OUT OF THE LAB AND INTO THE WOODS:

KINEMATIC ANALYSIS IN RUNNING USING WEARABLE SENSORS

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ABOUT 65 % OF RUNNERS ARE INJURED IN AN AVERAGE YEAR.[2]

INJURIES IN RUNNING ARE OFTEN PROVOKED BY FATIGUE OR IMPROPER TECHNIQUE, WHICH ARE BOTH REFLECTED IN THE RUNNER'S KINEMATICS.

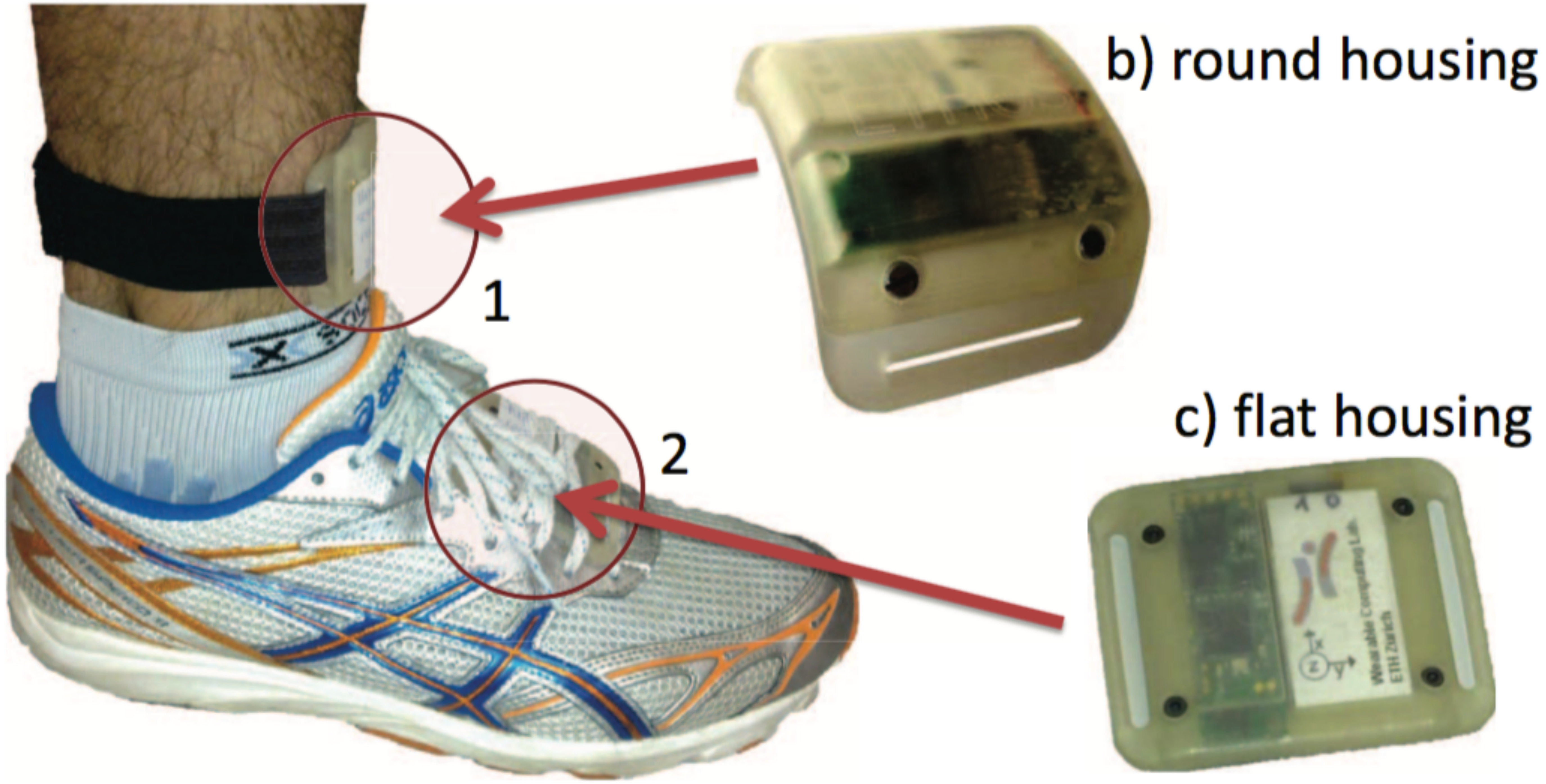
CURRENT RESEARCH ON KINEMATICS IN SPORTS IS USING "OPTICAL MOTION CAPTURE SYSTEMS" – INACCESSIBLE TO MOST ATHLETES, BECAUSE EXPENSIVE AND REQUIRES CONTROLLED ENVIRONMENT.

