*The WHO, WHAT and HOW of ACL Injury Prevention in Female Athletes**

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**None of the speakers have anything to disclose*

Overall Presentation Learning Objectives
1. Determine the age at which female athletes can successfully make changes in their motor programs.
2. Identify the content, frequency and duration of a successful injury prevention program.
3. Identify various motor learning strategies, including implicit and explicit learning.
4. Identify various verbal and visual cues that enhance motor learning.

The WHO

Objectives:
1. Discuss the historical background for the development of prevention programs
2. Discuss the evidence related to outcomes based on age
3. Identify optimal age for motor learning

The WHO of ACL Prevention Programs- Historical Perspective
1. 1982-Ekstand, Medical dissertation Linkoping University
2. 1988-Barratta (AJSM)
3. 1996-Caraffa (Knee Surgery Sports Trauma)
4. 1999-Hewett (AJSM)
5. Am J Sports Med Sept 2000; 2(5) 659-662
6. 2000-Heidt (AJSM)
7. 2002-Junge (AJSM)
8. 2003–Myklebust (Clin J Sports Med)
9.2005-Mandelbaum (AJSM)
10. 2008- Soligard (BMJ)

History of ACL tear prevention programs
1. SportsMetrics - 1999/2012 (US)
2. PEP (Prevent injury, Enhance Performance) - 2005 (US)
3. KLIP (Knee Ligament Injury Prevention Program - 2006 (US)
4. The “11” - 2008 (Norway)
5. HarmoKnee - 2010 (Sweden)
6. KIPP (Knee Injury Prevention Program) - 2006 (US)
7. Walden 2012 - (Sweden)

Historical perspective-Common risk factors identified

1. Poor landing
2. Pivot style
3. Quads overpower the hamstrings
4. Shoe surface interface
5. Surface quality
6. Female

The WHO of ACL Prevention Programs- How young is old enough?

Age appropriate motor learning

1. What is motor learning?
    a. 3 phases
    b. Skill development
    c. Correcting faults
2. Fundamental aspects in development of muscular strength
    a. Middle to late childhood
    b. Early to late childhood thru adolescence
3. Age classifications
    a. Chronological age
    b. Developmental age
    c. Skeletal age
    d. General training age
    c. Sports Specific training age
    d. Relative age
4. Optimal years for motor learning
    a. Growth curves
    b. 6? 12? 14?
5. Physiologic considerations - PEAK HEIGHT VELOCITY (PHV)
    a. Motor Skills period
    b. Long Term Athlete Development (LTAD)
    c. Stamina
    d. Strength
    e. Suppleness
    f. Speed

Outcomes of participation
Do these programs work?
Keys to success

Remember…
Practice DOES NOT make perfect.
Practice only makes PERMANENT.
PERFECT practice makes perfect.

WHAT Are The Program Components?

Objective: Identify the contents of a successful ACL prevention program, including frequency and duration.

Let's consider some of the well-researched programs that have been developed:

1. **SportsMetrics**
2. **PEP**
3. **FIFA 11+**
4. **HarmoKnee**

1. SportsMetrics

- First program developed with supported research (1999)
- Updated and revised in 2012

Content:

- A 3x/week jump training program (lasting 6 weeks)
- Progressed through 3 phases: the technique phase, fundamental phase, and the performance phase
- Training sessions are 60-90 minutes
- http://sportsmetrics.org/

Research supporting SportsMetrics:

- 2 groups of female athletes, one trained before sports participation and the other not trained, and a group of untrained male athletes
- Monitored throughout the high school soccer, volleyball, and basketball seasons.
- The knee injury incidence per 1000 athlete-exposures was 0.43 in untrained female athletes, 0.12 in trained female athletes, and 0.09 in male athletes (P 5 0.02, chi-square analysis).
- Untrained female athletes had a 3.6 times higher incidence of knee injury than trained female athletes (P 5 0.05)
- *Hewett, Am J Sports Med, 1999*

2. PEP Program (Prevent Injury and Enhance Performance)

- Santa Monica Sports Medicine Foundation and the PEP (Prevent Injury and Enhance Performance)http://smsmf.org/smsf-programs/pep-program (FREE download!)

