Difference of Postural Sway Angle while Performing Ballet Turn (\textit{pirouette en dehors}) in Novice and Experienced Dancers

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Introduction: *Ballet turns*

- Turning movements are common in ballet performance
  - Dramatic
  - Call “Pirouette”
  - Rotation of body around a vertical axis over one supporting foot on floor
Introduction: *Risk factors*

- **Overuse injury**
  - Long duration practice with little self-correction
  - Demi-pointe $\rightarrow$ tension of Achillie’s tendon
  - Fatigue

- **Ankle sprain**
  - Smaller base of support
  - Plantarflexed with whole body weight
  - Demands of foot and ankle
Introduction: *Skill levels*

- High-skilled technique
- Differences among different skill levels
  - Experts adopt various preparatory distance
    - (Sugano A et al., 2002)
  - Beginners have greater posterior inclination angle
    - At baseline of *pirouette*
      - (Chatfield SJ et al., 2007)
- No completed movement analysis in whole task
To verify the difference in postural control between novice and experienced dancers while turning
Methods: *Subjects & Procedure*

- **26 ballet dancers**
  - **13 experienced**
    - (>5 years ballet training)
    - (ability to perform 2 revolution)
  - **13 novice**
    - (2-5 years ballet training)

**Determination of dominant leg**

- *Pirouette en dehors* with D leg support
  - One revolution
  - Modified Helen-Hays marker set
  - Motion analysis and two forceplates
Phase definition

Turning phase

Preparatory
- PRE
- initiation
- SL knee flexion

Turning with double-leg support
- TDS
- upper extremity apart

Turning with single-leg support in pre-swing
- TSSp
- GL push-off

Turning with single-leg support in mid-swing
- TSSm
- GL retire

Ending
- END
- GL down
- SL knee extension
Data reduction: *Duration & Kinetic*

- **Duration in each phase**
- **Peak push force** during TDS phase
  - Supporting leg & gesture leg
  - AP, ML, and vertical directions
  - Normalized to BW
Data reduction: Postural sway angle

- COM & COP
- Instantaneous sagittal and frontal inclination angles
  - COM-COP
  - COM-ankle
Statistical Analysis

- Independent t-test
  - Duration
  - Peak push force
  - Ranges of postural sway angle
Results: *Duration*

- **Novice dancers**
  - Longer PRE
  - Shorter TDS & TSSp

![Graph showing duration in each phase for experienced and novice dancers. The graph illustrates the duration in seconds for each phase: PRE, TDS, TSSp, TSSm, and END. The experienced group is represented by red squares, and the novice group by gray diamonds.](image)
Results: *Peak push force*

- **Novice dancers**
  - SL: Greater peak anterior force
  - GL: Greater peak posterior force
Results: Postural sway angle

- Range in AP direction

![Bar charts showing AP range during TDS, TSSp, TSSm, and END for Experience and Novice groups.](image)
Results: *Postural sway angle*

- **Range in ML direction**

![Graphs showing range in ML direction during TDS, TSSp, TSSm, and END for experience and novice groups.](image)
Discussion: Duration

- Longer duration in PRE in novice
  - Consistent with a previous study
  - Reasons
    - Hesitate to initiate turns

- Shorter duration in TDS & TSSp in novice
  - Rush movement pattern in turning
  - Resulted in greater angular velocity

(McMillan, 1972)
Discussion: *Kinetics*

- Greater push force in novice
  - Excessive force in AP direction
  - Challenge postural control
**Discussion: Postural sway angle**

- Greater ranges of postural sway angle in novice
  - Excessive push force during TDS
  - Hip strategy during END
Conclusion & application

- Significant different postural control
  - Hesitate in PRE but rush in turning
  - Greater postural sway angle
    - Greater push force during TDS

- Application
  - Control speed and push force in turning, especially in TDS phase
Thank you for your attention!
Introduction
III. Classification of turns