TEAM DEVELOPED A SMALL AND LIGHTWEIGHT INERTIAL MEASUREMENT UNIT (IMU), SPECIFICALLY OPTIMIZED FOR LONG-TERM, OUT OF THE LAB MEASUREMENTS.

EXTRACTED KINEMATIC FEATURES FROM THE SENSORS TO ASSESS THE THREE MAIN APPLICATION AREAS :

- SKILL LEVEL ASSESSMENT
- FATIGUE MONITORING,
- TRAINING ASSISTANCE.

FROM THE OBSERVATIONS IT WAS FOUND THAT KINEMATIC FEATURES FROM TWO SENSORS, ON THE FOOT AND ON THE SHIN, SUFFICE TO COVER THESE.



SENSOR SETUP

SENSORS USED : ETHOS

- ETHOS is an inertial measurement unit.
- Compromises of: a 3D accelerometer, a 3D gyroscope, and a 3D magnetic field sensor.
- Microprocessor: 16-bit dsPIC.
- Data storage in a 2GB memory card.
- In a typical ETHOS use case, in which data are sampled at a frequency of 128 Hz and stored locally, a system runtime of seven hours is achieved.
- The orientation is calculated from sensor data by fusing acceleration, gyroscope, and magnetic field data.

METHOD OF EVALUATION : EXPERIMENT DESIGN

Skill Level Group	training [km/week]	speed [km/h]	number of subjects
beginner	0-5	9-10.5	6
Intermediate	5-25	10.5-12	6
Advance	25-45	12-14.5	6
Expert	>45	14.5-17.8	3

- Data used for assessment of kinematic parameters was recorded during a 45 min run on an outside track.
- 21 healthy subjects (13 men, 8 women) with an average age of 33.8 ± 8.4 years participated in the experiment.
- Chosen participants showed a balanced skill level distribution ranging from beginners to competitive runners.

EXPERIMENT DESIGN

- Subjects were instructed to maintain a speed of 75–85 % of their maximum aerobic speed to provoke a change in running kinematics due to fatigue.
- Maximum aerobic speed was conducted preliminary to the study in a standardised endurance test on a treadmill.

AFTER THE RUN

DATA ANALYSIS

1. NFC: NORMALISED FOOT CONTACT DURATION
2. FOOT STRIKE TYPES
3. HEEL LIFT

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1. NFC: NORMALISED FOOT CONTACT DURATION

- NFC: normalized foot contact duration. It denotes the percentage of time one foot is on the ground during one step cycle. It decreases with increasing skill level, since shorter contact allows for faster running

- The beginner's NFC showed greater variations throughout the run compared to the expert, and increases over time, probably due to fatigue.

- From GPS measurements it was observed that the beginner runner was not able to maintain her individual speed. Since step duration was kept stable, it was concluded that flying phase was shortened.

- Results indicated that an analysis of the normalized foot contact duration shows potential for skill level assessment and fatigue monitoring.

