees/min
13	Minimum abduction-adduction velocity	Terminal-Stance	degrees/min
14	Minimum flexion-extension velocity	Pre-Swing	degrees/min

Table 4. 4 gait parameters for knee joint JNI.

	Knee joint	Gait Phase	Unit
1	Range of flexion-extension angle	Swing	degrees
2	Mean flexion-extension velocity	Loading-Response	degrees/min
3	std* of abduction-adduction angle	Stance/Swing	degrees
4	Minimum flexion-extension velocity	Terminal-Stance	degrees/min

3. Result

3.1 Differences between normal and pathological walking groups

3.1.1 Joint kinematic data

Fig. 3 and Table 6 present the differences in the joint kinematic data between the normal and pathological walking groups during a gait. In order toTo compare the differences between the time series of the joint kinematic results of the normal and pathological walking groups, the Pearson coeffi-

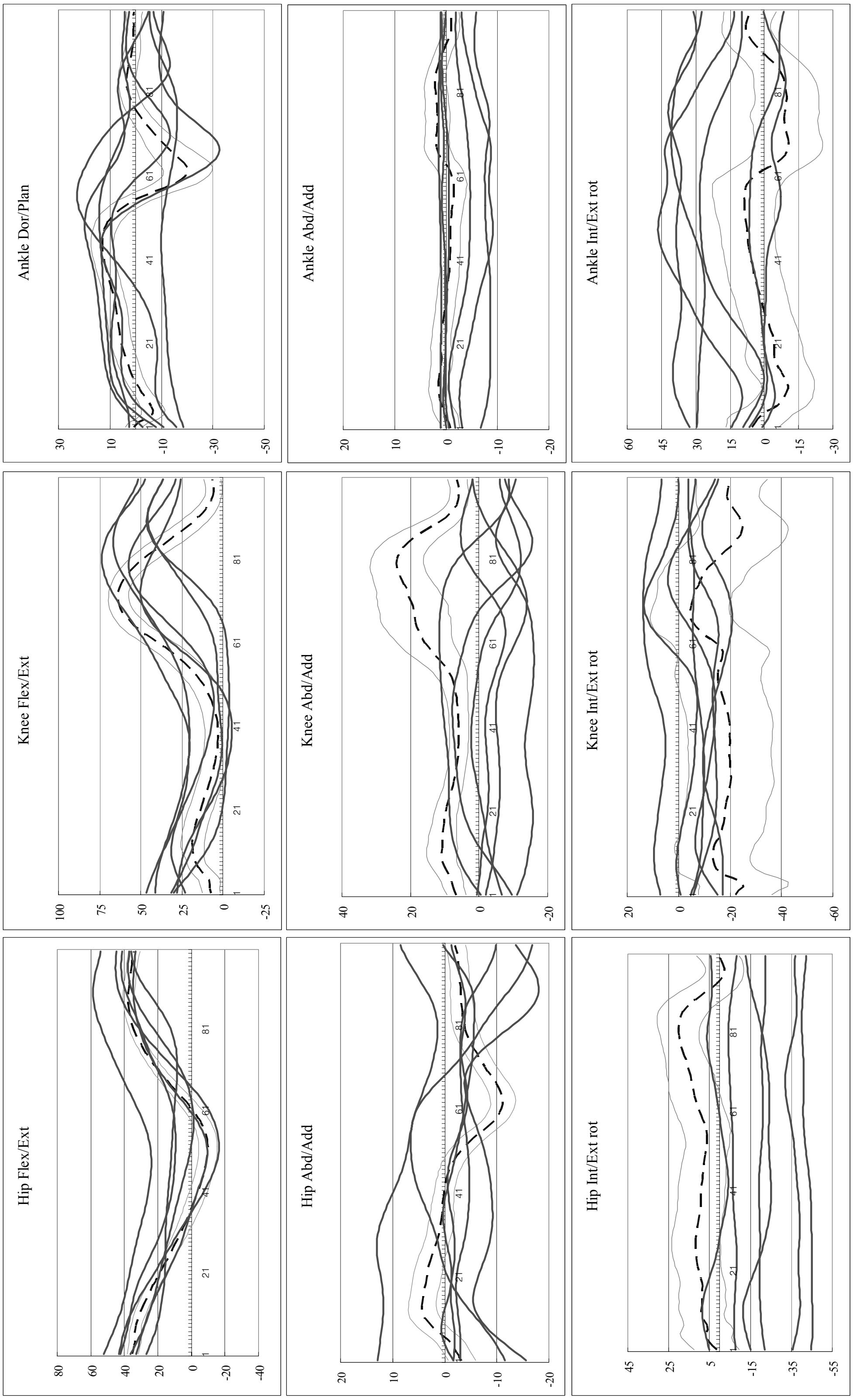

Fig. 3. The average joint kinematic data in the normal and pathological walking groups (---: Normal walking group, —: Pathological walking group; x-axis: Gait cycle (100%), y-axis: degree (°)).

