Biomechanics I: Principles of Movement

An introduction to the principles and terms used to describe athletic movement and the basic application of these principles and terms to figure skating skills and coaching.

Charlene Boudreau
Director, Sports Sciences & Medicine
U.S. Figure Skating

Supporting the ART and BUSINESS of SCIENCE-based coaching.
Everyday I coach, I find myself saying the same things, over and over and over again …

1. …

2. …

3. …
BIOMECHANICS - *the study of movement through body physics and human anatomy.*

An understanding of movement can help coaches and **break down** and **describe** the spectrum of skating skills.

Regular routine review of movement principles and effects can also help coaches **discuss** skating skills with athletes and off-ice specialists and **explain** why certain techniques work well while others do not.

The application of biomechanics principles **minimizes “trial and error” coaching** and fosters the development of effective teaching strategies and training programs that are specific to the unique needs of individual skaters and teams.

*Check out Don Laws “Physics on Ice”  
Friday, Rink 2, 12:35pm*
SIMON SAYS...

FLEX!
All body movements can be **described** using a combination of standard terms that reference the type of muscle action that creates the movement, the direction the body part moves relative to its joints, and the “plane” in which the movement occurs.

**Types of Muscle Actions:**
- Concentric/Eccentric Contraction

**Directions of Joint Motion:**
- Flexion/Extension
- Abduction/Adduction

**Planes of Movement:**
- Frontal/Sagittal/Transverse

Different *combinations* of muscle actions, joint motions and movement planes create different body movement effects, which ultimately affect the execution of on-ice and off-ice elements and skills.

---

**Principles & Effects of Movement**

- Center of Mass
- Force
- Torque
- Velocity
- Moment of Inertia
- Momentum

The fundamental measures of these effects (distance, time) are put into context by incorporating the characteristics of the skater.
Types of Muscle Actions

Concentric and Eccentric Contraction

Body movements are created by *combinations* of muscle contractions.

A concentric muscle contraction occurs when a muscle *shortens* as it contracts or “fires.” Concentric contractions often initiate motion.

An eccentric muscle contraction occurs when a muscle *lengthens* as it contracts or “fires.” Eccentric contractions often control or stop motion.

All body movements can be described using a combination of standard terms that reference the *type* of muscle action that creates the movement, the *direction* the body part moves relative to its joints, and the “*plane*” in which the movement occurs.
For example, concentric contractions of the quadriceps muscles on the front of the thigh initiate the upward motion of a jump take-off.

However, on landings, eccentric quadriceps contractions that start as soon as the landing toe-pick touches the ice help slow down and eventually stop the downward motion, thereby preventing the skater’s knee from bending all the way and preventing the rest of the skater’s body from falling all the way down to the ice.

Eccentric contractions tend to produce more force than concentric contractions, which explains why athletes become sore after workouts that focus on “motion-stopping” skills (as opposed to “motion-starting” skills).

All body movements can be described using a combination of standard terms that reference the type of muscle action that creates the movement, the direction the body part moves relative to its joints, and the “plane” in which the movement occurs.
Types of Muscle Actions

Concentric and Eccentric Contraction

Going into and maintaining a spiral position requires eccentric contractions of the hamstrings on the skating leg side to control the lowering and stabilization of the upper torso.

Eventually, concentric contraction of the hamstrings on the skating leg side initiates the repositioning of the torso to the upright position.

All body movements can be described using a combination of standard terms that reference the type of muscle action that creates the movement, the direction the body part moves relative to its joints, and the “plane” in which the movement occurs.
## PRINCIPLES OF MOVEMENT

<table>
<thead>
<tr>
<th>Directions of Joint Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flexion and Extension</strong></td>
</tr>
</tbody>
</table>

Flexion is the joint motion that occurs when a joint “bends.” You can visualize joint flexion by visualizing the bones on either side of a joint coming toward each other such that they approach parallel and/or by visualizing the angle inside the joint becoming smaller. Flexion is usually the result of the muscles on the **inner or front** side of a joint contracting concentrically. When someone says “Flex your bicep,” you respond by showing your muscle. When the biceps “flex” or contract, it forces the elbow to bend, which is called flexion of the elbow joint.

