INTRODUCTION

The goal of jumping is to jump vertically as high as possible using one foot or both feet (Park, 2005). Of jumping movements in ballet, grand pas de chat, a technique that appears in many ballet performances, requires a high skill level. In grand pas de chat, following various preparation steps, the dancer throws the jumping leg forward, lifting it more than 90°, stretches the other leg backward in synchrony with power with two legs stretched in opposite directions as maximally as possible, and then lands on one leg. During the movement, the upper body should show soft, artistic expression, in contrast to the powerful legs, and a straight posture should be maintained until the completion of the jump. This jumping technique requires coordination among various body segments, and should be performed by effectively controlling the energy generated in each of the involved joints. In particular, lower limb muscle strength, as well as flexibility, can be an indicator of the ability to perform jumping movements in ballet with excellence, affecting the time in the air during the jump and the vertical height of the jump. Therefore, in order to improve ballet performance, it is very important for ballet dancers to strengthen the lower limb muscles.

In ballet, the goal of body training is to develop interdependence among posture, balance, and harmonious movement, which is considered as the most crucial factor in aesthetics (Lee, 2000; Shim, 2004). Ballet dancers are increasingly practicing pilates or using fitness equipment for body training in order to efficiently develop ballet skills. Such exercises help ballet dancers not only with flexibility but also with muscle strengthening. To better enable ballet dancers to improve ballet skills through physical exercise training, it is necessary to provide ballet dancers with basic data on fundamental training approaches.

Until now, kinematic studies on dancing movements have been only intermittently conducted. Of the studies conducted so far, Yoon (2010) has reported that the grand pas de chat movement is influenced by the type of running start, and that a forward jump using inertia is a crucial factor for grand pas de chat. In addition, Sin, Song and Choi (2009) conducted kinematic analysis on ballerinas’ jumping motions and stressed the importance of the displacement of the center of gravity. Such studies as these are of significance because they not only examine techniques but also emphasize artistry. The aforementioned studies demonstrate that in dancing, jumping is not only a technique but also...
a criterion based on which artistry is evaluated. Nevertheless, research has not yet been conducted to analyze the relationship between the kinematic variables of grand pas de chat, a basic jump skill in ballet, and experts’ subjective assessment in regard to artistry.

Dancing is a total art delivered by the human body’s movements in space and time (Kwon, 2006; Park, 2005; Jeong, 2000; Hyun, 1993), and is perfected through training to artistically transcend high level techniques. In order to express their emotions maximally, dancers perform a variety of movements of high difficulty, which require a high level of health in terms of flexibility, agility, speed, and muscle strength (Golomer & Fery, 2001). Grand pas de chat, whilst considered a basic ballet move, is also a high level technique, during which perfect beauty should be expressed, as the two legs are stretched out momentarily in the air. Thus, scientific analysis of grand pas de chat, and the development of an evaluation scale which reflects experts’ subjective assessment in regard to artistry whilst describing the movement more scientifically and precisely, will help ballet dancers more efficiently train for high level techniques and artistry of ballet.

Accordingly, in the present study, we aimed to provide suggestions for efficient performance skill and professional assessment criteria of a ballet move and to present a scientific basis for the assessment of a move by using a scientific analytical approach that considers both artistic and technical aspects. Additional aims were to identify biomechanical characteristics of excellent movement by performing comparative analysis on excellent and non-excellent movements and to provide kinematic data which can be used to improve artistic expression supported by high level techniques.

**METHODS**

1. Study participants

Participants of the study were 14 male and female professional dancers working for G Metropolitan City Ballet Company who had not had any specific medical complaints concerning the lower limbs in the last 6 months (mean age, 31.64 ± 5.58 years; mean height, 1.69 ± 0.07 m; mean body weight, 54.64 ± 9.19 kg; and, mean career length, 18.07 ± 4.08 years). The 14 professional dancers had an average dancing career of over 15 years, and their professionalism was recognized, as each of them appeared as a soloist or in a more important role in all of their performances. The study objectives were explained to all participants, and all signed a written consent form for voluntary participation.

2. Procedure

1) Videotaping

Each participant was videotaped 3 times while performing the grand pas de chat movement. The video images were viewed by 3 ballet experts (the artistic director at G Metropolitan City Ballet Company, a former artistic director at a city ballet company, and a professor at the Department of Dancing in C University) to subjectively assess the movements and to choose excellent and non-excellent performances of the movement. The chosen video images were divided into one of two groups according to the experts’ assessment: excellent and non-excellent movement groups. Before videotaping participants, control objects were arranged in the room to set spatial coordinates in a range within which the grand pas de chat movement could be completely captured (2 m x 1 m x 2 m for y, x, and z axes). Of the three videotaped movements for each participant, one excellent and one non-excellent movement, as evaluated by 3 experts, were further analyzed, for a total of 28 trails.

