KJSB Korean Journal of Sport Biomechanics 2016; 26(1): 1-9
http://dx.doi.org/10.5103/KJSB.2016.26.1.1
http://e-kjsb.org eISSN 2093-9752

ORIGINAL

Correlation Analysis between Dance Experience and Smoothness of Dance Movement by Using Three Jerk-Based Quantitative Methods

Yang Sun Park[1,2]

[1]Department of Physical Education, College of Performing Arts & Sport, Hanyang University, Seoul, Korea
[2]Movement Science Center, Research Institute for Sports Science and Sports Industry, Hanyang University, Seoul, Korea

Received : 31 January 2016
Revised : 24 February 2016
Accepted : 16 March 16

Corresponding Author
Yang Sun Park
Department of Physical Education, College of Performing Arts & Sport, Hanyang University, 222 Wangsimni-ro Seongdong-gu, Seoul, 04763, Korea
Tel : +82-2-2220-4199
Fax : +82-2-2220-1337
Email : ysunp@hanyang.ac.kr

Objective: The aim of this study is to investigate the association between dance experience and smoothness of hand trajectory during dance by using three jerk-based quantitative methods (integrated squared jerk, mean squared jerk, and dimensionless jerk).

Methods: Eleven Korean traditional dancers whose experience of dancing ranged from 5 years to 20 years participated in this study. Dancers performed the Taeguksun motion in Korea traditional dance. Six infrared cameras were used to capture the movement of the hands of the dancers. The smoothness of hand movement was calculated using three jerk-based methods.

Results: With regard to the smoothness of the right hand, dance experience was significantly correlated with dimensionless jerk (r=0.656, p=0.028), while dance experience was not significantly correlated with integrated squared jerk (r=0.581, p=0.552) and mean squared jerk. With regard to the smoothness of the left hand, there was no correlation between dance experience and any of the three jerk values.

Conclusion: Our results showed that individuals with more dance experience performed the task more smoothly. This study suggests that dimensionless jerk should be used as a predictor for smoothness in dance movement. Thus, our results support the idea that smoothness is an aspect of movement quantity distinct from speed and distance.

Keywords: Jerk, Dimensionless jerk, Smoothness, Dance, Dance experience

I. INTRODUCTION

The jerk-based quantitative method was first introduced for explaining the process and prediction of hand movement in space early on, and it was based on the principle that the maximum smoothness theory could be predicted by a bell-shaped velocity curve and straight line trajectory, which were the scales for assessing dynamic optimization by using kinematic end-point trajectory (Flash & Hogan, 1985). The jerk theory involved a method for calculating the jerk cost at the early stage. The jerk cost was calculated by differentiating the position coordinates during motor performance three times with respect to time (Schneider & Zernicke, 1989). Many researchers in the field of kinematics discovered through the jerk theory that a skilled individual moved his or her arms as smoothly as possible, which was based on the minimum-jerk hypothesis that states that the intensity of jerk decreased in more skilled motor performance. Moreover, the smoothness was quantitatively measured by integrated squared jerk (Platz, Denzler, Kaden, & Mauritz, 1994). In other words, from a kinematic perspective, this represented a concept that the integral

Copyright © 2016 Korean Journal of Sport Biomechanics
This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (http://creativecommons.org/licenses/by-nc/3.0/) which permits unrestricted noncommercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

value of jerk squared was minimized for the movement of the entire body (Zatsiorsky, 1998).

However, other researchers discovered a problem with jerk cost, i.e., the jerk-cost value increased as the entire performance time of movement increased (Kitazawa, Goto, & Urushihara, 1993). In order to address this problem, jerk cost was quantified by methods such as mean squared jerk (Hogan & Sterned, 2009) and normalized jerk (Park & Lee, 2005), which normalized jerk cost to movement performance time. These methods were used to calculate the jerk value of the smoothness theory by normalizing the time spent in performing motions that required different amounts of time for analysis of motion and movement.