Table 5. 16 gait parameters for ankle joint JNI.

	Ankle joint	Gait Phase	Unit
1	Mean dorsi-flexion angle	Stance/Swing	degrees
2	Mean dorsi-flexion velocity	Mid-Stance	degrees/min
3	std* of dorsi-flexion angle	Stance/Swing	degrees
4	Minimum dorsi-flexion velocity	Stance/Swing	degrees/min
5	Maximum dorsi-flexion velocity	Terminal-Swing	degrees/min
6	Minimum dorsi-flexion velocity	Initial-Swing	degrees/min
7	Range of dorsi-flexion angle	Loading-Response	degrees
8	Maximum foot rotational velocity	Stance	degrees/min
9	Mean foot rotational velocity	Terminal-Stance	degrees/min
10	Range of foot rotation angle	Stance/Swing	degrees
11	Maximum dorsi-flexion velocity	Stance	degrees/min
12	Minimum foot rotational velocity	Stance	degrees/min
13	Maximum foot rotation angle	Mid-Stance	degrees
14	Range of dorsi-flexion angle	Mid-Stance	degrees
15	Range of foot rotation angle	Loading-Response	degrees
16	Maximum foot rotational velocity	Mid-Swing	degrees/min

Table 6. Joint kinematic analysis results for the normal and pathological walking groups.

	RMS diff. mean (S.D)	Correlation mean (S.D)	Max diff. mean (S.D)
Hip	18.05 (15.40)	0.33 (0.53)	28.45 (17.43)
Knee	18.40 (7.17)	0.13 (0.48)	33.94 (13.71)
Ankle	14.92 (12.52)	0.20 (0.37)	26.65 (18.01)

cients of correlation and the RMS error were calculated for all trials [24].

As shown in Fig. 4, the kinematic results of the patients with cerebral palsy displayed a clearly different pattern than the normal walking group. In addition, the average RMS differences were 18.05, 18.40 and 14.92 in the hip, knee and ankle joints, respectively (Table 6). The average correlations from each joint with regard to the kinematic correlation between the normal and pathological walking groups were 0.33, 0.13 and 0.20, respectively, (Table 6).

3.1.2 Joint Normalcy Index

The JNI for the normal and pathological walking groups are shown in Table 7 and Table 8. The mean JNI of the pathological walking group (81.23-248.39) was higher than that of the normal walking group (2.97-8.78). As shown in the Fig. 4, the difference between the JNI of the normal and pathological walking groups was statistically significant at the $p<0.01$ level. This result demonstrates that the proposed JNI was able to distinguish the gait pathology group from the normal walking group at the joint level.

Table 7. JNIs of the normal walking group.

JNI	Normal walking group (n=36)			
	Min	Max	Mean	S.D
Hip	2.6	15.3	8.78	3.70
Knee	0.53	13.89	2.92	3.25
Ankle	2.49	24.16	8.79	4.38

Table 8. JNIs of the pathological walking group.

JNI	Pathological walking group (n=6)			
	Min	Max	Mean	S.D
Hip	36.45	605.62	203.73	171.59
Knee	26.75	199.74	81.23	52.13
Ankle	58.04	666.81	248.39	149.99

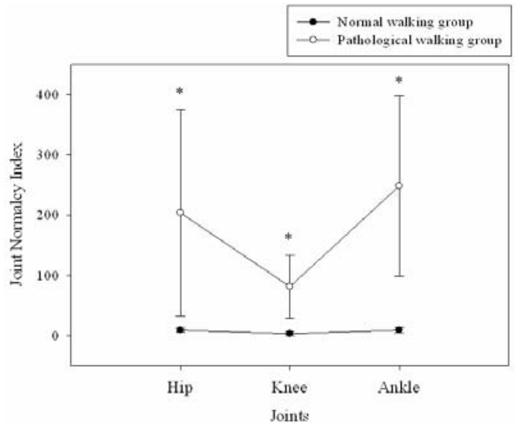

Fig. 4. Joint normalcy index in the normal and pathological walking groups (*: statistically different at $p<0.01$).