2) Electromyogram (EMG)

To collect EMG data, a total of 6 surface electrodes were placed on rectus femoris, gastrocnemius, and erector spinae on both sides, and maximum muscle activation from the moment of the jumping foot lifting from the ground to the moment of the foot landing on the ground was measured. EMG data were processed by using the Myo-research program (U.S.A). Generally, EMG data are standardized with the MVIC or % RVC method, but we used a method based on maximum microvolt value (µV) to standardize the data, because participants were repeatedly measured.

3) Markers

Joints were identified by placing anatomical markers on the participants’ body. A total of 17 markers were attached, including to the ankles, knees, hips, shoulders, elbows, wrists, heels, and toes on either side, as well as the head.

**Figure 1. EGM attachment sites**

1. Rt. Rectus femoris
2. Lt. Rectus femoris
3. Lt. Medial gastrocnemius
4. Rt. Medial gastrocnemius
5. Lt. erector spinae
6. Rt. erector spinae
3. Scales for subjective assessment

Three ballet experts (two university professors and the artistic director at the City Ballet Company) gave subjective assessments of the videotaped performances of the movement. All 3 experts evaluated all participants, and, in order to examine the extent to which subjective assessments were congruent among the different experts, Cronbach’s α values were computed to assess reliability. For the movement to be objectively evaluated, the experts were asked to assess the performances separately for technicality (order, flexibility, power, and balance) and artistic properties for a total of 20 items. Cronbach’s α values of the scales used to assess technical aspects were as follows: 0.756 for order, 0.718 for flexibility, 0.746 for power, and 0.703 for balance. Cronbach’s α of the scale for artistry was 0.818, and that of the entire scale was 0.894. Thus, reliability of the measurements was high.

4. Phase analysis

As the purpose of the present study was to analyze biomechanical and EMG variables associated with grand pas de chat, we divided the movement into 3 events: Event 1 (Toe off) defined as the jumping foot being lifted off the ground, Event 2 (Maximum height) defined as the maximum vertical distance, and Event 3 (Toe contact) defined as the jumping foot landing on the ground. Two phases were determined based on the 3 events: Phase 1 (Jumping phase) defined as the phase between Events 1 and 2, and Phase 2 (Landing phase) defined as the phase between Events 2 and 3. Details are shown in (Figure 2) below.

5. Data analysis

The Kwon3D XP program was used to conduct data analysis, including localization of the images taken from 4 cameras within a coordinate system and the computation and smoothing of 3D coordinate values. The reference coordinate system was defined with the y axis for the direction of movement, the z axis for a perpendicular vector from the ground, and the x axis for horizontal (left and right) orientation. Analysis variables included time in the air and maximum height, predictive of technicality; trunk angle, a criterion based on which aesthetic balance is judged; and displacement of the center of gravity, a criterion based on which power is judged.

6. Statistical analysis

Excellent and non-excellent movement groups were created on the basis of experts’ subjective assessment of participants’ ability to perform the movement in videotaped images. With 2 groups defined as such, the following statistical analyses were performed.

First, Cronbach’s α values were computed to assess reliability of the subjective assessment scales.

Second, a series of matched-sample t-tests were conducted to test for biomechanical and EMG differences between the excellent and non-excellent movement groups defined on the basis of experts’ subjective evaluation.

Third and finally, Pearson correlational coefficients were calculated to examine intervariable correlations.
RESULTS

1. Difference in subjective assessment scales

Data regarding subjective assessment are shown separately for excellent and non-excellent movements in (Table 1). Scores for three of the technicality sub-variables, (order, flexibility, and power), were significantly higher for excellent movements than non-excellent movements, whereas balance did not show a statistically significant difference between groups. With regard to artistry, the mean score was 14.40 ± 2.13 for excellent movements and 13.33 ± 2.13 for non-excellent movements, showing that the excellent movement group was assessed to be more aesthetically artistic than the non-excellent movement group (p < 0.05).

2. Biomechanical differences between excellent and non-excellent movements

(Table 2) shows the results regarding time in the air, trunk angle, maximum height, and displacement of the center of gravity separately for excellent and non-excellent movements of grand pas de chat, as assessed by the 3 experts. Overall, the values of all variables were more favorable for excellent movements, but none of the differences were statistically significant.

