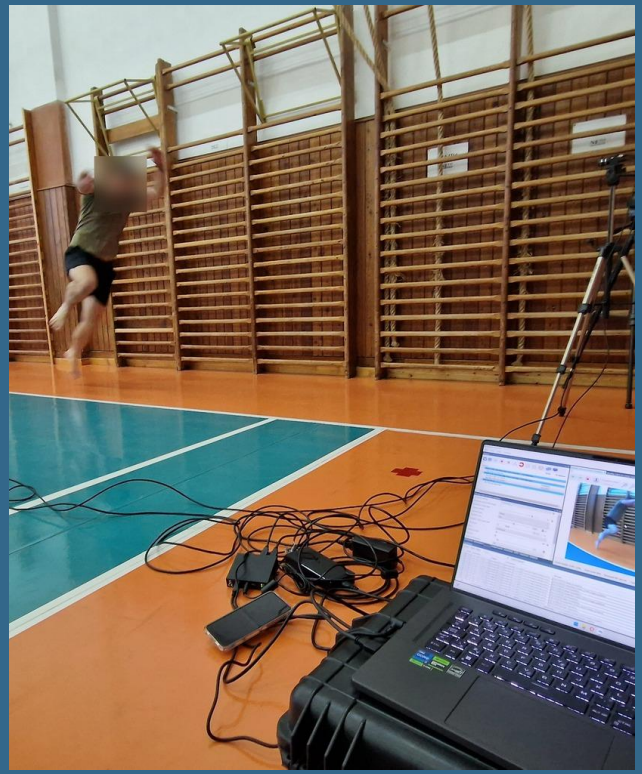
Portable Vision-Based Assessment of Movement Quality

P.Kutílek; J. Hejda; M. Sokol; P. Volf; L. Leová;
A. G. Fischer; L. Radus

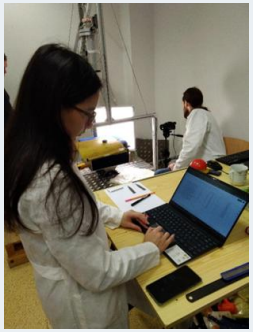


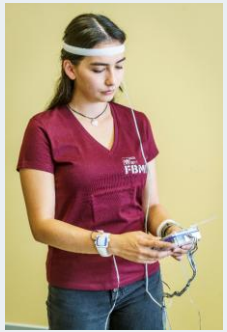
Biomechanics and Assistive Technologies Research group

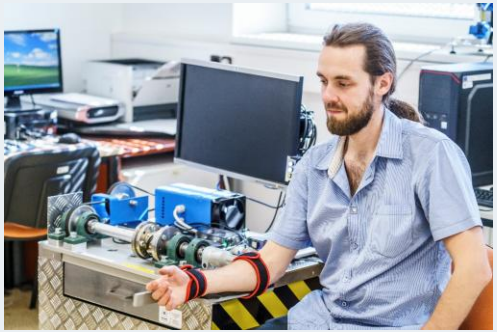
Czech Technical University

BAT is a multidisciplinary team developing and applying assistive technologies.









Bilateral project

MŠMT INTER-EXCELLENCE II / INTER-ACTION, August 2024–July 2027

CTU and Technion – Israel Institute of Technology
BioMotion Lab, Arielle Fischer, PhD

Project goal

Reduce musculoskeletal injury risk in military personnel, first responders and athletes.

Methods

AI-based movement and ECG assessment, complemented by questionnaires.

Target output: portable measurement hardware and AI software for individual training and rehabilitation.

System selection

Technology	Measurement target	Study role
Camera systems	Landmarks, 2D angles and movement timing	Core analysis: push-ups and hops
Inertial systems (IMU)	Acceleration and angular motion	For synchronization
Force platforms	Ground reaction forces and centre of pressure	Reference measurements for future validation
Physiological systems	Muscle activity (EMG) and cardiac signals (ECG)	Broader context for future field studies

Motion capture in the lab and field

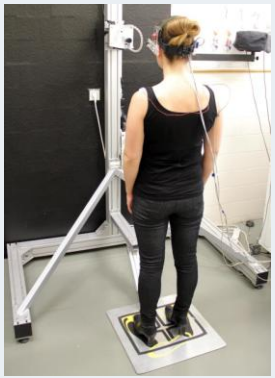
Body movement assessment in the laboratory

