Anne Benjamínse
Motor learning in ACL injury prevention
Blessure preventie

Risicofactoren bepalen

Interventie

Monitoren programma

Implementatie programma
Knie - Voorste Kruisband

Injury mechanism (1)
Injury mechanism (2)
Noncontact Blessure Mechanisme

Richtingsverandering / landing

Valgus + lichte flexie + rotatie

McNair 1990
Boden 2000
Olsen 2004
Knie - Facts & Figures NL

- **1e frequentie 970.000 per jaar**
- **21% van jaartotaal**
- **⅔ ontstaat acuut**
- **Vooral VKB leidt tot langdurige sportuitval**
- **Fysieke en psychosociale gevolgen**
- **Kosten per VKB blessure €10.000,-:**
  - **Medische ingreep €2500,-**
  - **Fysiotherapie €1000,-**
  - **Verzuimkosten €6500,-**
- **↑10x kans op artrose**
- **Na 2 jaar > 60% sport op oude niveau**
- **Kans op re-ruptuur 6%-31%**
Warrior Girls
Protecting Our Daughters Against the Injury Epidemic in Women's Sports
Michael Sokolove

Every female athlete has an Achilles' heel.

The statistics are startling: female athletes in specific sports are three to four times more likely to injure their knees than men — a problem.

![Graph showing the number of cases by age group for men and women](graph.png)
Impact VKB ruptuur

- Chronische instabiliteit
- Secundaire schade
- Quality of life issues
- Hoge kosten
- Kans op re-ruptuur
MULTIFACTORIEEL PROBLEEM

Age
Physical fitness
Anatomy (alignment)
Prior injury
Skill levels

Biomechanical influences and coordination

Alertness

ACL injury

Sport factors (rules, coaching)
Equipment (shoes)
Environment (weather, surface)

Restrictive dietary habits
Carbohydrate intake
Calcium intake
Disordered eating

Inadequate sleep
Fatigue

Sport specialization
Overtraining
Burnout

Stress (depression, anxiety, low self-esteem)
Performance climate

Substance use, alcohol

Elliot 2010
Increased Lateral Tibial Plateau Slope Predisposes Male College Football Players to Anterior Cruciate Ligament Injury


RISICOFACTOREN

MULTIVARIATE

INTERVENTION

IMPLEMENTATION

MONITOR
Primaire risicofactoren

**Extern**
- Niveau competitie
- Ondergrond

**Intern**
- Anatomisch
- Hormonaal
- Neuromusculair
- Biomechanisch

*Bahr 2005  Griffin 2006  Hewett 2006*

---

*Non-contact ACL injuries in female athletes: an International Olympic Committee current concepts statement*


doi:10.1136/bjsm.2008.048934
Biomechanical Measures of Neuromuscular Control and Valgus Loading of the Knee Predict Anterior Cruciate Ligament Injury Risk in Female Athletes

A Prospective Study
The Influence of In-Season Injury Prevention Training on Lower-Extremity Kinematics during Landing in Female Team Handball Players: A Prospective Intervention Study Over Three Seasons

Christine D. Pollard, PhD
Karen Lang, MSc
Gisela Tendick, PhD
Inger H. Myklebust, MD, PhD

Effect of Neuromuscular Muscle Strength, and Proprioceptive Training Program in Preventing Anterior Cruciate Ligament Injuries in Female Athletes

2-Year Follow-up

Bert R. Mandelbaum,* MD, Holly J. Silvers,* MPT, Diane S. Watanabe,* MA, ATC, John F. Knarr,* PT, ATC, Stephen D. Thomas,* MPT, Letha Y. Griffin,^† MD, Donald T. Kirkendall§ PhD, and William Garrett, Jr,§ MD, PhD


The Effects of Plyometric vs. Dynamic Stabilization and Balance Training on Power, Balance, and Landing Force in Female Athletes