In recent times, analysis of jerk has been approached from a different perspective. Hogan and Sterned (2009) indicated that the reason why many studies based on the fundamental principle of jerk (Goldvasser, McGibbon, & Krebs, 2001; Wininger, Kim, & Craelius, 2009) showed inconsistent results was because of the sensory-motor dysfunction that each individual has. This theory is based on an assumption that each individual has a varying degree of control over his or her own movement, and because many variables are involved in an individual's ability to control motion and movement, it is difficult to quantify and to analyze jerk collectively or with simple units, or specific variables. One of the methods proposed to address this problem was a dimensionless quantity (Hogan & Sterned, 2009; Lee, Ranganathan, & Newell, 2011), which was a quantitative method that eliminated a variety of movement variables (e.g.; speed, time, etc.). Hogan and Sterned (2009) applied the dimensionless quantity to a jerk motion, and presented a method for calculating dimensionless jerk that eliminated unit dimensions. Those dimensions were established as motion time and speed that took an expressive movement into account and the jerk theory was re-established through a method of eliminating the units of these two dimensions.

Recently, there have been studies on quantifying a dance from an aesthetic perspective (Calvo-Merino et al., 2010; Cross et al., 2011; Torrents, Castañer, Jofre, More, & Reverter, 2013). Bronner and Shippen (2015) trained 18 dancers on three types of motion and dance with speed of developed arabesque motion as the condition. Then, the dancers were divided into two groups and analyzed pre- and post-training differences by using dimensionless jerk values. The results showed significant difference in dimensionless jerk value based on motion, but no difference was found for group condition.

Ultimately, the jerk-based theory was based on the concept of smaller jerk amount in an individual who was more experienced, which was used in the prediction of smoothness, and this jerk-based theory has been used in dance-related studies, in Korea and abroad, in identifying smoothness of movement (Jung & Jung, 2007; Jung & Nam, 2007). Moreover, performing dance movements is considered as a representative movement expressing smoothness, and prediction of smoothness plays a part in quantifying artistic expressions and has also been used as a kinematic analysis method. However, among studies of smoothness in dancers' movement, one Korean study failed to find a significant difference in jerk values (Park, Kim, & Lee, 2014).

This study aimed to present the jerk values during while performing dance movements by using three types of jerk-based quantitative methods indicated above and to investigate their differences. For this, there are two hypotheses. First, a more experienced dancer will show difference in performing a movement, even if that movement is the same. If so, the second hypothesis is that in calculating the jerk values that quantify the smoothness of dance motion according to the experience levels, a dimensionless jerk that eliminates the unit conditions in both time and speed of dance performance will have a greater influence on smoothness theory that quantifies dance motion than the other two jerk calculation methods.

II. METHODS

1. Participants

The participants in this study consisted of 11 dancers, ranging from amateur dancers majoring in traditional Korean dance to professional dancers with 5 to 20 years of dance experience. The physical characteristics of participants were shown in Table 1.

Table 1. Physical characteristics of participants

Subject	Career (yrs)	Age (yrs)	Height (cm)	Weight (kg)
1	5	18	161	48
2	6	18	165	49
3	7	18	165.4	50
4	10	20	156	45
5	12	32	165	49
6	12	18	168	56
7	14	30	166	51
8	14	18	165	50
9	15	30	168	55.4
10	18	31	166.5	54
11	20	33	168	47.2
M±SD	12.09 ±458	24.18 ±6.48	164.90 ±3.40	50.42 ±3.29

2. Kinematic variable measurements

In the experiment, images were acquired using six high-speed infrared cameras (Motion 100) after securing enough space to perform traditional Korean dance motions. The settings were camera speed of 100 field/s, shutter speed of 1/500, frequency of 1,000 Hz, low pass filter of 6 Hz, and amplifier gain of 4,000. By taking the participant's direction of progress as a center, the y-axis was set as forward and backward directions, x-axis as left and right directions, and z-axis as up and down directions. In order to determine the end-point trajectory of arm movement while performing traditional Korean dance motion, ball markers were attached to the tips of left and right fingers (middle fingers). To obtain the best possible position values, a control object point of 1×2×3 m was used for calibration over 1 min.

3. Motion settings

Traditional Korean dance motions were performed by dancers who were already familiar with Korean dance. In order to select motion with a medium or higher degree of difficulty among traditional Korean dance motions, a difficulty of the lower limb increased and the upper limb motion was set to basic motion that could best express the curved beauty. The lower extremity performed Doldamchae motion (stand on one leg after half-revolution turn), which required dynamics and fast balancing, while the arm motion was set as a motion going from Duichoom-hurigamgi to Taeguksun motion (semi-circular motion in taeguk shape with the right hand on top and the left hand below the chest). Although the motion has been divided and illustrated, as shown in Figure 1, for easier understanding, the jerk value was derived at a continuous motion from 1 to 4. Gutgeori jangdan, a traditional Korean dance rhythm (1, 2, 3, 4 count) was selected as the motion time and the dancers were encouraged to complete the motion set in the study within half jangdan (3, 4 count). Each dancer was given 5 to 10 practice sessions to become familiar with the motion, after which the actual measurements for the motion were taken.