Extension is the joint motion that occurs when a joint “straightens.” You can visualize joint extension by visualizing the bones on either side of a joint moving away from each other such that they begin to create a straight or continuous line and/or by visualizing the angle inside the joint becoming larger. Extension is usually the result of the muscles on the **outer or back** side of a joint contracting concentrically. When someone says “Extend your arm,” you respond by reaching your arm out. When the arm extends out, it forces the elbow to straighten, which is called extension of the elbow joint.

All body movements can be described using a combination of standard terms that reference the **type** of muscle action that creates the movement, the **direction** the body part moves relative to its joints, and the “**plane**” in which the movement occurs.
**PRINCIPLES OF MOVEMENT**

<table>
<thead>
<tr>
<th>Directions of Joint Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion and Extension</td>
</tr>
</tbody>
</table>

A traditional spiral involves:

1. Hip flexion on the skating leg side
2. Hip extension on the free leg side
3. Knee extension on both sides
4. Elbow extension on both sides
5. Ankle extension on the free leg side

Muscles themselves do not undergo flexion or extension; The terms apply only to joint motions and are used in conjunction with the joint term itself (ex. elbow flexion, hip extension).

While all joints in the body can go through flexion and extension, these terms are most often used in figure skating in describing the degree of bend in the elbows, knees, wrists, ankles, spine and hips.

All body movements can be described using a combination of standard terms that reference the type of muscle action that creates the movement, the direction the body part moves relative to its joints, and the “plane” in which the movement occurs.
In the bigger picture of the body, *multi-joint appendages* have additional movement patterns beyond flexion and extension.

Often called “A-B-duction,” **abduction** is the joint motion that occurs when the arms and legs are moved **upward away** from the sides of the skater, or away from the axis of the body.

Often called “A-D-duction,” **adduction** is the joint motion that occurs when the arms and legs are moved **down from outward** or outside positions back to their original positions, or towards the axis of the body.

In basic stroking, the act of lifting the hands up and away from the outer thigh so that the arms are extended out to the sides is an example of shoulder **abduction**. When a skater is finished demonstrating basic stroking, the act of lowering the hands from the extended outside position down and toward the outer thigh is an example of shoulder **adduction**.

The terms abduction and adduction are most often used in figure skating in describing motion within or movement about the **shoulder and hip joints**.

All body movements can be described using a combination of standard terms that reference the **type** of muscle action that creates the movement, the **direction** the body part moves relative to its joints, and the “**plane**” in which the movement occurs.
### PRINCIPLES OF MOVEMENT

<table>
<thead>
<tr>
<th>Planes of Movement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frontal, Sagittal and Transverse Planes</strong></td>
</tr>
</tbody>
</table>

- At its highest level, body movement is described in terms of the “plane” in which it occurs.
- Planes are *abstract walls* that divide the body into front and back, left and right, or top and bottom.
- Each plane has a *movement axis* perpendicular (90°) to it about which broad body movement occurs.

#### The FRONTAL Plane:
Splits the body into front and back.
Posterior axis runs front-to-back.

#### The SAGITTAL Plane:
Splits the body into left and right.
Medial-lateral axis runs side-to-side.

#### The TRANSVERSE Plane:
Splits the body into top and bottom.
Longitudinal axis runs top-to-bottom.

![Image of skater in a front position](image1)

Shoulder abduction occurs in the frontal plane because the arms move around the anterior-posterior axis.

![Image of skater in a left position](image2)

Hip flexion is an example of movement in the sagittal plane because the movement of the leg and/or body around the medial-lateral axis.

![Image of skater in a top position](image3)

Spins and jumps are described as occurring in this plane because the movement of the body is about/around the longitudinal axis.

---

*All body movements can be described using a combination of standard terms that reference the type of muscle action that creates the movement, the *direction* the body part moves relative to its joints, and the “plane” in which the movement occurs.*
All body movements can be described using a combination of standard terms that reference the type of muscle action that creates the movement, the direction the body part moves relative to its joints, and the “plane” in which the movement occurs.

Types of Muscle Actions:
- Concentric/Eccentric Contraction

Directions of Joint Motion:
- Flexion/Extension
- Abduction/Adduction

Planes of Movement:
- Frontal/Sagittal/Transverse

Different combinations of muscle actions, joint motions and movement planes create different body movement effects, which ultimately affect the execution of on-ice and off-ice elements and skills.

The fundamental measures of these effects (distance, time) are put into context by incorporating the characteristics of the skater.