3. EMG differences between excellent and non-excellent movements

1) Differences in medial gastrocnemius

Differences in the EMG measurements of medial gastrocnemius between excellent and non-excellent movements are shown in (Table 3). The mean value of maximum EMG observed in the left medial gastrocnemius during Phase 2 was 704.54 ± 274.88 μV for excellent movements and 539.39 ± 122.54 μV for non-excellent movements, showing that the excellent movement group had a significantly higher value of maximum EMG in the muscle (p < 0.05).

In regard to average EMG, the mean value observed in the left medial gastrocnemius during Phase 1 was 346.78 ± 162.45 μV for excellent movements and 161.90 ± 32.14 μV for non-excellent move-
ments, showing that the excellent movement group had a significantly higher value of average EMG in this muscle ($p < 0.05$).

2) Differences in rectus femoris

Differences in the EMG measurements of rectus femoris between excellent and non-excellent movements are shown in (Table 4). The mean value of maximum EMG observed in the right rectus femoris during Phase 1 was 187.66 ± 125.14 μV for excellent movements and 275.60 ± 125.14 μV for non-excellent movements, and the value was significantly lower in the excellent movement group ($p < 0.05$). The mean value of maximum EMG measured during Phase 2 was 286.54 ± 137.36 μV for excellent movements and 395.10 ± 123.99 μV for non-excellent movements, and again, the value was lower in the excellent movement group ($p < 0.05$).

In regard to average EMG, the mean value observed in the right rectus femoris during Phase 2 was 109.32 ± 65.74 μV for excellent movements and 193.28 ± 103.84 μV for non-excellent movements, showing that the excellent movement group had a significantly lower value of average EMG in the muscle ($p < 0.05$).

3) Differences in erector spinae

Differences in the EMG measurements of erector spinae between excellent and non-excellent movements are shown in (Table 5). Overall, the mean values of maximum EMG observed in erector spinae were lower in excellent movements than in non-excellent movements, but none of the differences were statistically significant. In regard to average EMG, the mean value of the left erector spinae during Phase 1 was 135.46 ± 62.45 μV for excellent movements and 85.17 ± 46.23 μV for non-excellent movements, and the between-group difference was statistically significant ($p < 0.05$).
4. Relationships between biomechanical variables and subjective assessment

(Table 6) shows correlational coefficients computed between experts’ subjective assessment and biomechanical variables of the grand pas de chat movement. Of the sub-variables of subjective assessment, order was positively correlated with time in the air, and power was positively correlated with time in the air and with displacement of the center of gravity. Additionally, artistry was positively correlated with maximum height and displacement of the center of gravity. These findings suggest that the longer the time to complete a grand pas de chat, the better the movement looks in terms of order; and that as power increases, the time to complete the movement increases and the center of gravity is further displaced. Finally, the movement looks more artistic as the maximum height increases and the center of gravity is further displaced.

5. Relationships between EMG variables and subjective assessment

1) Average EMG and subjective assessment

(Table 7) shows correlational coefficients computed between the sub-variables of subjective assessment and average EMG variables of grand pas de chat. Order was positively correlated with the left erector spinae, while power was negatively correlated with the left medial gastrocnemius and positively correlated with the right medial gastrocnemius. In addition, balance was negatively correlated with the right rectus femoris. Flexibility, however, was not significantly correlated with any of the muscles. Finally, artistry was positively correlated with the left erector spinae.

2) Maximum EMG and subjective assessment

(Table 8) shows correlational coefficients computed between the sub-variables of subjective assessment and maximum EMG variables of grand pas de chat. The right rectus femoris was negatively correlated with flexibility, balance, and artistry, whereas none of the muscles were significantly correlated either with order or with power.

DISCUSSION

This study was conducted to investigate biomechanical and EMG differences between excellent and non-excellent movements of grand pas de chat, as assessed by experts, and to examine correlational relationships between experts’ subjective assessment and biomechanical variables.