Figure 1. Arm movement in Korea dance.

4. Data processing

Kwon3d XP software was used for calculation of the position data of fingertips (middle fingers) for this study. For jerk-based measures data processing, position data obtained from three different directions were recalculated as a sum vector, and the jerk values were analyzed using three methods as shown in Table 2. First, the position vector of a fingertip obtained through motion analysis was differentiated 3 times and the resulting value was squared, then subsequently integrated with respect to motion time to obtain the integrated squared jerk. Second, a mean squared jerk value that took the mean value of jerk cost associated with the total time required to perform the motion was derived. Third, total motion time and speed

Table 2. Three types Jerk-based measure of movement smoothness and their dimensions

Types	Formula	Dimension	Study
A	$Integrated\,squared\,jerk = \int_{t1}^{t2} \dddot{x}(t)^2\,dt$	$\frac{L^2}{T^6}$	Platz, Denzler, Kaden, & Mauritz (1994)
B	$Mean\,squared\,jerk = \frac{1}{t2-t1}\int_{t1}^{t2} \dddot{x}(t)^2\,dt$	$\frac{L^2}{T^6}$	Wininger, Kim, & Craelius (2009)
C	$Dimensionless\,jerk = \frac{D^3\int_{t1}^{t2} \dddot{x}(t)^2\,dt}{V_{mean}^2}$	None	Hogan & Sternad (2009)

Note. t1= time of initial movement; t2= time of final movement; x(t)= position variable; L= length; T= time; D= duration of the trial; Vmean= average velocity of the trial.

were set as the normalizing variables to derive dimensionless jerk. In this study, jerk-based smoothness measurements did not significantly influence the filtering (Wininger, Kim, & Craelius, 2009), and hence low pass filtering was not performed when calculating the jerk values.

MATLAB 8.2 version (Mathworks, USA) was used as the analytic tool in calculating the jerk values. For testing changes in the jerk values according to dance experience, a correlation analysis was performed based on the number of years of dance experience for 11 dancers. The significance level, *p*-value, was set to 5%.

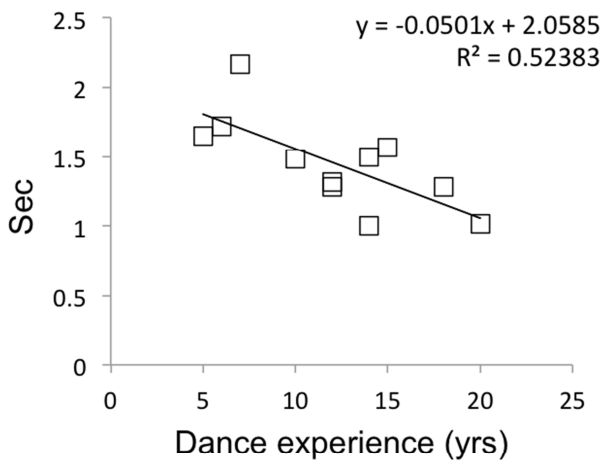

Figure 2. Correlation result of motion time between dance experience.

III. RESULTS

1. Correlation between time difference and dance experience

As a result of performing the Taeguksun motion (which was selected as the movement to be performed within half jangdan of gutgeori jangdan of Korean dance), a correlation between motion expression time and dance experience was found (r=0.724, p=0.011) (Figure 2).

2. Correlation between three types of jerk values and dance experience

For comparison of jerk tendencies of the right and left hands, position data, primary-differentiated speed, secondary-differentiated acceleration, and tertiary-differentiated jerk graph of participant #1 with the lowest dance experience (5 years) and participant #11 with the highest dance experience (20 years) are shown in Figure 3.