1. NFC: NORMALISED FOOT CONTACT DURATION
2. FOOT STRIKE TYPES
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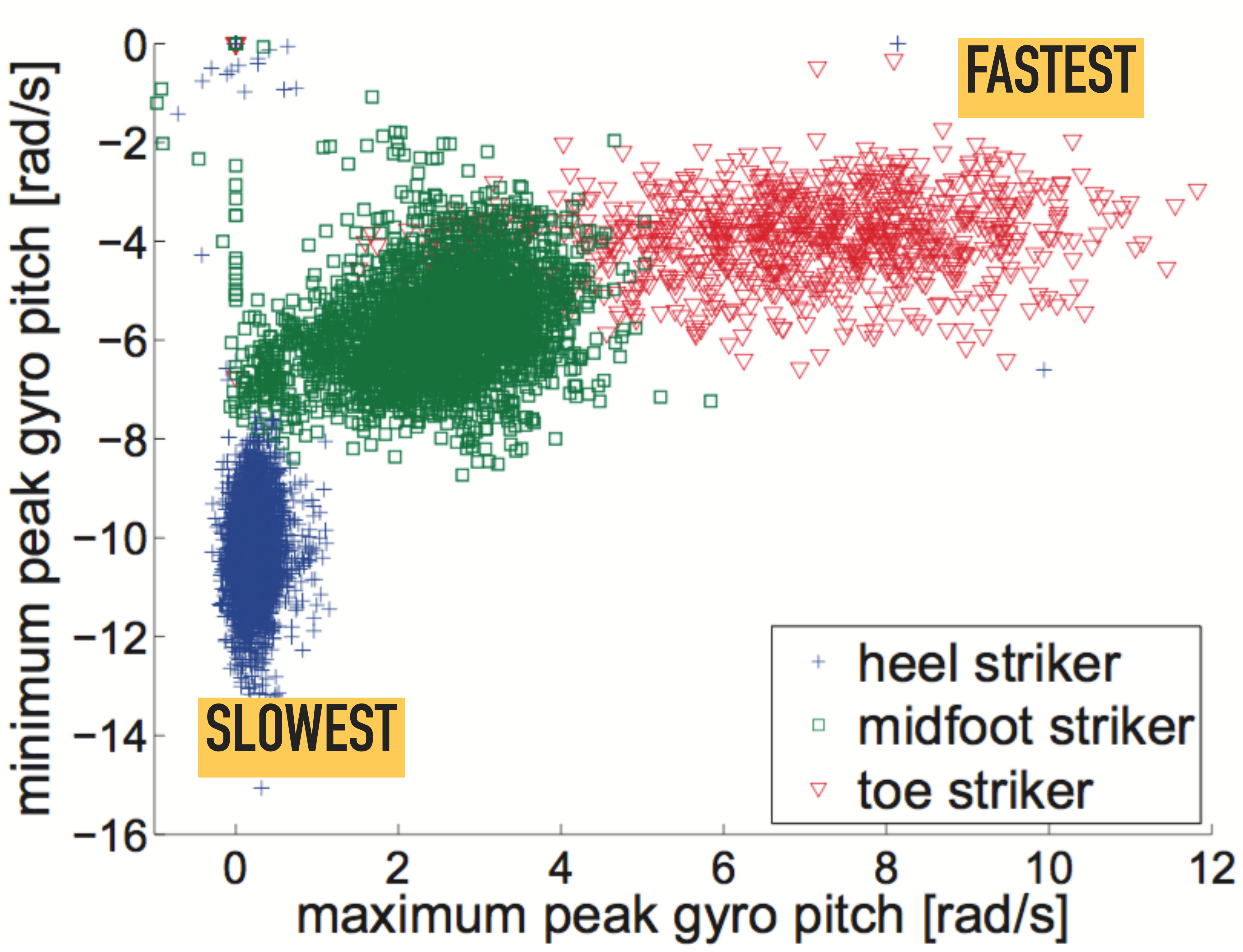
2. FOOT STRIKE TYPES

- Three different foot strike types are common, named after the part of the foot that touches the ground first: (1) heel, (2) midfoot, or (3) toe strike.
- Each of the strike types has advantages and disadvantages. Heel strikers have less stress on their calves and Achilles tendon but are slowed down. As the knee is not bent during the strike it experiences high impact stresses, which promotes injuries over time.
- Midfoot runners experience more stress on the calves and Achilles tendon but absorb shock better since the knee is bent. Most long distance runners are midfoot runners.
- Toe striking contributes to a better form and faster running but it keeps calf muscles contracted contributing to various injuries. However, toe strikers experience less stress on knees and ankles.

2. FOOT STRIKE TYPES

- The analysis of the foot strikes was performed stepwise based on the gyroscope data recorded by the right foot mounted sensor.



- This trend indicated muscle fatigue and could be utilised for retrospective assessment of the training quality.
- We conclude that foot strike type analysis enables training assistance and fatigue monitoring.