To that end, we measured three biomechanical variables: time in the air, trunk angle, and maximum height, while ballet dancers performed a grand pas de chat, and compared them between excellent and non-

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**Table 6. Correlation between subjective evaluation and kinematic variables**

<table>
<thead>
<tr>
<th>Subjective evaluation</th>
<th>Kinematic variables</th>
<th>Artistry</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Order</td>
<td>Flexibility</td>
</tr>
<tr>
<td>Time</td>
<td>0.428*</td>
<td>-0.057</td>
</tr>
<tr>
<td>Trunk angle</td>
<td>0.138</td>
<td>-0.276</td>
</tr>
<tr>
<td>Maximum height FB</td>
<td>0.265</td>
<td>0.212</td>
</tr>
<tr>
<td>Displacement LR</td>
<td>-0.036</td>
<td>0.208</td>
</tr>
</tbody>
</table>

*p<0.05

**Table 7. Correlation with subjective evaluation and average EMG variables**

<table>
<thead>
<tr>
<th>Subjective evaluation</th>
<th>Average EMG variables</th>
<th>Technique</th>
<th>Artistry</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Order</td>
<td>Flexibility</td>
<td>Power</td>
</tr>
<tr>
<td>Medial gastrocnemius</td>
<td>L -0.234</td>
<td>-0.063</td>
<td>-0.504**</td>
</tr>
<tr>
<td></td>
<td>R 0.116</td>
<td>0.091</td>
<td>0.409*</td>
</tr>
<tr>
<td>Rectus femoris</td>
<td>L 0.206</td>
<td>0.297</td>
<td>-0.170</td>
</tr>
<tr>
<td></td>
<td>R -0.009</td>
<td>-0.323</td>
<td>-0.140</td>
</tr>
<tr>
<td>Erector spinae</td>
<td>L 0.422*</td>
<td>0.274</td>
<td>0.290</td>
</tr>
<tr>
<td></td>
<td>R -0.107</td>
<td>-0.243</td>
<td>0.012</td>
</tr>
</tbody>
</table>

*p<0.05, **p<0.01
excellent movements. We included the measurement of trunk angle to identify the precise location of the upper body while the lower limbs are maximally stretched out during a perfect grand pas de chat. Neither the time in the air, trunk angle, nor maximum height showed any statistically significant differences between the excellent and non-excellent movement groups, and we speculate that this was because all 14 study participants were professional dancers who had been performing as a main character and also as a soloist, and attained a high level of skill to perfectly show ballet movements through training and performing on a daily basis. However, time to complete a grand pas de chat was longer in the excellent movement group compared to the non-excellent movement group, and trunk angle showed a difference of approximately 2° between groups during Event 1. We believe that this is because in an excellent movement of grand pas de chat, the dancer lifts the lower limbs as high possible, which results in a narrower angle between the upper body and the lower limbs. In addition, trunk angle varied across Events 1, 2, and 3 in the excellent movement group, whereas it did not vary in the non-excellent movement group, which was probably related to the finding that time to complete a grand pas de chat was shorter and the maximum height was lower in the non-excellent group.

There was a large difference in EMG values of medial gastrocnemius between excellent and non-excellent movements, with a higher EMG value observed in the excellent movement group. Particularly, the EMG value was higher in the left medial gastrocnemius at landing than at jumping, and we speculate that power was generated in the left medial gastrocnemius because the dancer strongly activated this muscle all the way to the tip of the toes in order to perform a perfect movement. This suggestion is supported by Kim (1997), who reported that differences in how lower limb muscles worked resulted in differences in ballet jumping. Additionally, Sin et al. (2009) argued that the most aesthetically ideal movement can be performed if the dancer is not rushed after landing from a ballet jump, which also supports the current study finding. The EMG value in the right medial gastrocnemius was also higher in the excellent movement group, but was not significantly higher compared to the non-excellent group. The discussion so far indicates that as observed in experts’ subjective assessment, for a grand pas de chat to be assessed to be excellent depends on a maximal stretch in the air propelled by the power of the left medial gastrocnemius.

The EMG results of rectus femoris showed that in the excellent movement group, overall, the muscle showed greater activation on the left side as compared to the right at landing, and that more power was used in Phase 2 than in Phase 1. In the non-excellent movement group, however, power levels were similar between the left and right sides. Particularly, in the excellent movement group, power was twice as strong in Phase 2 as in Phase 1. Hence, we believe that to increase the time in the air and maintain maximal stretch in the legs during a grand pas de chat, it is important to maintain the posture of the left rectus femoris through muscle activation in the left medial gastrocnemius.

In the excellent movement group, there was less power in rectus femoris on the right side compared to the left during Phase 1. A direct reason for this dynamic is trunk angle, which enables jumping with the lower limbs lifted toward the upper body as close as possible to achieve maximum stretch and maximum vertical jump. Moreover, during Phase 2, it serves the purpose of maintaining the posture by putting more power in the left rectus femoris in preparation for landing and finally, completing the movement with stability and precision. To summarize the discussion so far, for a grand pas de chat to be highly evaluated in terms of artistry, the dancer should maintain muscle activation in the rectus femoris of the forward leg, as opposed to increasing it. In addition, it is more important to maintain the movement in a soft manner after the jump rather than jumping high simply by relying on muscle power. Accordingly, to perform a grand pas de chat with excellence, ballet dancers should train more to be able to use muscles efficiently, rather than train to contract muscles with power.