1) Right hand movement

Jerk values and integrated squared jerk values of the right hand based on dance experience showed r=0.581 and p=0.552. Mean squared jerk values showed r=0.534 and p=0.090. Therefore, no correlation according to dance experience was found. Dimensionless jerk values showed r=0.656, p=0.028, and therefore, relationship with smooth-

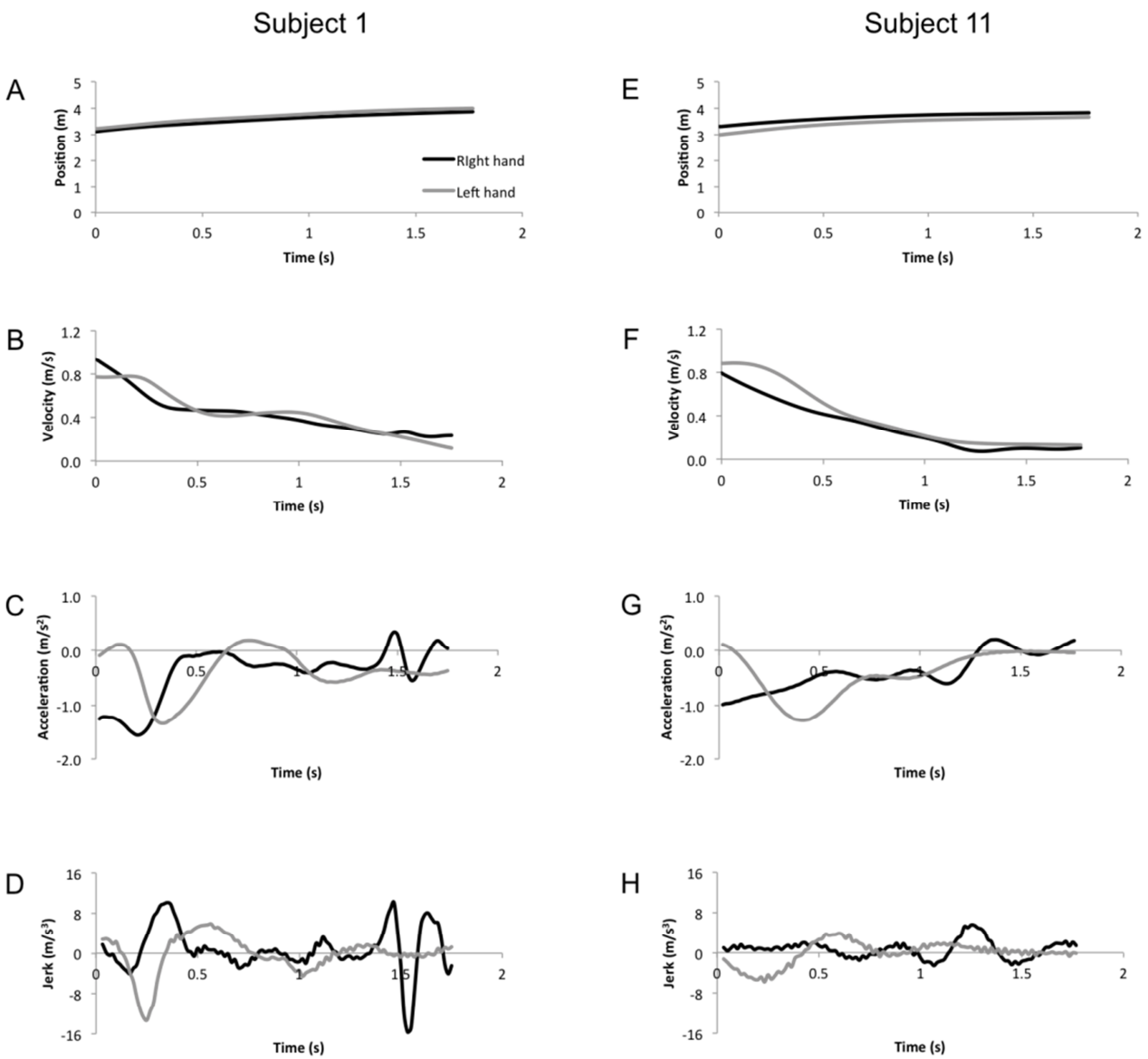

Figure 3. Graph of position and jerk result of right and left hand by each subject 1 and subject 11. A, B, C, and D show the position, velocity, acceleration and jerk result graph in the right and left hand of subject 1 (5 yrs dance experience). E, F, G, and H show the position, velocity, acceleration and jerk result graph in the right and left hand of subject 11 (20 yrs dance experience).

ness based on dance experience was found to be correlated (Figure 4, R(A), R(B), R(C)).