- Center of Mass
- Force
- Torque
- Velocity
- Moment of Inertia
- Momentum
Center of mass is an exact position within or around our physical body representing the balance point of our entire body mass.

- Center of mass location is most often identified by 3D body coordinates (ex. 2 cm above the umbilicus on the inside of the body frame, or 5 cm above the pelvis on the outside of the body frame).

- When a skater stands up straight with his arms at his sides, his center of mass is generally located between his hips.

- Due to typical gender differences in body shape and therefore body weight distributions, the center of mass location in men is slightly higher in the body than in women.

- When pairs and dance partners are in close physical contact with one another, especially in “vertically stacked” positions, they become a single unit from a physics perspective, thereby establishing a new center of mass for the entire “structure.”

Because body parts themselves carry various amounts of our body weight, this center of mass or balance point changes continuously as we move our body around. **Any object whose center of mass is below the fulcrum will not topple!**

Different combinations of muscle actions, joint motions and movement planes create different body movement effects, which ultimately affect the execution of on-ice and off-ice elements and skills.
Force is a push or pull on an object, which then causes an acceleration or deceleration. This effect is based on the principle of physics that states that every action has an opposite and equal reaction.

When a skater is standing still and then pushes her blade against the ice behind her, that push creates a force that accelerates her forward.

Likewise, when that same skater is standing still and then pushes her blade against the ice in front of her, that push creates a force that accelerates her backward.

**The harder the push, the greater the force created and the greater the reaction.**

Different combinations of muscle actions, joint motions and movement planes create different body movement effects, which ultimately affect the execution of on-ice and off-ice elements and skills.
When the skater is moving forward and pushes his blade against the ice in front of him, a force into the ice is created and met with an equal force in the opposite direction (i.e. backwards) causing him to slow down.

**The harder the push, the greater the force created and the greater the reaction.**

All forces can be measured, but it is not always completely practical to do so.

Force measurements are most often reported in Newtons or kilogram meters per second squared (kgm/s²).

---

Different combinations of muscle actions, joint motions and movement planes create different body movement effects, which ultimately affect the execution of on-ice and off-ice elements and skills.
EFFECTS OF MOVEMENT

Torque

Torque is the turning or rotational effect of a force that is applied “off-center” from the object’s rotational axis and therefore causes the object to start or stop rotating.

For example, pushing through the center of the ball will only cause the ball to slide forward across a flat surface. To spin/roll the ball, you push against the outside of the ball, using an off-center force in the direction you want it to roll.

A skater uses torque during the entrance to a spin by pushing against the ice while creating the entry edge. This push against the ice creates a torque (off the center of gravity and spinning axis) and helps initiate the rotation for the spin.

A skater also uses torque to stop rotating during the ‘check out’ of a jump.

Different combinations of muscle actions, joint motions and movement planes create different body movement effects, which ultimately affect the execution of on-ice and off-ice elements and skills.
Increasing torque can be accomplished by increasing the off-center force and/or increasing the distance from the axis of rotation that the force is applied.

Torque measurements are most often reported in Newton-meters (Nm) or foot-pounds (ftlb).

Different combinations of muscle actions, joint motions and movement planes create different body movement effects, which ultimately affect the execution of on-ice and off-ice elements and skills.
Velocity in its simplest definition is the speed at which a skater or team is traveling. It is a simple function of the distance covered in a specified timeframe.

Velocity is also a function of direction. At any given time, a skater can (and probably will) be traveling in more than one direction.

For example, during a jump, a skater travels up, over and around, all in one motion. Therefore, the velocity of this element should be described in terms of its horizontal ($V_H$), vertical ($V_V$) and rotational ($V_R$) components.

Different combinations of muscle actions, joint motions and movement planes create different body movement effects, which ultimately affect the execution of on-ice and off-ice elements and skills.
**Velocity**

The velocity of an element should be described in terms of its horizontal, vertical and rotational components.

- **Horizontal velocity** ($V_H$) is the speed at which a skater (or team) is moving **across** the ice. Horizontal velocity is a simple function of the **horizontal distance** covered relative to the **time** taken to cover it. Therefore, horizontal velocity can be measured both on the ice, as in gliding, stroking and landing, as well as in the air, as in jumping. Horizontal velocity is most often reported in meters per second (m/s).