- **Supporting leg**
  - Right
  - Left

- **Turning direction**
  - En dehors
  - En dedans

<table>
<thead>
<tr>
<th>Turning direction</th>
<th>Right leg support</th>
<th>Left leg support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clockwise</td>
<td>En dedans</td>
<td>En dehors</td>
</tr>
<tr>
<td>Counter-clockwise</td>
<td>En dehors</td>
<td>En dedans</td>
</tr>
</tbody>
</table>

(Kirstein and Stuart, 2004)
IV. Inadequate training

- High-skilled technique

- Difference between dancers and non-dancers
  - Preparation phase
    - Motor imagine
    - Shoulder-hip angle
  - Rotation phase
    - Foot displacement

(Golomer et al., 2010)
### IV. Inadequate training

- **Difference between experts and novices**

<table>
<thead>
<tr>
<th></th>
<th>Baseline at start</th>
<th>Plié fondu</th>
<th>Forward weight shift</th>
<th>Baseline at resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Beginner</strong></td>
<td>-9.75 ±1.25</td>
<td>-8.25 ±2.25</td>
<td>-13.50 ±2.75</td>
<td>-10.25 ±2.50</td>
</tr>
<tr>
<td><strong>Expert</strong></td>
<td>-4.50 ±0.75</td>
<td>-0.50 ±1.37</td>
<td>-5.75 ±1.50</td>
<td>-1.25 ±1.00</td>
</tr>
</tbody>
</table>

*Values were calculated from 90 trials for each group. Negative numbers indicate posterior positions relative to 0° vertical. All values are in degrees.*

(Steven J et al., 2001)
Various types of turns

- Pirouette en retire
- Fouette turn
- Arabesque turn
Shoes in ballet

POINTE SHOES

SOFT SHOES
Methods
Motion system
Instruments

- 8 three-dimensional digit cameras system
  - Sampling rate: 200 Hz

- Two force plates
  - Sampling rate: 1000 Hz
  - Mount wood plates on force plates to expand working area
  - Tape vinyl floor
Procedures

Participants

Measure foot length

2 types of *pirouette* in different preparatory distance

Ballet soft shoes

44 retro-reflective markers
Procedures

Participants

Measure foot length

2 types of *pirouette* in different preparatory distance

Determine dominant-leg

1.5-fold of FL

1.0-fold of FL

0.5-fold of FL
Procedures

Participants

Measure foot length

2 types of *pirouette* in different preparatory distance

- D leg support
- ND leg support
- Self-selected (PDss)
- 0.5 fold of FL (PD05)
- 1.0 fold of FL (PD10)
- 1.5 fold of FL (PD15)
Data Process - kinetics

- **Peak push force** during TDS phase
  - Supporting leg & gesture leg
  - AP, ML, and vertical directions
- Normalized to BW
- Foot displacement in whole task
- Angular velocity at retire position
Data Process - inclination angle

- **Instantaneous screw axis (ISA)**
  - Trunk markers
  - TSSp and TSSm phases
  - Angle relative to *vertical axis*
Data Process

Kinematic Data
- Butterworth Filter
  - 6 Hz

Kinetic Data
- Butterworth Filter
  - 25 Hz

MatLab

Define segment coordination
- Euler Angle 2-1-3

Calculate Force
- Define the phase

Joint angle in hip, knee, ankle joints, trunk inclination angle, COP-COM inclination angle, and anchoring index, and force distribution
COP and ankle

- Combined COP

\[ \text{COP}_{\text{combine}} = \frac{F_{z1}}{F_{z1} + F_{z2}} \times \text{COP}_1 + \frac{F_{z2}}{F_{z1} + F_{z2}} \times \text{COP}_2 \]

- Ankle
Center of Mass (COM)

- From kinematic data and anthropometry data

(Dempster via Miller & Nelson, 1973)
Center of Mass (COM)

Segment center = (tophead - C7) \* 0.567 + C7

\[ \text{Head and Neck} \]

\[ \text{Head and Neck} \]

(C7 - Sacrum) \* 0.37 + Sacrum

\[ \text{Trunk} \]

Right = (R shoulder - R Elbow) \* 0.564 + R Elbow

\[ \text{Upper arms} \]