2) Left hand movement

Jerk values and integrated squared jerk values of the left hand based on dance experience showed $r=0.201$, $p=0.166$, while mean squared jerk values showed $r=0.147$ and $p=0.666$. Dimensionless jerk values showed $r=0.383$ and $p=0.244$, and therefore, all three types of jerk calculation results were found to have no correlation with smoothness based on dance experience (Figure 4, L(A), L(B), L(C)).

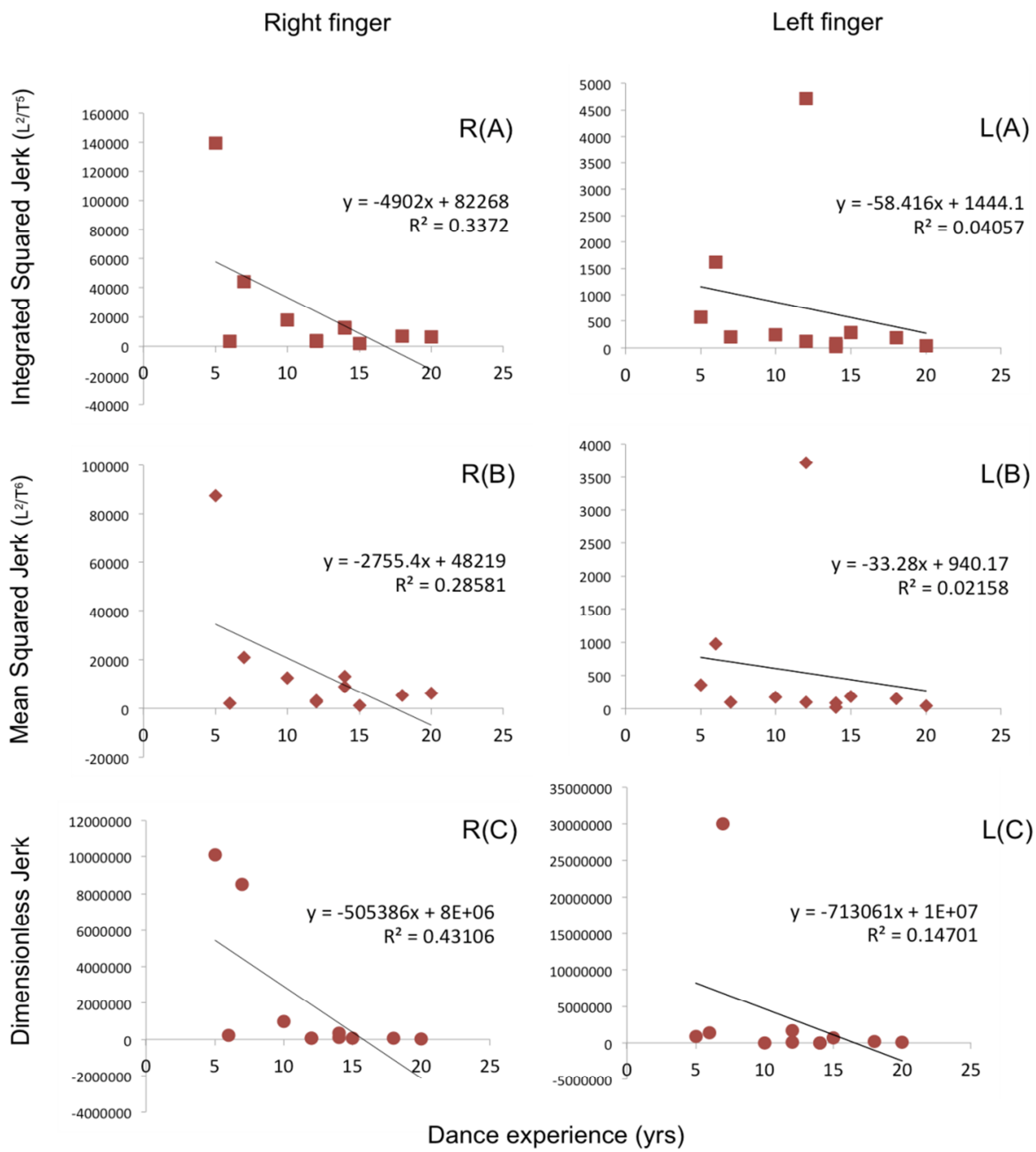

Figure 4. Statistically significant relationship between 3-types Jerk values vs. dance experience. R(A), R(B), R(C) show regression analysis in the right hand jerk values. L(A), L(B), L(C) show regression analysis in the left hand jerk values. Correlation of determinations (R^2) and linear regression models are shown from simple regression analysis.