- **Vertical velocity** ($V_V$) is the speed at which a skater (or team) is moving upward (or downward). Similar to horizontal velocity, vertical velocity is a simple function of the vertical distance covered relative to the **time** taken to cover it. The measurement of vertical velocity therefore applies primarily to elements in which there is “lift off” from the ice, floor or other surface. Vertical velocity is most often reported in meters per second (m/s).

- **Rotational velocity** ($V_R$) is the speed at which a skater (or team) is spinning or rotating. It is a measure of how fast a skater is spinning or rotating in a jump or throw. Rotational velocity is most often reported in rotations per second (rps) or rotations per minute (rpm).

*Different combinations of muscle actions, joint motions and movement planes create different body movement effects, which ultimately affect the execution of on-ice and off-ice elements and skills.*
Moment of Inertia

Moment of inertia is a skater’s resistance to rotation which must be overcome in order to rotate about an axis.

- Moment of inertia is determined by mass in general AND the location of mass relative to the axis of rotation.
- More mass and/or more mass further away from the axis means more resistance that must be overcome in order to rotate.
- A skater can lower his moment of inertia by moving his arms and free leg towards the body, thereby increasing rotational velocity.
- A team can lower their moment of inertia by staying closer together (horizontally) during an “in-contact” element.
- A skater’s moment of inertia may increase as he/she experiences biological maturation, during which time the shoulders and/or hips may broaden, thereby increasing the distance of mass from the rotational axis.

Different combinations of muscle actions, joint motions and movement planes create different body movement effects, which ultimately affect the execution of on-ice and off-ice elements and skills.
Momentum quantifies the amount of positive motion the skater is carrying.

Like velocity, momentum is also a function of direction and must be described in terms of its directional components.

**Linear momentum** quantifies the amount of linear (or straight ahead) motion of a skater.

**Linear momentum = mass X linear velocity** (either $V_H$ or $V_V$)

**Rotational momentum**, on the other hand, quantifies the amount of rotational motion that a skater possesses about her axis of rotation.

- Rotational momentum is created during the entrance to a spin or during a jump preparation and take-off.
- It combines both how fast a skater is rotating and the current body position: **Rotational momentum = $V_R$ X moment of inertia**
- On the ice, rotational momentum is created when the forces the skater applies to the ice with her blade create a torque.
- Once in the air, however, there is no surface for the skater to push against, so she will maintain the same amount of rotational momentum that she has when she leaves the ice at take-off.
- Rotational momentum represents a skater’s potential to rotate fast, but it is intangible and cannot be seen, felt, or heard by a skater or coach.
- However, since it determines the rotation speed that a skater will be able to attain in a jump or spin when the arms and legs are brought into a tight position, its conservation is of utmost importance in elements involving jumping and spinning.

Different combinations of muscle actions, joint motions and movement planes create different body movement effects, which ultimately affect the execution of on-ice and off-ice elements and skills.
All body movements can be described using a combination of standard terms that reference the type of muscle action that creates the movement, the direction the body part moves relative to its joints, and the “plane” in which the movement occurs.

**Types of Muscle Actions:**
- Concentric/Eccentric Contraction

**Directions of Joint Motion:**
- Flexion/Extension
- Abduction/Adduction

**Planes of Movement:**
- Frontal/Sagittal/Transverse

Different combinations of muscle actions, joint motions and movement planes create different body movement effects, which ultimately affect the execution of on-ice and off-ice elements and skills.

The fundamental measures of these effects (distance, time) are put into context by incorporating the characteristics of the skater.

- Center of Mass
- Force
- Torque
- Velocity
- Moment of Inertia
- Momentum
Regular review of movement principles and effects can help coaches discuss, explain and therefore analyze skating skills.

**BUT…**

In order to teach a new skill and/or coach an existing one, we must establish some sense of a flow in movement/skill analysis.

---

**MECHANICALLY**, what do I see in the skill?

- Is it good?
- Is it bad?
- Is it important?
- Why is it happening?
  - Is it mental?
  - Is it physiological?

---

Top 3 Precautions to Avoid Missing the Mark:
1. Don’t Lose it in Translation.
2. Prioritize Feedback.
3. Focus on Critical Features (AP-MM).

---

Enhance **YOUR ART** and **BUSINESS** of **SCIENCE-based coaching**.