Body movement assessment outside the laboratory

Stationary

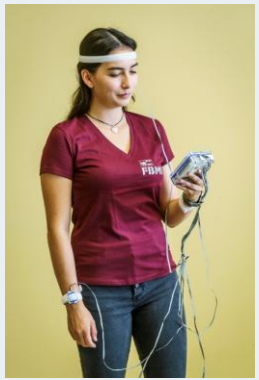
Portable

Wearable



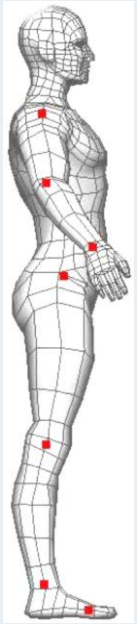
Camera and accelerometer measurements at Motol University Hospital, Prague

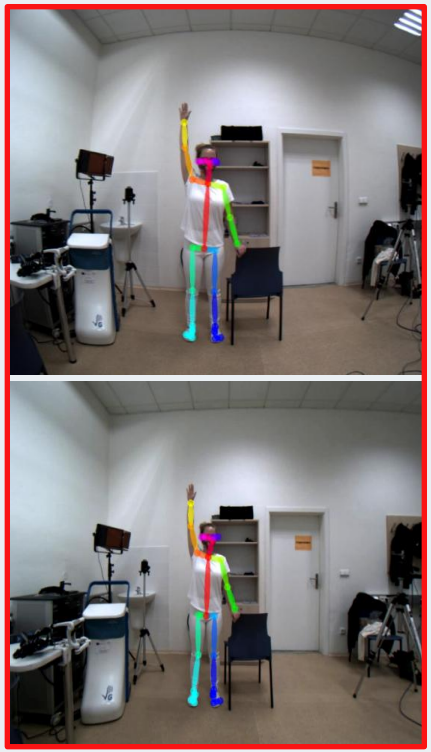




Camera and accelerometer measurements at the Czech Army Sport Research Institute

Camera-based motion analysis





Calibration and recording

Movement parameter extraction

Min, max,
ROM, SD

SW

Derived
metrics

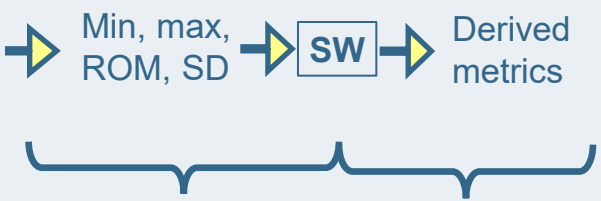
Kinematic
descriptors

Mechanical estimates
require models or
additional sensors

Inertial motion analysis



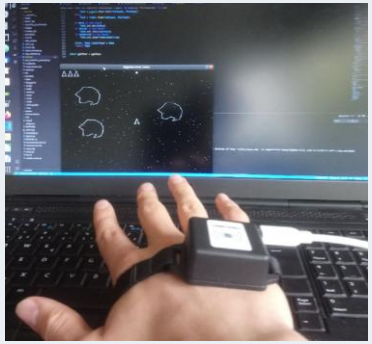
Movement parameter extraction



Multiple sensors: clinical movement analysis
Single sensor: wearable monitoring



CTU accelerometer system for fast movements at 3 kHz, including tremor and falls.



Laboratory and field constraints

Laboratory	Field (this study)
one person in view	**staff and assistants in view (cameras)**
controlled background	**changing environment**
setup without time pressure	**setup inside a running test session**
trials repeated on demand	**one recording per participant and task**

Field protocol and camera setup



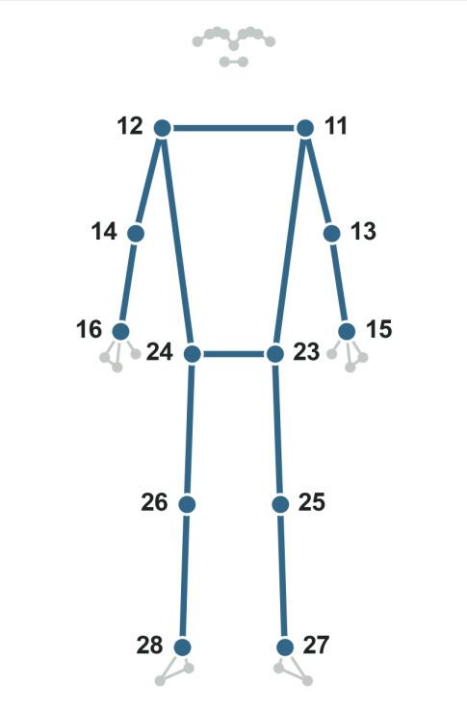
Hop trial: two tripod cameras, trigger cabling, live capture