Gregory D. Myer,^† Kevin R. Ford,^† Jensen L. Brent,^† and Timothy E. Hewett^†,^‡

Prevention of Anterior Cruciate Ligament Injuries in Female Athletes
The changes aimed to make the exercises more specific to team handball, as well as more challenging. However, the focus of the exercises (i.e., to improve awareness and knee control during standing, cutting, jumping, and landing) did not change. The players were encouraged to be focused and conscious of the quality of their movements, with emphasis given to core stability and hip and knee position in relation to the foot (the “knee over toe” position). The players were also asked to watch their partner closely and to give feedback to each other during training.
Anterior Cruciate Ligament Injury in National Collegiate Athletic Association Basketball and Soccer

A 13-Year Review


Julie Agel, MA, ATC,* Todd Rockwood, PhD,† and David Klossner, PhD, ATC‡
The ACL Injury Enigma: We Can’t Prevent What We Don’t Understand

Scott G. McLean, PhD
University of Michigan, Ann Arbor, MI
Oke, stap naar de bal.
ACL injury prevention, more effective with a different way of motor learning?

Anne Benjamisce · Egbert Otten
Motorisch leren

Knowledge of performance

Focus

Stimuleert automatische leerprocessen

Knowledge of results

Focus
Knowledge of performance

IMPORTANT

When viewed from the front, the hip, knee and foot of your supporting leg should be in a straight line

Do not let your knee buckle inwards

Always keep the hip and knee of your supporting leg slightly bent

Keep your weight on the ball of your foot

Keep your upper body stable and facing forwards

Keep your pelvis horizontal and do not let it tilt to the side
Optimization of the Anterior Cruciate Ligament Injury-Prevention Paradigm: Novel Feedback Techniques to Enhance Motor Learning and Reduce Injury Risk
• Brace

• Ankle disk training
  • ↓ reactie tijd spieren rondom enkel
  • ↓ ’giving way’ gevoel
  • ↑ coördinatie en balans
  • ↑ spierkracht

The Effect of a Balance Training Program on the Risk of Ankle Sprains in High School Athletes

Timothy A. McGuine,* PhD, ATC, and James S. Keene, MD
From the University of Wisconsin, Hospital and Clinics, Sports Medicine Center, Madison, Wisconsin

Handoll 2001
Effect of Focus of Attention on Transfer of a Postural Control Task Following an Ankle Sprain

Effect of Attention Focus on Acquisition and Retention of Postural Control Following Ankle Sprain

Yocheved Laufer, DSc, PT, Nirit Rotem-Lehrer, MSc, PT, Zohar Ronen, MBA, PT, Giora Khayutin, MHA, PT, Ilanit Rozenberg, BPT
Focus of Attention

“KEEP YOUR BALANCE BY STABILIZING YOUR BODY”

“KEEP YOUR BALANCE BY STABILIZING THE PLATFORM”
Verbale Instructie

“KEEP YOUR BALANCE BY STABILIZING YOUR BODY”

“KEEP YOUR BALANCE BY STABILIZING THE STICK”

INTERNAL FOCUS

EXTERNAL FOCUS

Wulf 2004
Double legged squat

Real Time Visuele Feedback

Externe focus

Pictures Ford
Real Time Visual Feedback

A

B

McCough 2011
Balance

Squat

Lunge

Double legged drop vertical jump

Side step cutting

Jump shot
Verbale instructie

Interne focus

Externe focus
Balans

Squat

Lunge

Double legged drop vertical jump

Side step cutting

Jump shot

Mechanisme 1
Visuele feedback + verbale instructie

Modeling (expert or self)
Enhanced retention of drop vertical jump landing technique: A randomized controlled trial