1. NFC: NORMALISED FOOT CONTACT DURATION
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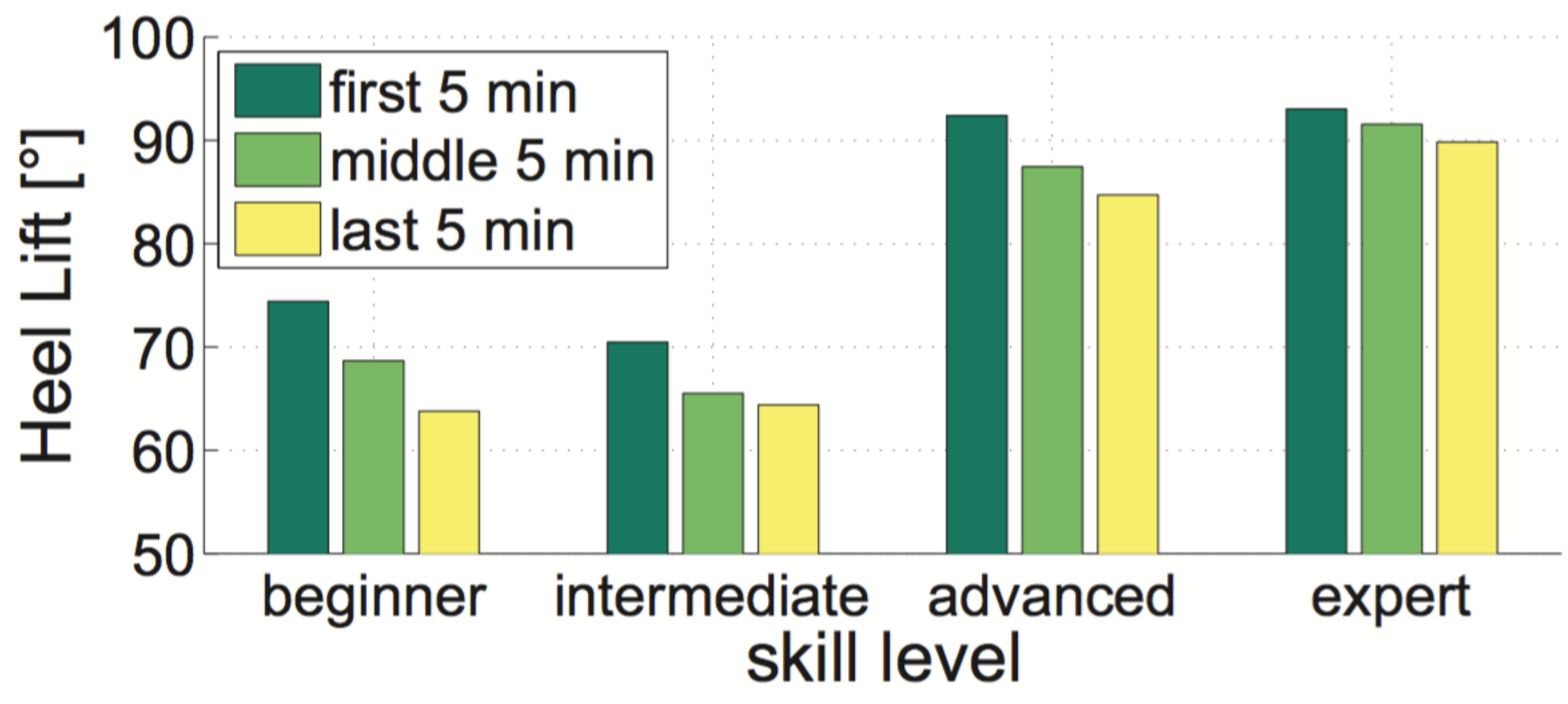
3. HEEL LIFT

- The Heel Lift (HL) denotes the amount of foot lifting, i.e; flection of the knee during the swing phase.

- An increased heel lift decreases the effective leg length, leading to a decreased moment during forward swing. Research concluded that high heel lift allows for energy efficient and fast running. It is shown that heel lift increases with speed, and tends to decrease during exhaustive runs owing to muscle fatigue.

- An angle of 0○ equals normal standing, i.e. the shin is vertical to the ground.