Cameras	2 × FLIR Blackfly S (BFS-U3-23S3C-C), 2.3 MP colour
Optics	Thorlabs MVL4WA, 3.5 mm wide-angle
Trigger	GPIO master/slave trigger for frame-level exposure synchronization
Rate	50 Hz on both cameras (20 ms per frame)
Geometry	Frontal and sagittal views Approx. 2.5 m distance, 1.2 m height

10 male soldiers
Age 18–23 years

Push-ups, 30 s | **Single-leg hops** | **Shuttle run: turn only** | **1 km run: no camera**

Pose landmarks used in this study

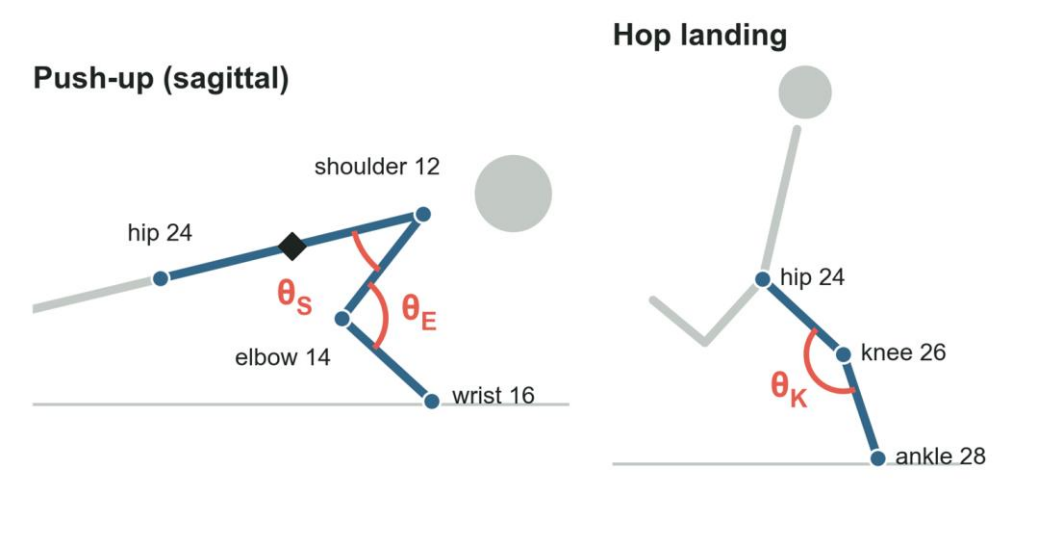


MediaPipe Pose Landmarker, Full model (12 of 33 points)

Landmark	Index (L / R)	Used for
Shoulder	11 / 12	θE, θS, torso centre
Elbow	13 / 14	θE, θS
Wrist	15 / 16	θE
Hip	23 / 24	θS, θK, torso centre, tracking
Knee	25 / 26	θK, landing-limb tracking
Ankle	27 / 28	θK, landing-limb tracking

- Per frame: pixel x, y, normalised x, y and visibility $v \in [0, 1]$
- Landmarks approximate body locations rather than anatomical joint centres

Joint angles from 2D coordinates



$$\theta = \arccos[(u \cdot v) / (\|u\| \, \|v\|)]$$

$u = A - B$, $v = C - B$, vertex B

$\theta \in [0, 180°]$

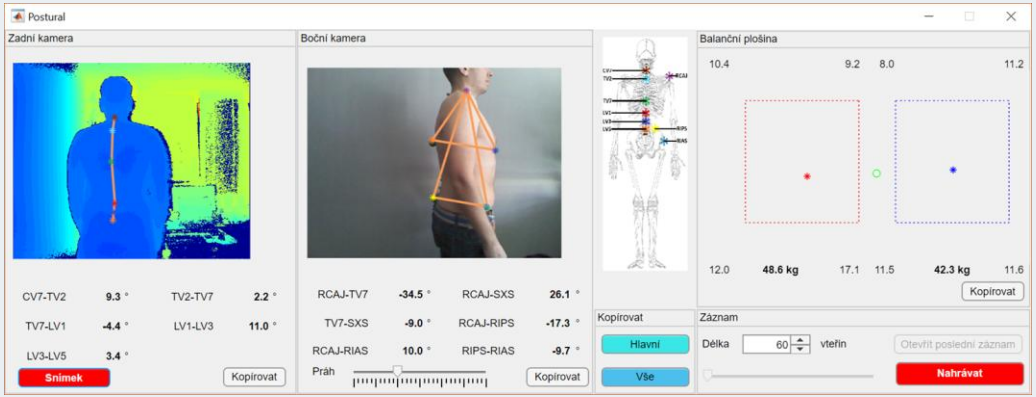
Angle	A – B – C
θE elbow	shoulder – elbow – wrist
θS shoulder	hip – shoulder – elbow
θK knee	hip – knee – ankle