Wouter Welling a, Anne Benjaminside a,b,*, Alli Gokeler a, Bert Otten a

a University of Groningen, University Medical Center Groningen, Center for Human Movement Sciences, Groningen, The Netherlands
b School of Sport Studies, Hanzo University, Groningen, The Netherlands
<table>
<thead>
<tr>
<th>Frontal-Plane Motion</th>
<th>Sagittal-Plane Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Stance width</strong></td>
<td><strong>6. Initial landing of feet</strong></td>
</tr>
<tr>
<td>□ Normal (0)</td>
<td>□ Toe to heel (0)</td>
</tr>
<tr>
<td>□ Wide (1)</td>
<td>□ Heel to toe (1)</td>
</tr>
<tr>
<td>□ Narrow (1)</td>
<td>□ Flat (1)</td>
</tr>
<tr>
<td>□ Normal (0)</td>
<td>□ Large (0)</td>
</tr>
<tr>
<td>□ Externally rotated (1)</td>
<td>□ Average (1)</td>
</tr>
<tr>
<td>□ Internally rotated (1)</td>
<td>□ Small (2)</td>
</tr>
<tr>
<td><strong>3. Initial foot contact</strong></td>
<td><strong>8. Amount of trunk-flexion displacement</strong></td>
</tr>
<tr>
<td>□ Symmetric (0)</td>
<td>□ Large (0)</td>
</tr>
<tr>
<td>□ Not symmetric (1)</td>
<td>□ Average (1)</td>
</tr>
<tr>
<td><strong>4. Maximum knee-valgus angle</strong></td>
<td><strong>9. Total joint displacement in the sagittal plane</strong></td>
</tr>
<tr>
<td>□ None (0)</td>
<td>□ Soft (0)</td>
</tr>
<tr>
<td>□ Small (1)</td>
<td>□ Average (1)</td>
</tr>
<tr>
<td>□ Large (2)</td>
<td>□ Stiff (2)</td>
</tr>
<tr>
<td><strong>5. Amount of lateral trunk flexion</strong></td>
<td><strong>10. Overall impression</strong></td>
</tr>
<tr>
<td>□ None (0)</td>
<td>□ Excellent (0)</td>
</tr>
<tr>
<td>□ Small to moderate (1)</td>
<td>□ Average (1)</td>
</tr>
<tr>
<td></td>
<td>□ Poor (2)</td>
</tr>
</tbody>
</table>
Balans

Squat

Lunge

Double legged drop vertical jump

Sidestep cutting

Jump shot

MECANISME 2
Motor learning strategies in basketball players and its implications for ACL injury prevention: a randomized controlled trial

Anne Benjaminse¹,² · Bert Otten¹ · Alli Gokeler¹ · Ron L. Diercks³ · Koen A. P. M. Lemmink¹
Visuele Feedback

Modeling (expert or self)
Balans

Squat

Lunge

Double legged drop vertical jump

Sidestep cutting

Jump shot
Effect of video feedback on 2-dimensional landing kinematics in elite female handball players.

Anne Benjaminse, PhD*†; Wytze Postma, MSc*; Ina Janssen, PhD‡; Bert Otten, PhD*
Range of Motion over time
Visueele Feedback

EXPERT OR SELF-MODELING
Take Home Message 1

Literature review

Novel methods of instruction in ACL injury prevention programs, a systematic review

Anne Benjaminse, Wouter Welling, Bert Otten, Alli Gokeler

Retention & Transfer

Superior results EF vs IF:

- Performance
- Kinematics/Kinetics
- Electromyography
Mentaal motorisch leren

Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning

Gabriele Wulf¹ · Rebecca Lewthwaite²,³
MENTAAL MOTORISCH LEREN

- Self-controlled feedback (mode/frequency/timing)
- Motivation
- Active engagement
- Self-efficacy

Tailored towards athlete’s individual needs
Psychological needs of autonomy and competence
Return to sports

Feedback Techniques to Target Functional Deficits Following Anterior Cruciate Ligament Reconstruction: Implications for Motor Control and Reduction of Second Injury Risk