3. HEEL LIFT

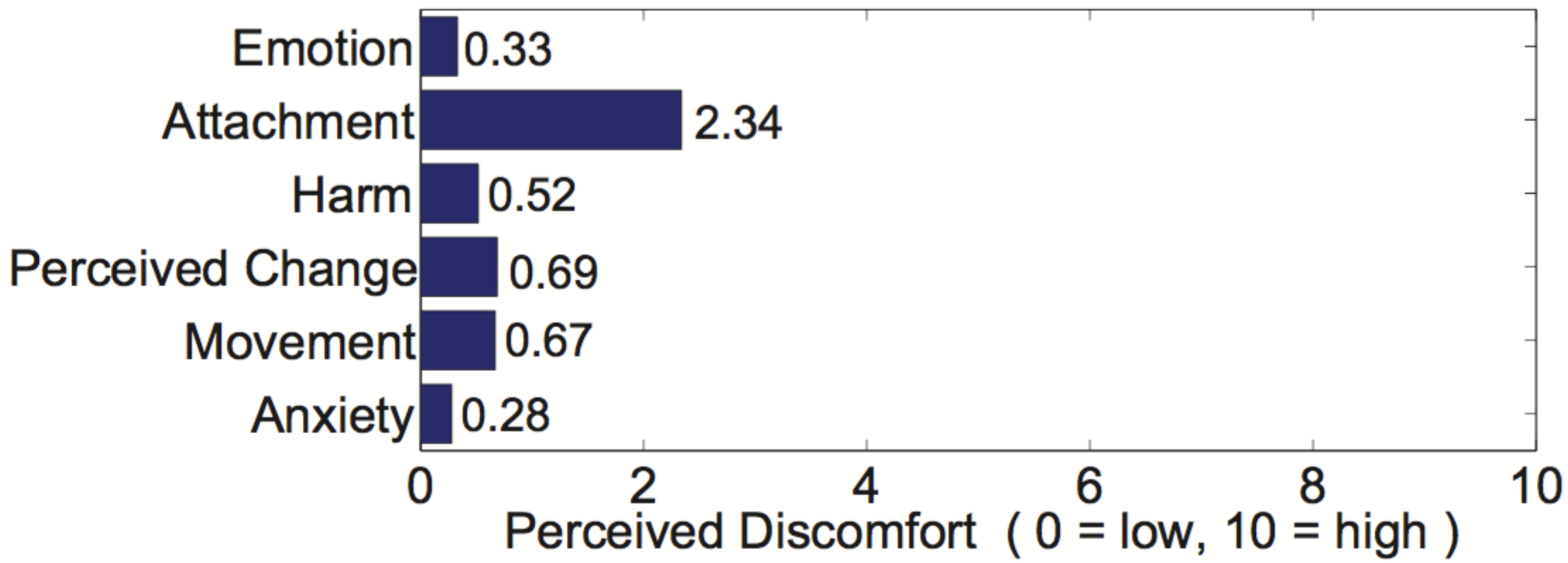


- The bars indicate that participants of higher skill level groups performed heel lift to a greater extent.
- Independent of the skill level, heel lift decreased through the course of the run due to progressive muscle fatigue.

FEEDBACK ON SENSOR WEARABILITY

- Subsequently to the experiments all subjects were asked to complete a questionnaire concerning wearability of sensors.
- Evaluation was based on the Comfort Rating Scales (CRS) introduced by Knight et al.
- Subjects graded the following aspects from 0 (low) to 10 (high)

FEEDBACK ON SENSOR WEARABILITY



- **Emotion**: I am worried about how I look when I'm wearing this device. I feel tense or on edge because of wearing the device.
- **Attachment**: I can feel the device on my body. I can feel the device moving.
- **Harm**: The device is causing me some harm. The device is painful to wear.
- **Perceived Change**: Wearing the device makes me feel physically different. I feel strange wearing the device.
- **Movement**: The device affects the way I move. The device inhibits or restricts my movements.
- **Anxiety**: I do not feel secure wearing the device.

CONCLUSION FROM THE CRS :

ETHOS UNITS WERE PERCEIVED AS COMFORTABLE TO WEAR, AND DID NOT CONSTRAIN MOVEMENTS OF THE SUBJECTS DURING RUNNING.

USER ACCEPTANCE COULD POSSIBLY BE FURTHER IMPROVED BY REMOVAL OF SPARE SENSORS OR INTEGRATING SENSORS IN SHOES OR CLOTHES.

USING WEARABLE DEVICES ENABLES A TRANSITION FROM SUBJECTIVE SELF-ASSESSMENT TO OBJECTIVE ASSESSMENT.

THE AUTOMATICALLY CALCULATED PARAMETERS CAN BE PROVIDED TO DOCTORS OR ATHLETES FOR POST TRAINING ANALYSIS.

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