IV. DISCUSSION

In dance, even with the same beat and motion, a temporal error in movement can occur depending on expression by the dancer. This can be explained by the synchronization of music in dance expressions that can appear when the same music is used, and studies on motion expression error and synchronization are already being con-

ducted using various methods. Minvielle-Moncla, Audiffren, Macar, & Vallet (2008) reported that in a solo dance, factors that make the timing of the dancer more complicated and require focused concentration from the dancer could increase timing errors not only in complex movements that have a high degree of difficulty, but also in simple walking movements. Recently, there have been studies on the ability of dancers to control their expressions. For example, Bläsing et al. (2012) conducted a study on the effects of concentration and experience of dancers on timing and motion performance synchronization, and the study reported that the timing skills of a dancer were related to experience with performing individual movements. According to the results of the study by Woolhouse & Lai (2014), the assessment of the ability to synchronize dance expressions with the music showed that a group which received dance training (six college students) was able to synchronize to music with a beat better than the group that did not receive dance training (14 college students). In other words, prior studies reported that having more experience in dancing had a significant effect on the timing of motion expression in a dance. Our finding that the timing of motion expression was shorter for a more experienced dancer seems to be consistent with the results of prior studies, when the same motion was performed with the same given beats ($r=0.724$, $p=0.011$). The dance motions presented in this study consisted of standing on one leg accompanied by doldamchae (sitting then standing), while performing wrapping the arms behind the back, to Taeguksun motion. This motion is a basic motion in Korean dance with a high degree of difficulty. The motion requires standing on one foot after a half-revolution turn; thus, when a dancer is able to maintain balance on one leg for a longer period of time, the expression can appear to be more stable and skilled. To explain this from an opposing concept; having less dance experience results in expressing highly difficult motion for a short time and expressing a motion with low difficulty for a long time. Therefore, the results in this study that showed that dancers who had more experience had shorter motion time can be interpreted as performing the difficult motion of standing on one foot for a longer period of time to use less time for the motion of sitting and standing, which resulted in a shorter total motion time (motion analysis measured the time taken for standing up completely). Therefore, this study showed a correlation of dance motion performance time based on the experience and skill level of a dancer, and such a correlation is potentially caused by the jerk-based calculation method for predicting the smoothness, which is the primary goal of this study.

In this study, three types of jerk-based calculation methods were used to calculate the smoothness in arm movements of a dancer. A significant correlation based on dance experience was found only in the dimensionless jerk values of the right hand movement (round movement above the head) that expressed a large movement path in creating Taeguksun motion. The left hand motion showed a slightly larger correlation tendency line in the graph of dimensionless jerk (Figure 4, L(C)) from the three types of jerk-based calculations. However, no significant difference was found in the three types of jerk-based calculations for prediction of smoothness. From the perspective of movement analysis on the end point in motion performance of dancers, the dancers selected for this study were amateurs and professionals who were studying or had already studied dance, and as such, there was no difference in smoothness based on dance experience when performing movements with low degree of difficulty, such as the motion of going from waist wrapping from the back to stretching the body forward that was similar to a basic motion.

The study found a significant correlation that dimensionless jerk calculation results became smaller as the experience of a dancer increased for the right hand, which was more dynamic and had a bigger movement path ($r=0.656$, $p=0.028$). Dimensionless jerk was applied first in a study by Yashiro, Nakamura, Mizumori, Yatani, & Takada (2004). It was a method proposed as a product of six different jerk-based calculations for design of a mouth guard to be used for effective use of the temporomandibular joint when people were giving speeches. It is also a proven method for predicting completely different patterns of smoothness based on comparisons of integrated squared jerk, mean squared jerk, normalized by peak speed jerk, and normalized by mean speed jerk values. Teulings, Contreras-Vidal, Stelmach and Adler (1997) also used dimensionless jerk to improve smoothness in performance of movement in patients with Parkinson's disease and age-matched healthy people, while Ketcham, Seidler, Gemmert,

& Stelmach (2002) used dimensionless jerk to find and quantify the factors that diminish qualitative movement in elderly.

