Player Surface Interaction: Injury and Performance

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Player Surface Interaction

- Injury
- Traction

- Performance
- Energy
Sport Surfaces and Injuries

Overuse and acute injuries

- non uniformity
- high stiffness
- minimal surface deformation
- insufficient friction
- excessive friction

⇒ Experimental evidence?
Soccer Injury

- Cutting and dribbling

- 2/3 of ACL injuries non-contact

Andreasson et al., 1986
Ekstrand and Nigg, 1989
## Tennis Injuries

<table>
<thead>
<tr>
<th>Surface</th>
<th>Frequency of pain [%]</th>
<th>Rel. Frequency of pain [%/hours/week]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>2.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Synthetic Sand</td>
<td>3.0</td>
<td>1.6</td>
</tr>
<tr>
<td>Synthetic Surface</td>
<td>10.7</td>
<td>3.0</td>
</tr>
<tr>
<td>Asphalt</td>
<td>14.5</td>
<td>3.9</td>
</tr>
<tr>
<td>Felt Carpet</td>
<td>14.8</td>
<td>4.8</td>
</tr>
<tr>
<td>Synthetic Grill</td>
<td>18.0</td>
<td>3.8</td>
</tr>
</tbody>
</table>

Nigg et al., 1980
Traction and Injuries

Torg and Quedenfeld, 1971-1974

- Quantified number and severity of knee and ankle injuries in American Football
- 4 seasons first season - 7 stud football shoe following seasons - 15 stud soccer shoe
## American Football Injury

<table>
<thead>
<tr>
<th></th>
<th>Football shoe</th>
<th>Soccer shoe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Injuries/team/game</td>
<td>Injuries/team/game</td>
</tr>
<tr>
<td>Public league</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee</td>
<td>0.33</td>
<td>0.14-0.17</td>
</tr>
<tr>
<td>Catholic league</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee</td>
<td>0.58</td>
<td>0.22-0.24</td>
</tr>
<tr>
<td>ankle</td>
<td>0.45</td>
<td>0.23-0.25</td>
</tr>
</tbody>
</table>

Torg and Quedenfeld, 1971
American Football Injury

• Rotational traction
• Release coefficients on grass

Football shoe: \(0.55 \pm 0.06\)
Soccer shoe: \(0.28 \pm 0.03\)

Torg and Quedenfeld, 1974
American Football - Traction

Release Coefficients 0.60

- Not safe
  - football shoes
    - 0.55 - 0.06 = 0.49

- Probably not safe
  - soccer shoes
    - 0.28 + 0.03 = 0.31

- Probably safe

- Safe

Torg and Quedenfeld, 1974
Traction and Injury

Lambson et al., 1996

- Quantified ACL injuries in American Football
- 3 seasons Prospective
- 4 shoe conditions
# Traction and Injury

<table>
<thead>
<tr>
<th>Shoe</th>
<th>ACL Tears</th>
<th>Injury Rate</th>
<th>Art. Turf Torque [Nm]</th>
<th>Nat. Turf Torque [Nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edge</td>
<td>38</td>
<td>0.017</td>
<td>52.0</td>
<td>31.0</td>
</tr>
<tr>
<td>Flat</td>
<td>3</td>
<td>0.004</td>
<td>40.0</td>
<td>25.5</td>
</tr>
<tr>
<td>Screw in</td>
<td>1</td>
<td>0.015</td>
<td>35.0</td>
<td>24.0</td>
</tr>
<tr>
<td>Pivot disk</td>
<td>0</td>
<td>0.000</td>
<td>38.5</td>
<td>21.5</td>
</tr>
</tbody>
</table>

Lambson et al., 1996
Factors Affecting Traction

- Not Coulomb friction (e.g. Van Gheluwe et al., 1983; Valiant et al., 1985; etc.)
- Relative velocity
- Normal force
- Surface contact area
Influence of Surface

Translation friction coefficient

\[ M_{\text{max}} \text{ [Nm]} \]

infilled turf surfaces
running shoe

HPL - Calgary
Sport Surfaces Research Forum
Influence of Surface

Translation friction coefficient

infilled turf surfaces
soccer shoe

$M_{\text{max}}$ [Nm]
Traction and Internal Loads

Joint loading ultimately plays a functional role in the development of sport injuries.
Knee Joint Moments

Sagittal  Frontal  Transverse

Flexion-extension  Ab-adduction  Rotation
PFPS Retrospective Study

Two groups of runners

Group 1 (n=20) positive PFPS diagnosis

Group 2 (n=20) never diagnosed with PFPS
External Rotation Knee Moment
Retrospective

- Asymp
- PFPS

Moment [Nm]