(R Elbow - R Wrist) \* 0.318 + R Wrist

\[ \text{Forearms and Hands} \]

\[ \text{COM} = (0.0145 \times (\text{rFO + lFO}) + 0.0465 \times (\text{lLEG + rLEG}) + 0.1 \times (\text{rTH + lTH}) + 0.142 \times (\text{rPEL + lPEL}) + 0.355 \times \text{THR} + 0.081 \times \text{HN} + 0.028 \times (\text{rUA + lUA}) + 0.022 \times (\text{rFA + lFA}))/10 \]
Center of Mass (COM)

Right=(Sacrum-R GT)*0.895+R GT

(RGT-R knee)*0.567+L knee

(R knee-R ankle medial)*0.567 + R ankle medial

(R anlek-R toe)*0.50+R toe

COM=(0.0145*(rFO+lFO)+0.0465*(lLEG+rLEG)+0.1*(rTH+lTH)+0.142*(rPEL+lPEL)+0.355*THR+0.081*HN+0.028*(rUA+lUA)+0.022*(rFA+lFA))/10
COM-COP inclination angle

(Lee HJ et al., 2007)
COM-COP inclination angle

- Vertical axis
- Frontal plane: medial-lateral angle
- Sagittal plane: anterior-posterior angle
COM-COP in local c.s.

- Origin: COP
- Rotation matrix

Frontal plane:
  - AP inclination angle: $\tan^{-1}\left(\frac{\text{DISmpF}}{\text{Hcom}}\right)$

Sagittal plane:
  - ML inclination angle: $\tan^{-1}\left(\frac{\text{DISmpS}}{\text{Hcom}}\right)$
Results
# Subject demographics

<table>
<thead>
<tr>
<th></th>
<th>Experience</th>
<th>Novice</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>17.77 ± 3.39</td>
<td>12.00 ± 1.91</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Experience of dance (yr)</td>
<td>11.31 ± 3.07</td>
<td>4.31 ± 2.02</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Experience of ballet (yr)</td>
<td>8.69 ± 3.30</td>
<td>3.23 ± 1.69</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Experience of pointe shoes (P/N)</td>
<td>13/0</td>
<td>5/8</td>
<td>-</td>
</tr>
<tr>
<td>Experience of pointe shoes (yr)</td>
<td>4.54 ± 2.88</td>
<td>0.23 ± 0.23</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Experience of one revolution <em>pirouette</em> in soft shoes (yr)</td>
<td>6.08 ± 3.40</td>
<td>0.92 ± 0.64</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Experience of one revolution <em>pirouette</em> in pointe shoes (yr)</td>
<td>2.75 ± 1.71</td>
<td>0.00 ± 0.00</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>159.27 ± 4.21</td>
<td>151.89 ± 11.48</td>
<td>.046*</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>51.54 ± 4.66</td>
<td>43.81 ± 9.68</td>
<td>.017*</td>
</tr>
<tr>
<td>BMI (kg/m^2)</td>
<td>20.29 ± 1.37</td>
<td>18.7 ± 2.14</td>
<td>.033*</td>
</tr>
<tr>
<td>Menstruation (positive/negative)</td>
<td>13/0</td>
<td>9/4</td>
<td>-</td>
</tr>
</tbody>
</table>

*, significant difference between novice and experienced groups (p<.05);
### Table 4-2: Basic anthropometry