In regard to EMG differences in erector spinae, a significant group-difference was observed in the left erector spinae at the moment of jumping, with a higher EMG value in the excellent movement group. Lee (2010) has analyzed muscle activity during the ballet move of attitude according to dancers’ skill level and reported that skilled dancers more actively used erector spinae than less skilled dancers did. Based on these findings, greater activation in the left erector spinae at the moment of jump in the excellent movement group was likely to be related to the dancer’s intention to stretch the right foot in the air as high as possible by using reaction force from the left side in order to jump higher and farther. These results are also of relevance to differ-

<table>
<thead>
<tr>
<th>Maximum EMG variables</th>
<th>Subjective evaluation</th>
<th>Technique</th>
<th>Artistry</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L</td>
<td>Order</td>
<td>Flexibility</td>
</tr>
<tr>
<td>Medial gastrocnemius</td>
<td></td>
<td>0.035</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.112</td>
<td>-0.079</td>
</tr>
<tr>
<td>Rectus femoris</td>
<td></td>
<td>L</td>
<td>0.250</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>-0.225</td>
<td>-0.531**</td>
</tr>
<tr>
<td>Erector spinae</td>
<td></td>
<td>L</td>
<td>0.221</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.177</td>
<td>-0.110</td>
</tr>
</tbody>
</table>

*p<0.05, **p<0.01
ences between excellent and non-excellent movements as judged by subjective aesthetic evaluation. Therefore, to perform a grand pas de chat with precision, dancers should train to strengthen the left and right medial gastrocnemius, rectus femoris, and erector spinae muscles.

Regarding the relationship between experts’ subjective assessment of a grand pas de chat and biomechanical variables, order had a positive correlation with the time in the air, and power had a positive correlation with the time in the air and with displacement of the center of gravity. These findings suggest a strong association of time to complete a pas de chat with some sub-variables of subjective assessment, i.e., order and power, and emphasize that to receive a high score for technicality, the moves from starting to jump until landing should be well ordered, and overall power should be wisely distributed.

Artistry was scored high when the jump was high. As discussed above, the grand pas de chat movements subjectively judged as excellent in technicality and artistry tended, from a biomechanical point of view, to show a farther and higher jump, with a longer time in the air and a farther displacement in the center of gravity. In regard to the relationship between experts’ subjective assessment of a grand pas de chat and average EMG variables, the left medial gastrocnemius was not correlated with power, while the right rectus femoris was not correlated with balance. In contrast, the left erector spinae had a strong correlation with artistry, indicating that a grand pas de chat was judged as excellent in subjective assessment, if more power was applied to the left erector spinae and the left lower limb muscles. Regardless of whether correlational coefficients were computed based on maximum or average EMG variables, the right rectus femoris did not show a significant correlation with subjective assessment.

To conclude, it is suggested that for a dancer to receive a high score determined by subjective assessment, he or she should express movements in a soft manner, and maintain the line showing in maximum stretch. Furthermore, high jump and maximum stretch are fundamental conditions required to perform a grand pas de chat.

CONCLUSION

The objectives of the study were to investigate the relationship between subjective assessment of the performance of a grand pas de chat and biomechanical variables. The following conclusions were made based on the study findings.

First, biomechanical differences between excellent and non-excellent grand pas de chat movements, as judged by experts, were not observed.

Second, based on average and maximum EMG variables, difference between excellent and non-excellent movements was found in the erector spinae, rectus femoris, and gastrocnemius muscles. These findings provide evidence for the importance of muscle activation in jumping and landing moves.

Third, to score high in technicality, dancers should train to use muscles efficiently from the moment of starting to jump until the moment of landing, rather than training to contract muscles with power.

Fourth and lastly, movements judged to be excellent in subjective assessment scored high because the left erector spinae and the left lower limb muscles had more power.

In this study, differences between excellent and non-excellent movements, as judged by experts, were investigated by using EMG measurements and biomechanical variables. In future research, kinetic variables based on reaction force, which is an important factor in jumping, should be included.

ACKNOWLEDGEMENTS

This article excerpts are noted for some of the doctoral thesis Jung eun Jung (2015).

REFERENCES