Time [% of stance]

50 100

0 25 50 75

-25 -50
Abduction Knee Moment Retrospective

- Asymp
- PFPS

Moment [Nm]

Time [% of stance]
Retrospective PFPS

- Maximal external rotation moments were 8 Nm (22%) higher for injured runners

- Maximal abduction moments were 24 Nm (20%) higher for injured runners
Prospective Running Study

• 145 runners
• Bilateral data collected at beginning of running season
• Shod and barefoot
• Injury data collected over 6 month running season
Prospective PFPS

- 6 subjects diagnosed with PFPS

- Physical examination criteria

- None had previous PFPS
Prospective PFPS

• 2 to 1 matched with uninjured subjects
  - gender
  - weekly running distance
  - years of running experience
  - mass

• 3-dimensional knee joint moments
External Rotation Knee Moment
Prospective

Moment [Nm]

Asymp
PFPS

Time [% of stance]
Abduction Knee Moment
Prospective

Moment [Nm]

Time [% of stance]

Asymp
PFPS
Prospective PFPS

• Maximal external rotation moments were 9 Nm (90%) higher for injured runners

• Maximal abduction moments were 25 Nm (65%) higher for injured runners
Knee Moments and Injury

Hewett et al. 2005
- Prospective study
- Female ACL injury
- 205 subjects

Mizuno et al. 2004
- Adduction and rotational moments result in high ACL strain
Sport Surfaces - Joint Moments

- 5 indoor sport surfaces
- 21 subjects
  - 11 male 10 female
- Three movements
  - shuffle, vcut, run shuffle
- Standard court shoe
Knee Moments

Side Shuffle

Knee Extension Moment [Nm]

Normalized Time

Surface 1
Surface 2
Surface 3
Surface 4
Surface 5

Knee Rotation Moment [Nm]

Normalized Time

External
Internal

Knee Adduction Moment [Nm]

Normalized Time

Adduction

Knee Adduction Moment [Nm]

Normalized Time

Adduction

Normalized Time

Adduction

Normalized Time

Adduction

Normalized Time

Adduction

Normalized Time

Adduction

Normalized Time

Adduction
Forces
Side Shuffle

Force (vertical) [N]

Force (medio-lateral) [N]

Force (a-p) [N]

Normalized Time

Surface 1
Surface 2
Surface 3
Surface 4
Surface 5
Influence of Surface

\[ F_{\text{vertical}} \]

\[ F_{\text{resultant}} \]

\[ F_{m-l} \]

Surface 5

Surface 1
Translational Friction

Knee moments

External Rotation Moment [Nm]

Adduction Moment [Nm]

R² = 0.02

R² = 0.03
Rotational Friction

Knee moments

External Rotation Moment [Nm]

Adduction Moment [Nm]

\[ R^2 = 0.33 \]

\[ R^2 = 0.28 \]
Higher Friction
\[ \mu = 1.79 \]
Surface 1

Lower Friction
\[ \mu = 1.36 \]
Surface 2

movement
Soccer Shoes

- adidas Nova running
- adidas Copa
- adidas World Cup
- adidas TRX
Methods

- 12 recreational soccer players
- Two movements
  running cut, 180° turn
- Infilled artificial turf
- Kinetics and kinematics
Methods - Traction

6-DOF Stewart platform
Rotational Traction

Moment [Nm]

Nova  Copa  World  Trx
Cut – Knee Joint Moments

Knee Joint Moments [Nm]

Adduction

Rotation

Nova  Copa  World  Trx  Nova  Copa  World  Trx
Linear Traction – Knee Moments

Knee Joint Moment [Nm]

Linear coefficient

Knee adduction

Knee rotation

Cut

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180° Turn – Knee Joint Moments

Knee Joint Moments
[Nm]

Adduction

Rotation

Nova   Copa   World   Trx   Nova   Copa   World   Trx
Linear Traction – Knee Moments

Knee Joint Moment [Nm]

Linear coefficient

Knee rotation

Knee abduction

180° turn

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Rotational Traction–Knee Moments

Knee Joint Moment [Nm]

60

40

20

0

5 10 15 20

Rotational Traction Moment [Nm]

180° turn

Knee abdication

Knee rotation

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Soccer Cleat Summary

- Cleats only had a significant effect during **rotational movement**
- Rotational and possibly translational traction seem to affect knee joint moments
Injury Summary

• Traction plays a large roll
  – Rotational and possibly translational

• Influences joint moments

• Surfaces have large influence

• Rotational movements important

• Needs to be studied further
Energy

The ability to do work.