3.2 Differences among the classified three walking groups with imposed ankle equinus constraints

3.2.1 Joint kinematic data

As mentioned previously, to verify the applicability of using the JNI in the rehabilitation field, the results from three groups classified with different degrees of imposed ankle equinus were compared using the proposed taping method. Fig. 5 shows the joint kinematic analysis results of each group. There was a significant increase in ankle plantar-flexion for all phases of the gait from the normal/mild ankle equinus group to the severe ankle equinus group. A secondary deviation in the gait occurred in the hip and knee joints. There was also an increase in the joint flexion movement for the stance phase of the gait in the moderate and severe ankle equinus groups. However, no statistical differences were observed between the kinematic patterns of the knee and hip joints for the moderate

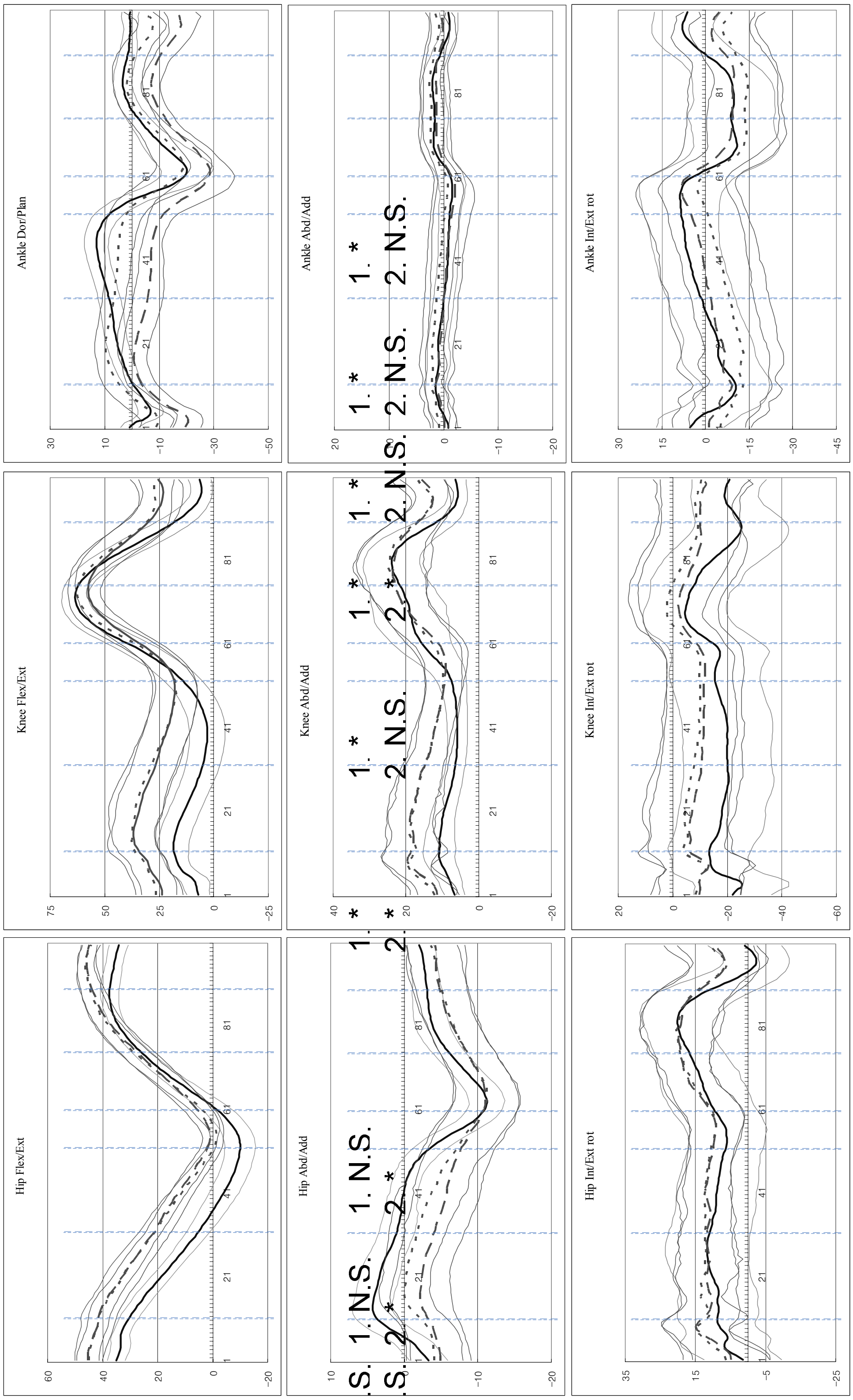

Fig. 5. Joint kinematic data of the three classified walking groups with imposed ankle equinus constraints.
(——: normal/mild group -----: moderate group – – –: severe group, x-axis: Gait cycle(100%), y-axis: degree(°); N.S.: statistically no significant different, *: statistically different in p<0.01)

Table 9. JNIs of the normal/mild group.

JNI	Normal/Mild group (n=6)			
	Min	Max	Mean	S.D
Hip	5.31	31.14	17.07	8.69
Knee	1.66	10.87	7.08	3.15
Ankle	2.14	34.25	13.61	10.24

Table 10. JNIs of the moderate group.

JNI	Moderate group (n=6)			
	Min	Max	Mean	S.D
Hip	28.43	98.82	57.46	21.20
Knee	26.17	86.07	41.04	15.55
Ankle	39.35	371.79	178.27	109.24

Table 11. JNIs of the severe group.

JNI	Severe group (n=6)			