Alli Gokeler · Anne Benjaminse · Timothy E. Hewett · Mark V. Paterno · Kevin R. Ford · Egbert Otten · Gregory D. Myer
Waarom?
Younger Patients Are at Increased Risk for Graft Rupture and Contralateral Injury After Anterior Cruciate Ligament Reconstruction

Kate E. Webster, PhD, Julian A. Feller, FRACS, Warren B. Leigh, FRACS, and Anneka K. Fichermnd, BSc(Hons)

Investigation performed at Epworth HealthCare and LaTrobe University, Melbourne, Australia

< 20 YEARS

IPSILATERAL INJURY

Risk: ↑ 6

CONTRALATERAL INJURY

Risk: ↑ 3

29% # !!!!
Quadriceps function following ACL reconstruction and rehabilitation: implications for optimisation of current practices

Alli Gokeler · Marsha Bisschop · Anne Benjaminse · Greg D. Myer · Peter Eppinga · Egbert Otten

but...full recovery may not be achieved with current rehabilitation practices
motor learning

is alleen krachttraining voldoende als patiënten hun aangedane been ontzien... ?

Involved knee

Uninvolved knee
Contributions of neural excitability and voluntary activation to quadriceps muscle strength following anterior cruciate ligament reconstruction

Adam S. Lepley a,⁎, Hayley M. Ericksen a, David H. Sohn b, Brian G. Pietsimone c

a Department of Orthopedic Surgery, University of Toledo, Toledo, OH, United States
b Department of Exercise and Sport Science, University of North Carolina at Chapel Hill, Chapel Hill, NC, United States
c Musculoskeletal Health and Movement Science Laboratory, Department of Kinesiology, University of Toledo, Toledo, OH, United States

⁎ Corresponding author at: Joint Injury and Muscle Inhibition Laboratory, Department of Orthopedic Surgery, University of Toledo, Toledo, OH, United States

E-mail address: 

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http://dx.doi.org/10.1016/j.knee.2014.02.008
functional strengthening

so how can we tackle the problem of persistent quad weakness?

full extension is prerequisite
do we as PT’s provide the right stimuli to target asymmetries?
WE CANNOT SOLVE OUR PROBLEMS WITH THE SAME THINKING WE USED WHEN WE CREATED THEM

-Albert Einstein
Biomechanical Measures During Landing and Postural Stability Predict Second Anterior Cruciate Ligament Injury After Anterior Cruciate Ligament Reconstruction and Return to Sport

Mark V. Paterno,‡∥§∥‡∥ PT, MS, SCS, ATC, Laura C. Schmitt,‡∥§∥‡∥ PT, PhD, Kevin R. Ford,‡∥∥∥ PhD, FACSM, Mitchell J. Raun,‡∥ PT, PhD, MPH, FACSM, Gregory D. Myer,‡∥∥∥ MS, CSCS, Bin Huang,‡∥∥ PhD, and Timothy E. Hewett,‡∥∥∥ PhD, FACSM
An Anterior Cruciate Ligament Injury Prevention Framework: Incorporating the Recent Evidence

C. J. Donnelly\textsuperscript{a}, B. C. Elliott\textsuperscript{a}, T. R. Ackland\textsuperscript{a}, T. L. A. Doyle\textsuperscript{a}, T. F. Beiser\textsuperscript{b}, C. F. Finch\textsuperscript{c}, J. L. Cochrane\textsuperscript{d}, A. R. Dempsey\textsuperscript{a,e} & D. G. Lloyd\textsuperscript{a,f}
FEEDBACK
Durham Phys Ther Res 2009

KNEE POSITION

correct

incorrect

INTERNAL FOCUS
Negative Effects on Postural Control After Anterior Cruciate Ligament Reconstruction as Measured by the Balance Error Scoring System

Mason D. Smith and David R. Bell

*Journal of Sport Rehabilitation, 2013, 22, 224-228*
The Balance Error Scoring System (BESS) provides a portable, cost-effective and objective method of assessing static postural stability. The BESS can be used to assess the effects of mild head injury on static postural stability. Information obtained from this clinical balance tool can be used to assist clinicians in making return-to-play decisions following mild head injury. The BESS can be performed in nearly any environment and takes approximately 10 minutes to complete.