Dimensionless quantification is widely used in the fields of engineering or physics, and in particular, it is used as a solution on how to specify physical properties when the size and scale of such properties are different. As an example, it is similar to the Froude number (ratio of inertia force relative to gravity), and quantification by dimensionless method has been used to predict optimal gait speed under environments with varying gravitational force (Minetti, 2001).

Jerk is not the only method to measure the smoothness. Rohrer and Hogan (2003, 2006) developed a very powerful and sensitive statistical method for discriminating basic movement sequences in continuous movement. However, this method has a problem of discarding most of the usable data. The beginning of smoothness is dependent on the flow of all data and measurement of this can be considered a statistically reliable method, given an adequate significance of quantification. With this significance in mind, the dimensionless-applied jerk-based calculation method was presented as a simple method that could quantify meaningful lines (shapes) and smoothness (Horgan & Sternad, 2009).

The dimensionless jerk calculation method used in the present study considered the dimensions as two factors, in other words motion time and motion speed, and made the calculations by eliminating them, just as in a prior study (Horgan, & Sternad, 2009). The first jerk-based calculation method in the present study, integrated squared jerk, did not take into account the two dimensions, while the second calculation method, mean squared jerk, took into account only the dimension of motion time. Ultimately, as shown in the results of this study, for expression of motion by the dancers, speed and distance can be viewed as being separate from a qualitative movement perspective and these two factors must be independent. Finally, the dimensionless jerk method that considers these two factors as being dimensionless seems to be more appropriate for predicting smoothness. Moreover, the present study used calculated dimensionless jerk values to prove that a longer dance experience led to an increase of smoothness in dance expression.

V. CONCLUSION

The present study used three types of jerk-based calculation methods (integrated squared jerk, mean squared jerk, and dimensionless jerk) to calculate and to analyze jerk values for proving the correlation between dance experience and smoothness. As a result, the following conclusions were derived:

1. A correlation between the total time for motion performance and Korean dance experience was found, in that a dancer with longer experience showed shorter time in performing sitting and standing on one leg.
2. With respect to relating Taeguksun motion of a dancer to Korean dance experience, longer experience was correlated with an increase of smoothness for dynamic motion and motion requiring large expressions (right hand motion in the present study).
3. The calculation results of integrated squared jerk, mean squared jerk, and dimensionless jerk showed a significant correlation between dimensionless jerk values and dance experience. Therefore, in order to assess smoothness in motion expression of a dancer, it would be appropriate to eliminate the two factors of time and speed of motion.

REFERENCES

Bläsing, B., Calvo-Merino, B., Cross, E. S., Jola, C., Honisch, J. & Stevens, C. J. (2012). Neurocognitive control in dance perception and performance. *Acta Psychologica*, 139(2), 300-308.

Bronner, S. & Shippen, J. (2015). Biomechanical metrics of aesthetic perception in dance. *Experimental brain research*, 233(12), 3565-3581.

Calvo-Merino, B., Urgesi, C., Orgs, G., Aglioti, S. M. & Haggard, P. (2010). Extrastriate body area underlies aesthetic evaluation of body stimuli. *Experimental Brain Research*, 204(3), 447-456.

Cross, E. S., Kirsch, L., Ticini, L. & Schütz-Bosbach, S. (2011). The impact of aesthetic appreciation and physical ability on dance perception. *Frontiers in Human Neuroscience,* 5, 102.

Flash, T. & Hogan, N. (1985). The Coordination Of Arm

Movements - An Experimentally Confirmed Mathematical - Model. *Journal of Neuroscience*, 5(7), 1688-1703.

Goldvasser, D., McGibbon, C. A. & Krebs, D. E. (2001). High curvature and jerk analysis of arm ataxia. *Biological Cybernetics*, 84, 85-90.

Hogan, N. & Sternad, D. (2009). Sensitivity of Smoothness Measures to Movement Duration, Amplitude and Arrests. *Journal of Motor Behavior*, 41(6), 529-534.