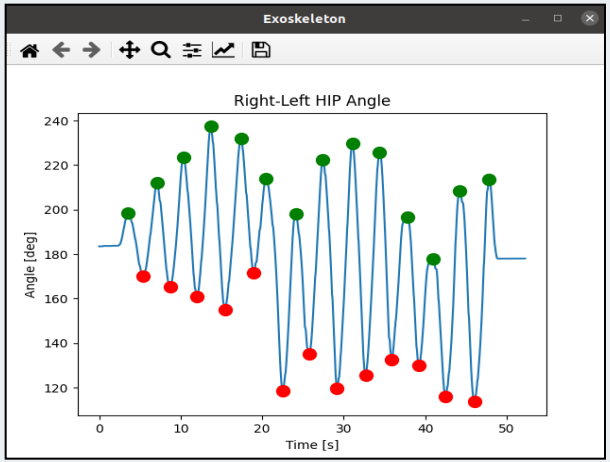
Image-plane angles depend on camera viewpoint and out-of-plane motion.

Movement analysis methods

I. Postural control

II. Movement → Cyclic
→ Non-cyclic



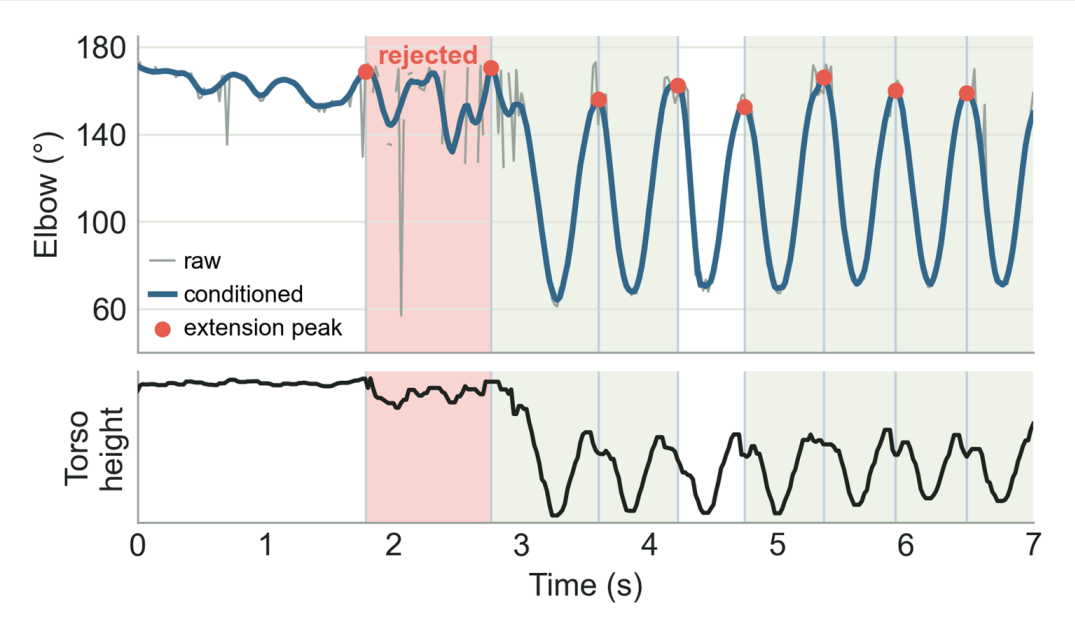


- Time-domain analysis
- Frequency-domain analysis
- Dependencies between signals
- Nonlinear analysis

Analysis methods by task

Task	Analysis methods
Postural control (capability)	Time and frequency analysis Dependencies
Push-ups (cyclic movement)	Range of motion (ROM), duration and variability
Hops (individual events)	Time analysis, duration and variability