Content:

- Warm-up, stretching, strengthening, plyometrics, and sport specific agility exercises for soccer
- Performed on the field before practice; no extra specialized equipment
- 19 components, ~20 minutes, 3x/week

Research supporting the PEP Program:

- 14-18 yo females
- >1000 female athletes in the intervention group (education, stretching, strengthening, plyometrics, and sports-specific agility drills)
- >1900 female athletes in the control group (traditional warm-up)
- Year 1: **88%** decrease in ACL injury rate in the intervention group as compared to the control group
- Year 2: **74%** reduction
- *Mandelbaum, Am J Sports Med, 2005*

- NCAA D1 females
- 61 female soccer teams consisting of 1435 athletes (852 control athletes; 583 intervention)
- ACL rate in the intervention group was 1.7 x less than in the control athletes (41% decrease)
- Intervention athletes with a history of ACL injury were significantly less likely to suffer another ACL tear compared to controls with previous ACL tears
- *Gilchrist, Am J Sports Med, 2008*

3. FIFA 11+

- http://f-marc.com/11plus/home/
- http://f-marc.com/11plus/manual/ (76 page manual in 7 languages; videos on the website as well!)

Content:

- Comprehensive warm-up program to improve strength, awareness, and neuromuscular control during static and dynamic movements

Research supporting the FIFA 11+:

- 125 soccer clubs in **Norway** followed for one league season (eight months)
- Participants were 1892 female players aged 13-17
- In the intervention group, there was a significantly lower risk of severe injuries, overuse injuries, and injuries overall
- *Soligard, BMJ, 2008*

4. HarmoKnee Program

- http://harmoknee.com/

Content:

- Increase awareness of injury risk while providing a structured warm-up program

- Also provides strengthening exercises that produces less strain to the knee joint

Research supporting the HarmoKnee Program:

- The training program: implemented at a practice session; athletes and coaches were trained in the correct way to perform and teach the exercises
- 5 parts: warm-up, muscle activation, balance, strength, and core stability
    - Integrated into the regular soccer practice sessions with no additional equipment
- 94% of intervention teams reported >75% compliance
- Control group: 13 knee injuries (5 ACL tears)
- Intervention group: 3 knee injuries (NO ACL tears)
- A **77%** reduction in knee injury incidence and a **90%** reduction in noncontact knee injury incidence
- *Kiani, Arch Intern Med, 2012*

Programs summarized:

- **PEP** (RR 0.18, CI 0.08 to 0.42) 82% reduction
    - The PEP also significantly reduced the risk of recurrence in those with previous non-contact ACL injuries (P = 0.046)
- **HarmoKnee** (RR 0.22, CI 0.06 to 0.76) 78% reduction
- The **11+** program (RR 0.48, CI 0.32 to 0.72) 52% reduction

- **PEP:** most effective in reducing ACL injuries
- **11+ and HarmoKnee**: significant reduction of knee injury risk
- *Herman, BMC Medicine, 2012*

ACL prevention programs are successful!!!!

- Especially adolescent female soccer players
- Mostly done as warm-up
- Little to no equipment
- *Some strength training, some plyometric activity and some balance*

Frequency:

- Agreement that an ACL prevention program should include at least 10 minutes of exercises 3x/week, as a bare minimum
  ****Most studies report performing 15-20 minutes of activity
- *Sadoghi, JBJS, 2012*

- Determined that the estimated protective effect was relatively stronger in studies involving **more training time each week** and in those studies with **better compliance**
- *Gagnier, Am J Sports Med, 2013*

Duration:

- Programs should begin prior to season, at least 6 weeks pre-season
  ***Most studies recommend 8 or more weeks in duration to allow sufficient neuromuscular changes and performance training effects
- Ideally, the program can be continued throughout the season, at a lower frequency or duration (i.e.-cut the warm-up to 10-15 minutes if necessary)
- *Sadoghi, JBJS, 2012*
- *Voskanian, Curr Rev Musculoskeletal Med, 2013*

Numbers Needed to Treat:

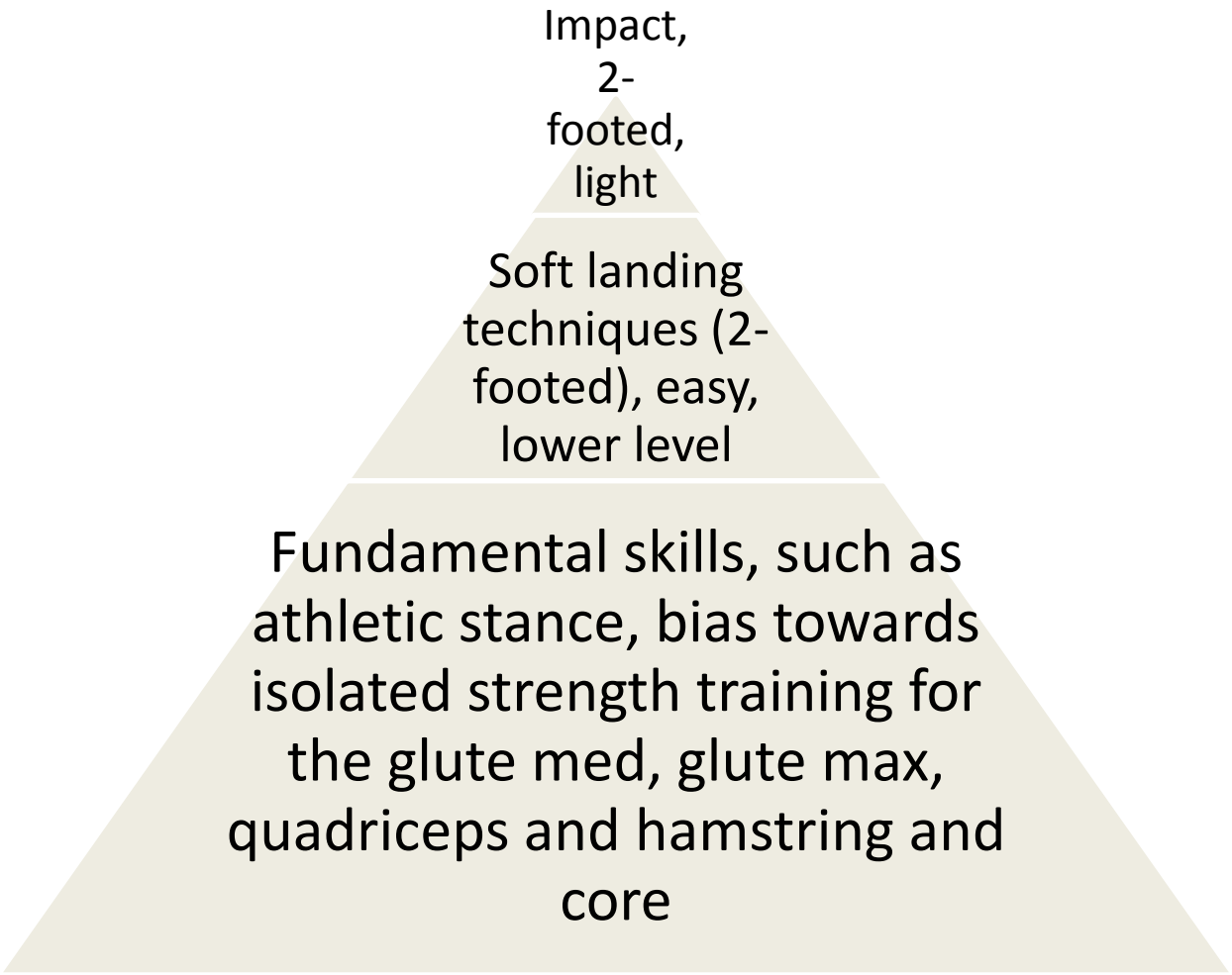
- Determine overall ACL injury risk in female athletes through relative risk reduction (RRR) and numbers needed to treat (NNT)
- 12 studies, Systematic review (ish)
- To prevent one ACL in one competitive season: ~108
- *Sugimoto, BR J Sports Med, 2012*

- PEP: (82% reduction): 70
- HarmoKnee: (78% reduction): 72
- The 11+ program: (52% reduction): 28 (?)
- *Herman, BMC Medicine, 2012*