The balance testing regime consists of three tests on two different surfaces. The three tests are double leg stance, single leg stance and tandem stance. The two different surfaces include both a firm (ground) and foam surface. Athletes’ stance should consist of hands on the hips, eyes closed and a consistent foot position depending on the stance. Shoes should not be worn.

In the double leg stance, the feet are flat on the testing surface approximately pelvic width apart.

In the single leg stance position, the athlete is standing on the non-dominant leg with the contralateral limb held in approximately 20° of hip flexion, 45° of knee flexion and neutral position of the ankle joint.

In the tandem stance testing position, one foot is placed in front of the other with heel of the anterior foot touching the toe of the posterior foot. The athlete’s non-dominant leg is in the posterior position. Leg dominance should be determined by the athlete’s kicking preference.

Administrating the BESS: Establish baseline score prior to the start of the athletic season. After a concussive injury, re-test the athlete and compare to baseline score. Only consider return to activity if scores are comparable to baseline scores. Use with Standardized Symptom Scale Checklist.

Scoring the BESS: Each test is 20 seconds. Count the number of errors (deviations) from the proper stance. The examiner should begin counting errors only after the individual has assumed the proper testing position.

B.E.S.S. SCORECARD

<table>
<thead>
<tr>
<th>Double Leg Stance (Firm Surface)</th>
<th>Single Leg Stance (Firm Surface)</th>
<th>Tandem Stance (Firm Surface)</th>
<th>B.E.S.S. TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>First error</td>
<td>First error</td>
<td>First error</td>
<td>(Firm + Foam total)</td>
</tr>
<tr>
<td>Number of Errors</td>
<td>Number of Errors</td>
<td>Number of Errors</td>
<td></td>
</tr>
<tr>
<td>Total Score</td>
<td>Total Score</td>
<td>Total Score</td>
<td></td>
</tr>
</tbody>
</table>

Errors:
- Moving the hands off the hips
- Opening the eyes
- Step, stumble or fall
- Abduction or adduction of the hip beyond 30°
- Lifting the forefoot or heel off of the testing surface
- Remaining off the proper testing position for greater than 5 seconds

The maximum total number of errors for any single condition is 5.

If a subject commits multiple errors simultaneously, only one error is counted.

Aero™ Foam Balance Pads available at www.power-systems.com or through most sporting goods stores.
Feedback Techniques to Target Functional Deficits Following Anterior Cruciate Ligament Reconstruction: Implications for Motor Control and Reduction of Second Injury Risk

Alli Gokeler · Anne Benjaminse · Timothy E. Hewett · Mark V. Paterno · Kevin R. Ford · Egbert Otten · Gregory D. Myer
STANDING LONG-JUMP PERFORMANCE IS ENHANCED WHEN USING AN EXTERNAL FOCUS OF ATTENTION

Jared M. Porter,¹ Erik J. Ostrowski,¹ Russell P. Nolan,¹ and Will F.W. Wu²

Verbale Instructie
Increased Jump Height with an External Focus Due to Enhanced Lower Extremity Joint Kinetics

Gabriele Wulf, Janet S. Dufek
University of Nevada, Las Vegas.
Injury Mechanism #1

Game situation

Lab situation

Myer 2012
Anterior cruciate ligament injury alters preinjury lower extremity biomechanics in the injured and uninjured leg: the JUMP-ACL study

Benjamin M Goerger,1 Stephen W Marshall,2 Anthony I Beutler,3 J Troy Blackburn,4 John H Wilckens,5 Darin A Padua4
Anterior cruciate ligament injury alters preinjury lower extremity biomechanics in the injured and uninjured leg: the JUMP-ACL study

Benjamin M Goerger,1 Stephen W Marshall,2 Anthony J Beutler,3 J Troy Blackburn,4 John H Wilckens,5 Darin A Padua4
## Original Research

Effect of fatigue on landing performance assessed with the Landing Error Scoring System (LESS) in patients after ACL reconstruction. A pilot study.