<table>
<thead>
<tr>
<th>Measure</th>
<th>Experience</th>
<th>Novice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turnout angle in <em>first position</em> (°)</td>
<td>122.5 ± 15.55*</td>
<td>103.46 ± 16.93*</td>
</tr>
<tr>
<td>Hallucis valgus (°)</td>
<td>dominant 12.77 ± 6.22</td>
<td>10.38 ± 4.43</td>
</tr>
<tr>
<td></td>
<td>non-dominant 13.77 ± 7.30</td>
<td>12.00 ± 4.45</td>
</tr>
<tr>
<td>Foot length (cm)</td>
<td>dominant 22.95 ± 0.57</td>
<td>22.26 ± 1.68</td>
</tr>
<tr>
<td></td>
<td>non-dominant 22.92 ± 0.51</td>
<td>22.31 ± 1.72</td>
</tr>
<tr>
<td>Foot width (cm)</td>
<td>dominant 9.25 ± 0.46</td>
<td>9.25 ± 0.65</td>
</tr>
<tr>
<td></td>
<td>non-dominant 9.18 ± 0.36</td>
<td>8.99 ± 0.72</td>
</tr>
<tr>
<td>Shank length (cm)</td>
<td>dominant 36.18 ± 1.56*</td>
<td>34.19 ± 3.13*</td>
</tr>
<tr>
<td></td>
<td>non-dominant 36.96 ± 1.46*</td>
<td>35.19 ± 3.59*</td>
</tr>
<tr>
<td>Maximum shank circumference (cm)</td>
<td>dominant 34.31 ± 1.22</td>
<td>31.40 ± 3.02</td>
</tr>
<tr>
<td></td>
<td>non-dominant 34.25 ± 1.32</td>
<td>31.67 ± 3.12</td>
</tr>
<tr>
<td>Thigh length (cm)</td>
<td>dominant 39.88 ± 2.17</td>
<td>38.92 ± 4.30</td>
</tr>
<tr>
<td></td>
<td>non-dominant 41.31 ± 3.98</td>
<td>38.77 ± 4.10</td>
</tr>
<tr>
<td>Mid-thigh circumference (cm)</td>
<td>dominant 48.65 ± 2.59</td>
<td>44.22 ± 5.54</td>
</tr>
<tr>
<td></td>
<td>non-dominant 49.28 ± 2.95</td>
<td>44.33 ± 5.67</td>
</tr>
</tbody>
</table>

*, significant difference between novice and experienced groups \((p < .05)\)
## Kinematics data

Table 4-14: Kinematics parameters

<table>
<thead>
<tr>
<th>Dominant (D)</th>
<th>Angular velocity (degrees/s)</th>
<th>Foot displacement (mm)</th>
<th>COP position in PRE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experience</td>
<td>538.77 ± 116.53</td>
<td>190.89 ± 125.68</td>
<td>55.83 ± 13.79</td>
</tr>
<tr>
<td>Novice</td>
<td>606.97 ± 170.67</td>
<td>240.19 ± 149.37</td>
<td>50.50 ± 19.75</td>
</tr>
</tbody>
</table>

Heel marker on supporting leg

Distance between heel marker and COP in anterior-posterior direction

COP position

Distance between heel marker and toe marker in anterior-posterior direction

Toe marker on gesture leg

Anterior

Medial
Joint angles

**Table 4-12: Joint angles during turning with single-leg support (TSSp and TSSm phases)**

<table>
<thead>
<tr>
<th>Dominant (D)</th>
<th>max. hip extension (-)</th>
<th>max. knee extension (-)</th>
<th>max. ankle plantarflexion (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experience</td>
<td>-8.40 ± 6.67</td>
<td>-5.29 ± 7.40</td>
<td>-10.69 ± 14.00</td>
</tr>
<tr>
<td>Novice</td>
<td>-5.52 ± 9.85</td>
<td>-7.85 ± 4.56</td>
<td>-5.48 ± 10.93</td>
</tr>
<tr>
<td>p value</td>
<td>.146</td>
<td>.089</td>
<td>.087</td>
</tr>
</tbody>
</table>

**Table 4-13: Joint angles during turning with single-leg support (TSSp and TSSm phases)**

<table>
<thead>
<tr>
<th>Dominant (D)</th>
<th>max. ankle eversion (+)</th>
<th>max. ankle inversion (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experience</td>
<td>36.43 ± 9.72</td>
<td>-23.79 ± 18.00</td>
</tr>
<tr>
<td>Novice</td>
<td>25.63 ± 12.96</td>
<td>-18.47 ± 8.14</td>
</tr>
<tr>
<td>p value</td>
<td>&lt;.001 *</td>
<td>.103</td>
</tr>
</tbody>
</table>