Components of an Injury Prevention Program:

- Muscle strengthening
- Plyometrics
- Neuromuscular training / control / balance
- Education and feedback regarding body mechanics and proper landing patterns in a dynamic atmosphere (HOW)
- *Voskanian, Curr Rev Musculoskeletal Med, 2013*

Weeks 1-3


Impact, 2-footed, light
Soft landing techniques (2-footed), easy, lower level
Fundamental skills, such as athletic stance, bias towards isolated strength training for the glute med, glute max, quadriceps and hamstring and core

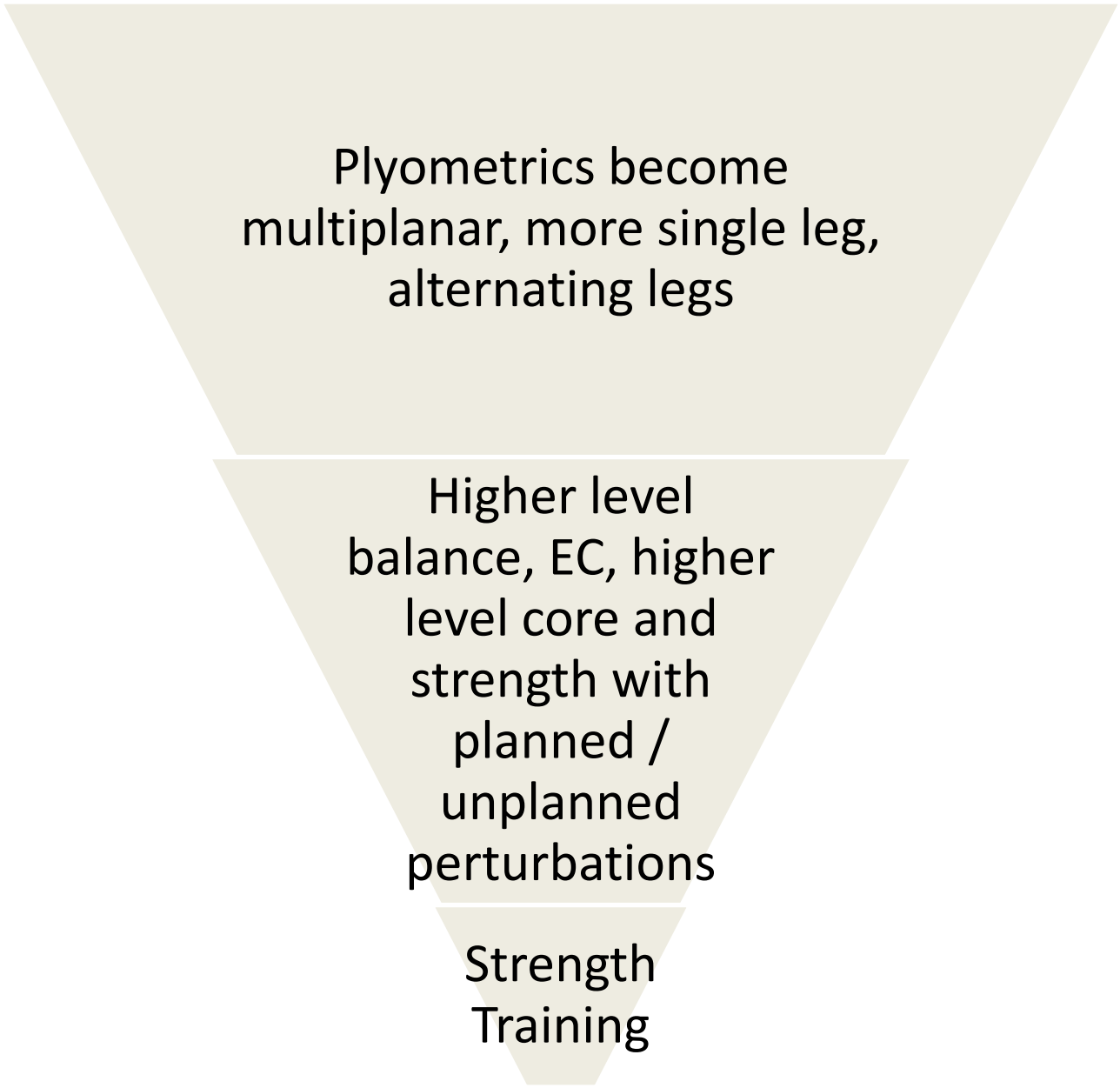
Weeks 4-6

Sagittal plane plyometrics get bigger, start introducing single leg impact and light plyometrics