	Min	Max	Mean	S.D
Hip	29.08	118.44	71.79	30.65
Knee	27.25	54.87	40.33	8.37
Ankle	129.73	888.05	356.45	229.83

and severe ankle equinus groups (Fig. 5). The joint kinematic differences among the three groups were represented by the six vertical lines including the gait phases and statistical results in each graph.

3.2.2 Joint normalcy index

The JNI for the normal/mild, moderate and severe ankle equinus groups are shown in Tables 9, 10 and 11. The mean JNI in the normal/mild ankle equinus group ranged from 7.08 to 17.07. In the moderate and severe ankle equinus groups, the mean JNI increased to 178.27 and 229.83, respectively.

The A statistical comparison of the JNI in the three groups is presented in Fig. 6. There were significant differences between the normal/mild and moderate groups for all joint. However, for the knee and hip joints, no significant differences between the moderate and severe ankle equinus groups were observed. The JNI of the ankle joint significantly increased as the degree of ankle equines increased.

3.2.3 Visualization of joint normalcy index

Fig. 7 presents an example plot of the JNI for a subject that participated in the second case study. In this case, the JNI for the three classified groups diminished as the degree of ankle equines decreased.

4. Conclusions

Pathological gait patterns are caused by a number of different bones, joint and muscle problems. In general, the pathological gait patterns are complex to evaluate due to the fact

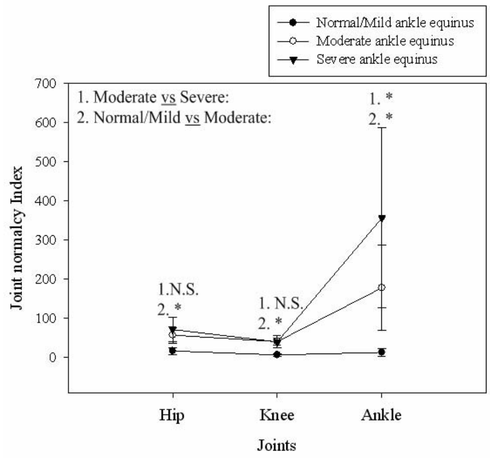

Fig. 6. Joint normalcy index in normal/mild, moderate and severe groups (N.S.: statistically no significant, *: statistically different in p<0.01).