Jung, C. S. & Jung, K. I. (2007). The Relationship between Smoothness and Breathing for The "Pal Duleo Gamaoligy" Technique in Korean Traditional Dancing. *The Korean Society Of Dance Science*, 14, 1-9.

Jung, K. I. & Nam, K, J. (2007). Does the Control of Breathing Help a Dancer to Perform a Smoother Ballet Pour de Bra? *Korean Journal of Sport Biomechanics*, 17(1), 185-190.

Ketcham, C. J., Seidler, R. D., Van Gemmert, A. W. & Stelmach, G. E. (2002). Age-related kinematic differences as influenced by task difficulty, target size, and movement amplitude. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, 57(1), 54-64.

Kitazawa, S., Goto, T. & Uruxhihara, Y. (1993). *Quantitative evaluation of reaching movements in cats with and without cerebellar lesions using normalized integral of jerk*. In N. Mano, I. Hamada, & J. Wartenweiler (Eds.), Role of the cerebellum and basal ganlia in voluntary movement (pp. 11-19). Tokyo: Elservier Science.

Lee, M. H., Ranganathan, R. & Newell, K. M. (2011). Changes in object-oriented arm movements that precede the transition to goal-directed reaching in infancy. *Developmental Psychobiology*, 53(7), 685-693.

Minetti, A. E. (2001). Invariant aspects of human locomotion in different gravitational environments. *Acta astronautica*, 49(3), 191-198.

Minvielle-Moncla, J., Audiffren, M., Macar, F. & Vallet, C. (2008). Overproduction timingerrors in expert dancers. *Journal of Motor Behavior*, 40(4), 291-300.

Park, S. H. & Lee, S. M (2005). Movement control of chip shot in golf: The validation of normalized jerk. *The Korean Journal of Physical Education-Natural science*, 44(6), 301-311.

Park, Y. S., Kim, M. Y. & Lee, S. R. (2014). The Analysis of Differences in Pulmonary Functions, Jerk Cost, and Ground Reaction Force Depending on Professional and Amateur Dancers in Korea Dance. *Korean journal of sport biomechanics*, 24(4), 349-357.

Platz, T., Denzler, P., Kaden, B. & Mauritz, K. H. (1994). Motor Learning after Recovery from Hemiparesis. *Neuropsychologia*, 32(10), 1209-1223.

Schneider, K. & Zernicke, R. F. (1989). Jerk-cost modulations during the practice of rapid arm movements. *Biological Cybernetics*, 60, 221-230.

Rohrer, B. & Hogan, N. (2003). Avoiding spurious submovement decompositions: a globally optimal algorithm. *Biological cybernetics*, 89(3), 190-199.

Rohrer, B. & Hogan, N. (2006). Avoiding spurious submovement decompositions II: a scattershot algorithm. *Biological cybernetics*, 94(5), 409-414.

Schneider, K. & Zernicke, R. F. (1989). Jerk-cost modulations during the practice of rapid arm movements. *Biological Cybernetics*, 60, 221-230.

Teulings, H. L., Contreras-Vidal, J. L., Stelmach, G. E. & Adler, C. H. (1997). Parkinsonism Reduces Coordination of Fingers, Wrist, and Arm in Fine Motor Control. *Experimental Neurology*, 146, 159-170.

Torrents, C., Castañer, M., Jofre, T., Morey, G. & Reverter, F. (2013). Kinematic parameters that influence the aesthetic perception of beauty in contemporary dance. *Perception*, 42(4), 447-458.

Wininger, M., Kim, N. H. & Craelius, W. (2009). Spatial resolution of spontaneous accelerations in reaching tasks. *Journal of Biomechanics*, 42, 29-34.

Woolhouse, M. H. & Lai, R. (2014). Traces across the body: influence of music-dance synchrony on the observation of dance. *Frontiers in human neuroscience*, 8.

Yashiro, K., Nakamura, T., Mizumori, T., Yatani, H. & Takada, K. (2004). Clinical Validity of Measuring Jerkcost of Jaw Movement during Speech: Effect of Mouthguard Design on Smoothness of Jaw Movements. Paper presented at the SICE Annual Conference; Sapporo, Hokkaido Institute of Technology, Japan. 4-6.

Zatsiorsky, V. M. (1998). *Kinematics of human motion*. Champaign, IL: Human Kinetics.