Signal conditioning and cycle detection

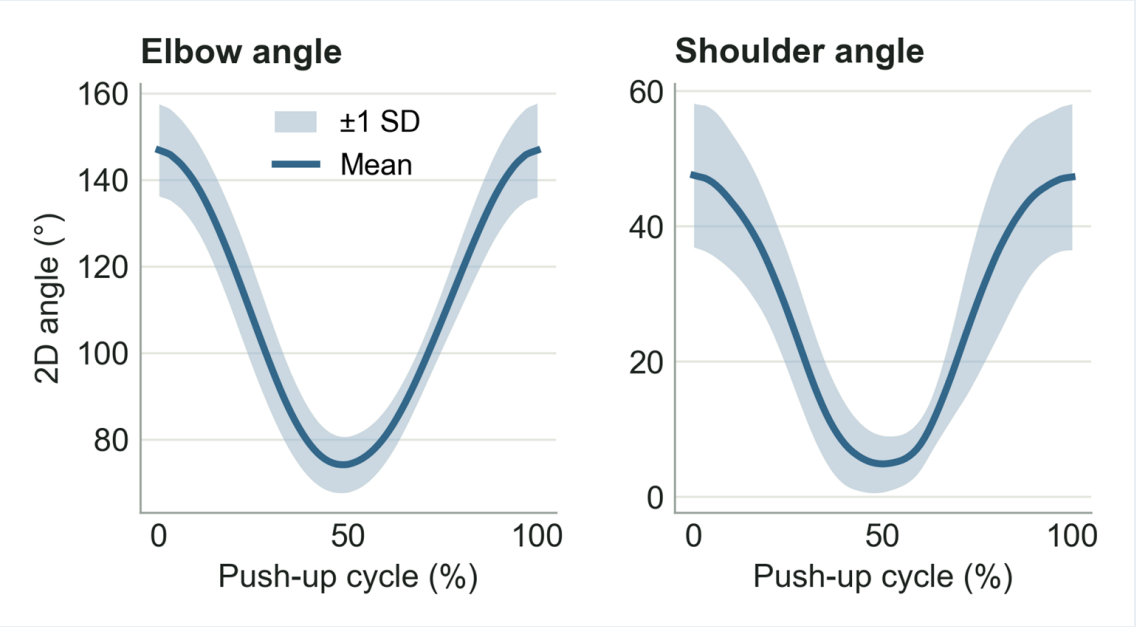


Example: raw and conditioned elbow angle, with torso height. Red marks the cycle rejected by the motion gate.

Conditioning

- Interpolate gaps ≤5 frames (100 ms)
- Median filter: 5 frames

Push-up results



Mean ± 1 SD across 10 recordings, resampled to 101 cycle points.