Impact and landing still stressed, add frontal and transverse planes movements, progress balance

Combined movements that incorporate multiple muscles, start sagittal, then progress to frontal and transverse planes, less isolated strengthening

Weeks 7+


Plyometrics become multiplanar, more single leg, alternating legs
Higher level balance, EC, higher level core and strength with planned / unplanned perturbations
Strength Training

HOW Do We Deliver The Information?

This talk will identify the most effective type(s) of motor learning, the appropriate verbal and visual cues to use, as well as identify tools (mirrors, video feedback) as sources of motor learning.

Objectives:
Upon completion of this course, you will be able to:

1.) Determine the age at which female athletes can successfully make changes in their motor patterns to improve their jumping, landing and cutting techniques.
2.) Identify the content, frequency and duration of a successful ACL prevention program.
3.) Identify various motor learning strategies, including implicit and explicit learning.
4.) Discuss implementation of successful motor learning strategies (which have demonstrated participant's increased retention of improved movement skill) in ACL prevention programs

I. Components of an Injury Prevention Program (Hewett 2006, Voskanian 2013)

A. Muscle strengthening
B. Plyometrics
C. Neuromuscular training / control / balance
D. Education and feedback regarding body mechanics and proper landing patterns in a dynamic atmosphere (HOW)

II. The state of ACL injuries in 2016

A. Injury rates continue to increase (Buller 2014)
   1. Studies on prevention programs show lab-based improvements in jumping/landing techniques
   2. Why not translating into the community?
      a) Is it compliance?
         (1) Lack of time/interest from coaches common barrier to implementation (LaBella 2011)
         (2) Only 53% of coaches implemented injury prevention program after attending workshop on the topic (Padua 2014)
            (a) "High levels of behavioral determinants do not appear to translate into high levels implementation compliance"
      b) **OR- are we missing something in training?**
B. High rate of second ACL injury
   1. Greater than 20% for young highly active athletes returning to sports within first year after surgery (Paterno 2010)
   2. Female soccer players: 22% of 15-18 yr olds with revision or contralateral ACLR during a 5-yr period (Ahlden 2012)

a) Soccer players perform average of 726 cutting maneuvers in a match (Bloomfield 2007)
b) If movement pattern not corrected- large opportunity for re-injury

3. Return to high activity level after unilateral ACLR- most important risk factor for contralateral ACL injury (Sward 2010)

C. Therefore— Even in a population that has been through PT (better chance of compliance!) we still cant prevent second injury!

D. Altered central nervous system may play a role

1. Brain functional MRI showed increased activation motor planning, sensory processing, and visual motor control areas <u>bilaterally</u> in an individual with unilateral ACL injury
   a) Alteration in neuromuscular control that may bilateral risk of second injury

E. <u>Is there a disconnect?</u> How do we take conscious awareness during training/PT to an automatic movement pattern?

III. The "HOW"- Motor Learning

A. Definition:

1. Relatively permanent acquisition of motor skills (Schmidt 2004)
2. Many different types of motor skills, however learning process is similar

B. 3 stages (Fitts & Posner):

1. Cognitive:
   a) Learner's conscious attempt to determine what exactly needs to be done
   b) Step by step.
   c) Must focus attention on entire pattern
2. Associative:
   a) Begins when basic movement pattern is acquired
   b) Movements more consistent, automatic, and economical
   c) Some attention directed to other aspects of performance
3. Autonomous:
   a) Motion is fluent and seemingly effortless
   b) Movements accurate, consistent, efficiently produced
   c) Little to no attention required- skill considered to be automatic

C. "Old school" belief: athletes need attention to every detail and step during acquisition phase

1. Must practice over and over
2. NOT supported in the literature
   a) Repetition may not be optimal
   b) Pattern variations may simulate brain to problem solve
      <u>(1)</u> <u>Find</u> the optimal solution during unanticipated events
      <u>(2)</u> "True" sports simulation?