*Authors: Gokeler A, Eppinga P, Dijkstra PU, Welling W, Padua DA, Otten E, Benjaminsen A*

<table>
<thead>
<tr>
<th></th>
<th>ACLR (N=12)</th>
<th>CTRL (N=10)</th>
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</thead>
<tbody>
<tr>
<td>Gender M/F</td>
<td>6/6</td>
<td>5/5</td>
</tr>
<tr>
<td>Age (Years)</td>
<td>27.4 ± 9.6</td>
<td>21.0 ± 0.8</td>
</tr>
<tr>
<td>Time post surgery (mo)</td>
<td>10.0 ± 2.4</td>
<td></td>
</tr>
<tr>
<td>Length (CM)</td>
<td>177.7 ± 7.4</td>
<td>179.1 ± 9.4</td>
</tr>
<tr>
<td>Mass (KG)</td>
<td>77.3 ± 12.5</td>
<td>72.6 ± 8.7</td>
</tr>
</tbody>
</table>
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Authors: Gokeler A, Eppinga P, Dijkstra PU, Welling W, Padua DA, Otten E, Benjaminse A
Development and Validation of a Clinic-Based Prediction Tool to Identify Female Athletes at High Risk for Anterior Cruciate Ligament Injury

Gregory D. Myer,1 MS, CSCS, Kevin R. Ford,1 PhD, FACSM, Jane Khoury,1 PhD, Paul Succop,1 PhD, and Timothy E. Hewett,1* PhD, FACSM

High KAM  > 21.74 Nm

JUST KNEE
Visueele feedback

Posterior view

External focus Modeling (expert or self)
Single leg hop tests conducted 6 months after ACL reconstruction can predict the likelihood of (un-)successful outcome (IKDC) 1 year after ACL reconstruction.
Original research

The effects of attentional focus on jump performance and knee joint kinematics in patients after ACL reconstruction

Alli Gokeler \textsuperscript{a,*}, Anne Benjamise \textsuperscript{a,b}, Wouter Welling \textsuperscript{a}, Malou Alferink \textsuperscript{a}, Peter Eppinga \textsuperscript{c,d}, Bert Otten \textsuperscript{a}

Materials & Methods

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Gender</th>
<th>Age (Y)</th>
<th>Mass (kg)</th>
<th>Length (cm)</th>
<th>Time since surgery (Monts)</th>
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<tbody>
<tr>
<td>Internal focus</td>
<td>8</td>
<td>4/4</td>
<td>23.75±4.46</td>
<td>73.75±10.32</td>
<td>180.10±7.53</td>
<td>5.0±3.45</td>
</tr>
<tr>
<td>External focus</td>
<td>8</td>
<td>3/5</td>
<td>22.63±6.02</td>
<td>76.50±12.02</td>
<td>181.25±7.70</td>
<td>6.4±6.44</td>
</tr>
</tbody>
</table>
Verbale instructie

Externe focus

Interne focus
Mechanisms for Noncontact Anterior Cruciate Ligament Injuries

Knee Joint Kinematics in 10 Injury Situations From Female Team Handball and Basketball

Hideyuki Koga, MD, PhD, Atsuc Nakamae, MD, PhD, Yosuke Shima, MD, PhD, Junji Iwasa, MD, PhD, Grethe Myklebust, PT, PhD, Lars Engebretsen, MD, PhD, Roald Bahr, MD, PhD, and Tron Krosshaug, PhD

IC 23°
Take Home Message 3

the knee is not normal after ACLR
Take Home Message 4

How I deal with my problems

MULTIVARIATE APPROACH KNEE AND PERSON