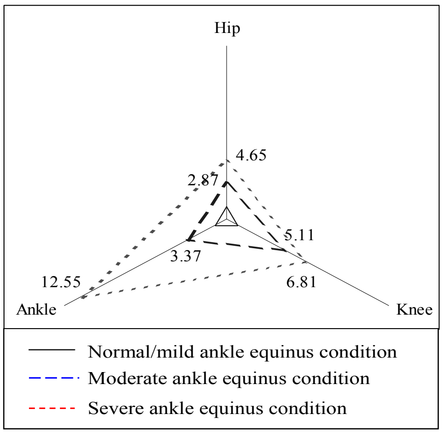

Fig. 7. Joint normalcy index chart for a single subject.

thatbecause the kinematic and kinetic results of each lower-body joint are highly coupled. Therefore, there is a need to provide indices that can simplify the evaluation of pathological gaits. For this purpose, a method to calculate the Joint joint Normalcy normalcy Index index (JNI) was developed based on a multivariate statistic technique. To validate the method under clinical conditions, two types of experimental tests were performed. The first experimental test was to validate whether the proposed method has the ability to distinguish pathological walking patterns from normal walking patterns. The second experimental test was performed to validate the method in a rehabilitation setting by comparing the differences in JNI among three classified pathological walking groups with different degrees of imposed ankle equinus.

The experimental results of this study are summarized as follows:

(1) In the first experimental test, the JNI was robust enough to distinguish the pathological walking patterns from normal walking patterns. The JNI of the normal walking group ranged from 0.53 to 24.16. In the pathological walking group with cerebral palsy, the JNI ranged from 26.75 to 666.81.

(2) In the second experimental test, the JNI was capable of evaluating the degree of rehabilitation, since the JNI of the ankle joint was significantly different as the degree of ankle equines increased. In the normal/mild ankle equinus group, the mean JNI of the ankle joint was 13.61. As the degree of ankle equines increased, the mean JNI also increased from 13.61 to 356.45.

These results revealed that the proposed JNI can be used as a scalar factor to evaluate each joint angular deviation in normal and patient groups. In addition, this approach can be adapted to evaluate rehabilitation and pre/post surgery. However, validation of the proposed method in a rehabilitation setting was conducted on subjects with imposed ankle equinus and not under real clinical conditions. Therefore, to more accurately evaluate the potential of using this method as an evaluation tool of rehabilitation, more experimental tests must be performed with real patients under clinical conditions.

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References

[1] D. H. Sutherland, The evolution of clinical gait analysis, *Gait and Posture*, 16 (2002) 159-179.

[2] J. Perry, *Gait Analysis, Normal and Pathological Function*, Slack Inc., New Jersey, USA (1992).

[3] C. Miyuki M. Kawamura, Mauro M. César C. de Morais Filho, Milena M. Moreira M. Barreto, Sabrina S. Kyoko K. de Paula Asa, Yara Y. Juliano and Neil N. Ferreira Novo, Comparison between visual and three-dimensional gait analysis in patients with spastic diplegic cerebral palsy, *Gait and Posture*, 25 (1) (2007) 18-24.

[4] Y. H. Rim, Ahn A. Ryul R. Choi, Sang S. Sik S. Lee, Kyoung K. Kee K. Min, Dong D. Hyuk H. Keum, Chang C. Hyun H. Choi and Joung J. Hwan H. Mun, The comparison of joint kinematic error using the Absolute and Relative coordinate systems for human gait, *International journal Journal of mechanical Mechanical science Science and technology Technology*, 22 (2009) 1537~1543.

[5] L. F. Boscarino, S. Ounpuu, R. B. Davis, J. R. Gage and P. A. DeLuca, Effects of selective dorsal rhizotomy on gait in children with cerebral palsy, *Journal of pediatric Pediatric orthopedics Orthopedics*, 13 (1993) 174-179.

[6] S. Ounpuu, E. Muik, R. B. Davis, J. R. Gage and P. A. DeLuca, Rectus femoris surgery in children with cerebral palsy. Part I: the effect of rectus femoris transfer location on knee motion, *Journal of pediatric Pediatric orthopedics Orthopedics*, 13 (3) (1993) 25-330.

[7] T. F. Winter, J. R. Gage and R. Hicks, Gait patterns in spastic hemiplegia in children and young adults, *Journal of Bone and Joint Surgery*, 69A (3) (1987) 437-441.

[8] J. Romkes and R. Brunner, Comparison of a dynamic and a hinged ankle–foot orthosis by gait analysis in patients with hemiplegic cerebral palsy, *Gait and Posture*, 15 (1) (2002) 18-24.

[9] D. Metaxiotis, W. Accles, A. Siebel and L. Doederlein, Hip deformities in walking patients with cerebral palsy, *Gait and Posture*, 11 (2) (2000) 86-91.