IV. Types of motor learning

<u>A.</u> <u>Explicit</u> motor learning: Acquisition of motor skills with an <u>internal focus</u>
   a) Internal focus: directed to body movements

(1) "Keep your knees over your toes"
(2) "Land with your feet shoulder width apart"

B. Implicit motor learning: Acquisition of motor skills with an external focus
1. External focus: directed towards outcome or effects of movement
a) "Imagine sitting down in a chair when landing"

V. Internal focus of attention

A. Constant focus on same performance may reduce athlete's motivation
B. Conscious control of athlete's own movements
1. New skills may not transfer to automatic performance
2. Less ability to "problem solve"
C. Can increase psychological stress- possible detrimental effect on performance (Masters 2008, Poolton 2007)

VI. Benefits of external focus of attention

A. Effective in establishing certain sport-specific movements (Schöllhorn 2006, Wulf 2001)
1. Basketball free throw
2. Tennis serve
3. Golf swing
B. Facilitates automation of movements, accelerates the learning process (Wulf 2009, Zachry 2005)
C. Better retention of newly learned skills
1. Better balance (Laufer 2007)
2. Reduced peak vertical ground reaction forces with jumping (Onate 2001)
D. Movement patterns resilient under fatigue and stress
1. ACL injury risk increased under fatigue
2. Prevention programs must minimize risk in fatigued state (i.e., end of soccer match, ski race, basketball game)

VII. Premotor cortex

A. Role in conscious attention to memorized movements (Simon 2002)
1. Active even when no movements are generated
2. Attention to memorized movements may reduce brain resources for motor control
B. Skill learned with external focus: more resources available to pay attention to other game factors
1. Opponent
2. Teammates
3. Field conditions

VIII. Specific benefits

A. Sports Performance Benefits
1. Training with external focus of attention:
a) Higher jump-and-reach height
b) More force production (Makaruk 2012, Wulf 2009)

2. Used vertex jump trainer as external object- "reach fingers as high as possible"

B. ACL Injury Prevention/Rehab
   1. Training with external focus…
      a) Improved knee flexion angles (Makaruk 2012, Onate 2005)
      b) Lower peak vertical ground reaction force (McNair 2000, Onate 2001, Wu 2012)
      c) Improved neuromuscular coordination (Wulf 2007)

C. Improved landing technique, increased jump performance- without reduced performance (Benjaminse 2015)

D. Post ACL reconstruction
   1. Gokeler 2015: 16 patients after ACL-R with instruction prior to single leg jump
      a) Internal focus (IF) vs external (EF)
         (1) IF: "Jump as far as you can. While you are jumping, I want you to think about extending your knees as rapidly as possible"
         (2) EF: "Jump as far as you can. While you are jumping, I want you to think about pushing yourself off as hard as possible from the floor.'
      b) EF group with significantly larger…
         (1) Knee flexion angle at initial contact
         (2) Peak knee flexion
         (3) Total ROM
         (4) Time to peak flexion
   2. Elias et al, 2015: landing instruction produced statistically and clinically significant change in mechanics in persons post ACL-R
      a) Decreased co-contraction noted with less hamstring activity
      b) Simple instruction/verbal cues had more effect on mechanics than hamstring strengthening!

IX. Types of externally-focused learning

A. Dyad training
   1. Athlete watches a teammate/peer; alternates roles
   2. Observation and practice: More effective in combination (Shea 2000, 1999)

B. Video feedback
   1. Mirror neurons: visuomotor neurons
      a) Fire when passively observing an action
      b) Link observation (visual input) to performance (motor output) (Buccino 2004, Iacoboni 2005, Molenberghs 2009)

C. Real-time feedback
   1. Positive effect on task performance
   2. Influences motor memory
   3. Clinical examples
      a) Gait modifications in real-time influenced kinematic/kinetic factors related to knee pain (Barrios 2010, Noehren 2011)