More work $\Rightarrow$ throw farther
$\Rightarrow$ skate faster
$\Rightarrow$ jump higher

Energy $\Rightarrow$ Work $\Rightarrow$ Performance
Energy and Performance

- Maximize energy return
- Minimize energy lost
- Optimize muscular output

Nigg and Segesser, 1992; Nigg, 2000
Energy and Performance

- Maximize energy return
- Minimize energy lost
- Optimize muscular output

Nigg and Segesser, 1992; Nigg, 2000
Maximizing Energy Return

Energy transfer in sports

body → foot → shoe → surface

and eventually

surface → shoe → foot → body
Energy Return

\[ E_{\text{returned}} = E_{\text{input}} - E_{\text{lost}} \]
Energy Input

\[ W_{\text{athlete}} = \int \vec{F} \cdot d\vec{r} = \Delta E_{\text{surface}} \]

\[ E_{\text{surface}} = \frac{1}{2} k x^2 \]

- deformation
- stiffness
## Energy Input

<table>
<thead>
<tr>
<th>Surface</th>
<th>Approx Stiffness [N/m]</th>
<th>Deform [m]</th>
<th>Energy [J]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tumbling floor</td>
<td>50000</td>
<td>0.100</td>
<td>250</td>
</tr>
<tr>
<td>Gymnastic floor</td>
<td>120000</td>
<td>0.050</td>
<td>150</td>
</tr>
<tr>
<td>Running track</td>
<td>240000</td>
<td>0.010</td>
<td>12</td>
</tr>
<tr>
<td>Gymnasium floor</td>
<td>400000</td>
<td>0.005</td>
<td>5</td>
</tr>
</tbody>
</table>
Energy Lost

![Diagram showing energy input, returned, and lost with respect to force and deformation.](image-url)
Energy Lost - Surfaces

Energy Loss [%]

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infilled Turf</td>
<td>80</td>
<td>100</td>
<td>100</td>
<td>80</td>
<td>60</td>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>Point Elastic</td>
<td>80</td>
<td>100</td>
<td>80</td>
<td>60</td>
<td>40</td>
<td>20</td>
<td>0</td>
</tr>
</tbody>
</table>
Criteria for Energy Return

- Large enough to influence performance
- Returned at the
  - right location
  - in the proper direction
  - at the appropriate time
  - with the right frequency

Nigg and Segesser, 1988
Right Location and Direction

Anterior – posterior force

Normalized time

25 50 75 100
Right Frequency

Deformation

\[ E_{\text{input}} \quad E_{\text{return}} \]

Sprinting

Time [s]

0.1

0.2

EEinputinput

EEreturnreturn

Sprinting
Tuned Indoor Track

- McMahon and Greene 1978, 1979
- Optimal stiffness dependent on runner’s lower leg stiffness
- Increased performance 2-3%

Outdoor tracks?
Current Outdoor Track Surfaces

Given subsurface
Solid - thin
Homogeneous
Isotropic
Sport Surfaces

$S_1$, $S_2$, $S_3$, $S_4$, $S_5$

running direction

(Baroud, Nigg and Stefanyshyn, 1999)
Conventional Surface

S_1

running direction
Conventional Surface

Energy production [J]

Time [msec]

$E_{\text{input}}$

$E_{\text{return}}$

$E_{\text{lost}}$

$S_1$
Structured Surface

$S_5$

running direction

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Benno M. Nigg, Director

HPL - Calgary
Structured Surface

Energy production [J]

Time [msec]

Energy production [J]

$E_{\text{input}}$

$E_{\text{return}}$

$E_{\text{lost}}$

conventional surface
Energy Return [J]

Mechanical energy 500 J per stride
Nigg and Segesser, 1992

(Baroud, Nigg and Stefanyshyn, 1999)
Right Direction

end of stance  middle of stance  beginning of stance
Maximizing Energy Return

Energy transfer in sports

body → foot → shoe → surface

and eventually

surface → shoe → foot → body
Surfaces and Shoes

Running direction

\[ S_1 \quad S_2 \quad S_3 \]

\[ S_4 \quad S_5 \quad S_{11} \quad S_{52} \]
Energy Return [J]

- 3% in Running
- 2%
- 1%

Add shoe!
FE Model Limitations

• Linear material model
• Only one material
• Only one set of input forces
• Arbitrarily selected structural shapes
• Not validated
Energy Return

- Large enough to influence performance
- Returned at the
  - right location
  - in the proper direction
  - at the appropriate time
  - with the right frequency

Nigg and Segesser, 1988
Energy/Performance in Surfaces

Relevant in:

• Tumbling floors
• Gymnastics
• Indoor tracks
• Outdoor tracks
Acknowledgements

Thank you