[10] M. Kendall, *Multivariate Analysis*, Charles Griffin, London, UK (1980).

[11] T. Maureen, Carla Wilson, E. Biden and W.R. Knight, An index to quantify normality of gait in young children, *Gait and Posture*, 16 (2002) 149-158.

[12] M. H. Schwartz, T. F. Novacheck and J. Trost, A tool for quantifying hip flexor function during gait, *Gait and Posture*, 12 (2000) 122-127.

[13] L. M. Schutte, U. Narayanan, J. L. Stout, P. Selber, J. R. Gage and M. H. Schwartz, An index for quantifying deviations from normal gait, *Gait and Posture*, 11 (2000) 25-31.

[14] J. Wu, J. Wang and L. Liu, Feature extraction via KPCA for classification of gait patterns, *Human movement Movement scienceScience*, 26 (3) (2007) 393-411.

[15] B. Garbor, Paulo P. Lisboa, Adrian A. Lees, Steve S. Attfield, Gait quality assessment using self-organising artificial neural networks, *Gait and Posture*, 25 (2007) 374-379.

[16] C. D. Mah, M. Hulliger, R. G. Lee and I. S. Callaghan, Quantitative analysis of human movement synergies: constructive pattern analysis for gait, *Journal of Motor Behavior*, 2 (1994) 683-102.

[17] M. Romei, M. Galli, F. Motta, M. Schwartz and M. Crivellini, Use of the normalcy index for the evaluation of gait pathology, *Gait and Posture*, 19 (2004) 85-90.

[18] A. Assi, Ismat Ghanem, El Mostafa Laassel, GeorgesG.-Francois F. Pennecot, Francois F. Lavaste and Wafa W. Skalli, Normalcy gait Index and kinematics: Uncertainty and repeatability on healthy children database preliminary application on cerebral palsy group, *Gait and Posture*, 24 (2) (2006) S49-S50.

[19] Carrie C. Stackhouse, Patricia P. A. Shewokis, Samuel S. R. Pierce, Brian B. Smith, James J. McCarthy and Carole C. Tucker, Gait initiation in children with cerebral palsy, *Gait and Posture*, 26 (2) (2007) 317-322.

[20] N. Moreau, Suzanne S.Tinsley and Li L. Lia, Progression of knee joint kinematics in children with cerebral palsy with and without rectus femoris transfers: a long-term follow up, *Gait and Posture*, 22 (2) (2005) 132-137.

[21] M. Goodman, J. Menown, J. West, K. M. Barr, D. W. Linden and M. L. McMulkin, Secondary gait compensations in individuals without neuromuscular involvement following a unilateral imposed equinus constraint, *Journal of Biomechanics*, 20 (3) (2003) 238-244.

[22] Yong Y. Hoon H. Rim, Young Y. Jin J. Kim, Sang S. Sik S. Lee and Joung J. Hwan H. Mun., A severity index for nondestructive dynamic analysis in equines gait. Key engineer-

ing Engineering Materials, 321 (2006) 1082-1085.

[23] D. A. Winter, *Biomechanics and Motor Control of Human Movement,* Second Ed., John Willey Wiley & Sons, New York, USA (1990).

[24] Idsart I. Kingma, Michiel M. P. de Looze, Huub H. M. Toussaint, Hans H.G. Klignsma and Tom T. B.M. Bruijnen, Validatation Validation of a full body 3-D dynamic linked segment model, *Human movement Movement science Science*, 15 (1996) 833-860.

Shin Ki Young received his M.S degree majoring in biomechatronic engineering from the Sungkyunkwan University in 2006. Mr. Shin is currently a Ph. D candidate at the Department of Biomechatronic engineering at Sungkyunkwan University in Suwon, Korea. Mr. Shin's research interests are in the area of dynamic human model, bio-signal processing, computer vision and medical image processing.

Joung Hwan Mun received his Ph.D. degree majoring in mechanical engineering from the University of Iowa in 1998. Dr. Mun is currently a Professor at the Department of Bio-Mechat-ronic engineering at Sungkyun-kwan University in Suwon, Korea. He is currently serving as a director of the Bio-Mechatronics center with regard to an international IMS project. Dr. Mun's research interests are in the area of digital human modeling, sports biomechanics, bioelectronics and digital factory for human oriented production system.