Type of Exercise	Instruction With Internal Focus	Instruction With External Focus
Single-leg stance on unstable platform (**FIGURE 1**)	Keep your balance by stabilizing your body	Keep the bar horizontal
Single-leg squat (**FIGURE 2**)	Stand on 1 leg and slowly bend your knee while keeping your knee over your foot	Stand on 1 leg and reach slowly toward the cone with your knee while bending your knee
Single-leg hop for distance (**FIGURE 3**)	Jump as far as you can. While jumping, focus on extending your knees as rapidly as possible	Jump as far as you can. While jumping, focus on jumping as close to the cone as possible
(Walking) lunges (**FIGURE 4**)	Lunge slowly at an even pace. Bend your hips and knees until your leading knee is flexed to 90°. Keep your front knee on top of your foot and prevent buckling inward with this knee	Lunge slowly at an even pace. While pretending you have a plank on your back, point your knee toward an imaginary point in front of you and reach slowly toward the cone
Double-leg squat	Bend your knees while keeping your knees over your feet	While bending your knees, reach toward the cones with your hands and point your knees toward the cones Pretend that you are going to sit on a chair while keeping a ball between your knees
Double-leg drop jump	Jump down from a 30-cm box, land with your feet at shoulder width, and bend your knees while keeping knees over toes	Jump down from a 30-cm box, land on the markers on the floor, and put your toes and knees toward the cones
Vertical jump with Vertec[95,96,103]	Jump as high as you can while concentrating on the tips of your fingers, reaching as high as possible during the jumps	Jump as high as you can while concentrating on the rungs of the Vertec/ball, reaching as high as possible during the jumps Jump as high as you can, push off against the ground as forcefully as possible, and pretend like you have to hold a ball between your knees
Countermovement jump	Jump as high as you can and reach your fingers as high as you can	Jump as high as you can and touch the hanging ball
Sidestep cutting maneuver	Run 4 to 5 steps straight ahead. While changing direction and making the cut, move your trunk forward, bend your knee, and keep your knee over your toe	Run 4 to 5 steps straight ahead. While changing direction and making the cut, try to make a fluent motion and point your face and toes toward the direction you are going

(Taken From: Optimization of the anterior cruciate ligament injury prevention paradigm: novel feedback techniques to enhance motor learning and reduce injury risk. Benjaminse A1, Gokeler A, Dowling AV, Faigenbaum A, Ford KR, Hewett TE, Onate JA, Otten B, Myer GD. J Orthop Sports Phys Ther. 2015 Mar;45(3):170-82. doi: 10.2519/jospt.2015.4986. Epub 2015 Jan 27.)

D. Intertial sensor-based feedback
   1. Vibratory buzzer near knee- gives athlete response at acceptable amount of knee flexion
   2. Auditory feedback- beeping when athlete completes exercise properly
   3. Visual feedback
      a) Graphs of progress
      b) Laser pointer- athlete can "point" knee to proper position

X. Feedback Frequency

A. Frequency of feedback important
   1. High frequency that promotes external focus superior to low frequency (Wulf 2010)
   2. High frequency that promotes internal focus- detrimental

B. Self-controlled learning
   1. Athlete can decide when to receive feedback
   2. Giving athlete control over a practice session may be better way to enhance motor learning (Wulf 2010)
      a) Allows athlete to assume a more active role in skill development
      b) Increased compliance?

C. Type of feedback: combination of expert and self-feedback improved peak knee flexion angles vs self-feedback alone (Etnoyer 2015)

XI. Clinical examples

A. Single leg squat
   1. Internal focus: "Keep knee over your foot"
   2. External focus: "Reach slowly toward cone with your knee"

B. Single leg hop
   1. Internal focus: "While jumping, focus on extending your knees as rapidly as possible"
   2. External focus: "While jumping, focus on jumping as close to the cone as possible"

XII. Other considerations

A. Sex-specific differences
   1. Side-step cutting maneuver (Benjaminse 2015)
   2. Males demonstrated increased vertical ground reaction force, knee flexion moment with externally focused (visual) cues.
      a) Females less responsive
         (1) Need to acknowledge sex-specific learning preferences
         (2) Possible future investigation/utilization different feedback modes for females
         (3) "May need to adopt safe landing strategies first?"

B. Stronger mirror neuron activation is found when observing the same gender (Benjaminse 2011)

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