0.69 s median cycle duration
IQR 0.68–0.72 s

72.2° θE range of motion
IQR 68.9–78.7°

43.8° θS range of motion
IQR 38.0–49.7°

ROM = P95 − P5 per cycle
Summaries: trial medians, n = 10

404 accepted cycles from 405 candidates in 10 recordings

Hop knee kinematics

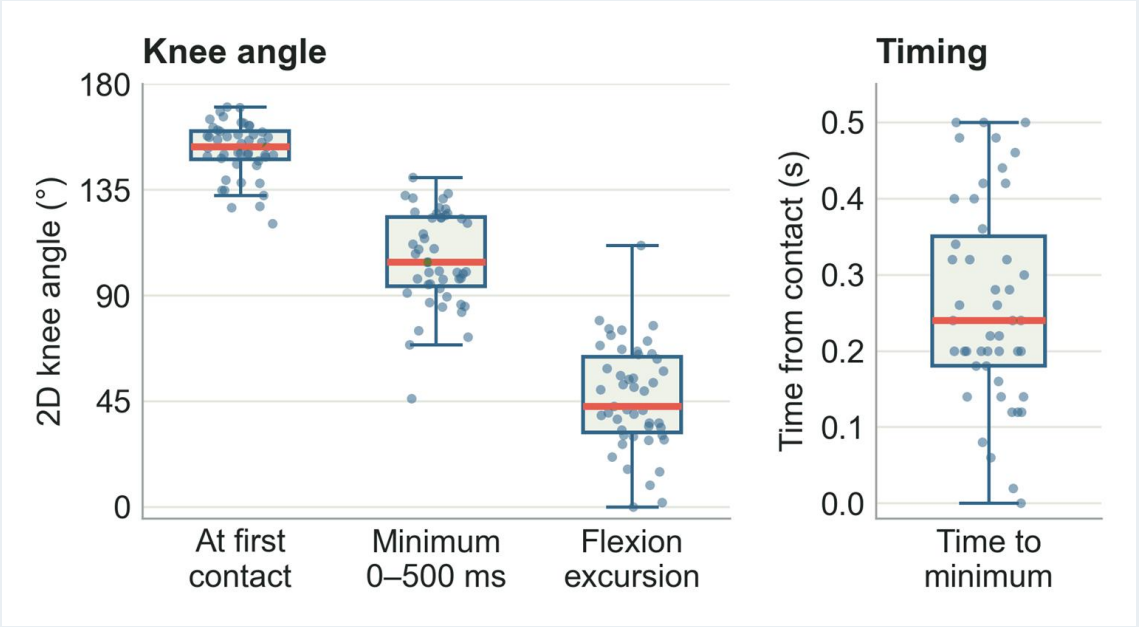
Median (IQR), 47 accepted hops

153° θK,c at contact
IQR 148–160°

104° θK,min, 0–500 ms
IQR 94–123°

43° Δθ = θK,c − θK,min
IQR 32–64°

0.24 s Time to θK,min
IQR 0.18–0.35 s

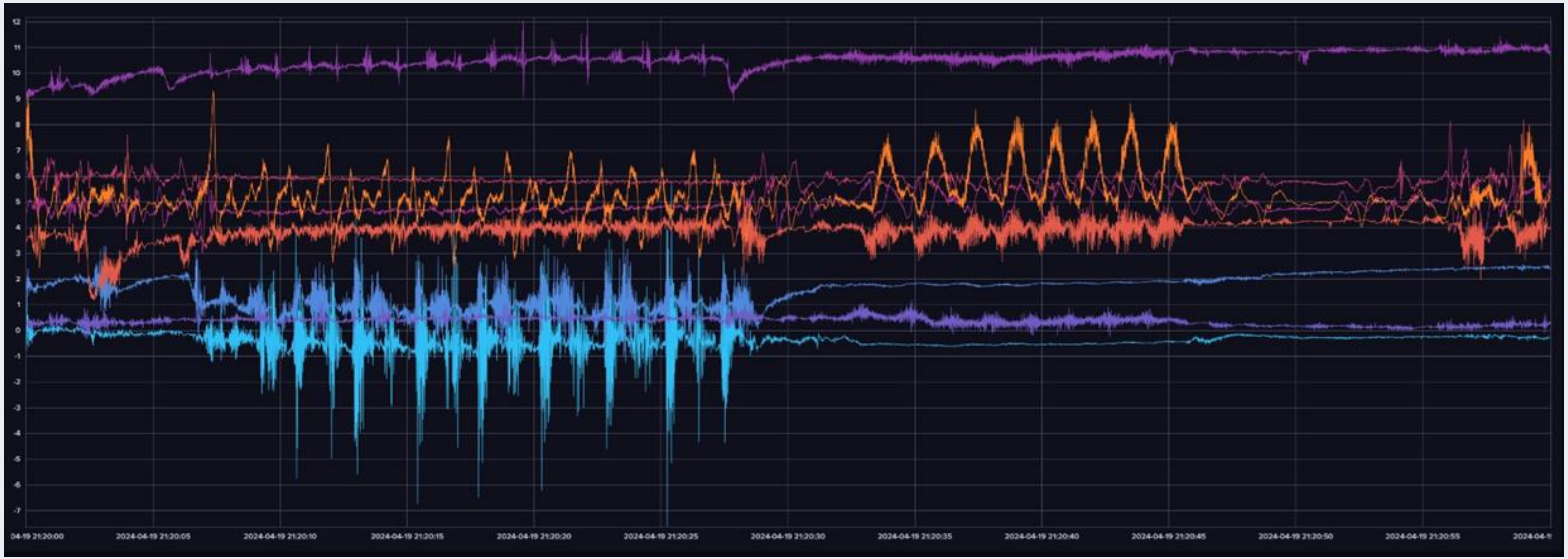


Box: median and IQR. Whiskers: up to 1.5 × IQR. Dots: individual hops.

47 of 57 hops passed post-contact QC (82.5%). Ten excluded, without imputation.

EMG and IMU analysis for follow-up

Real-time analysis ➔ Exercise classification
EMG and IMU ➔ Training feedback



Limitations and validation priorities

Limitations

- Ten participants, one session
- 2D angles depend on viewpoint, without marker-based validation
- Contact uncertainty: 20–40 ms at 50 Hz
- Manual contact annotation limits scale
- Limited coverage of shuttle-run turns
- Chest IMU peaks need validation as contact markers

Next steps

- Calibrated 3D triangulation
- Automatic contact detection validated against manual labels
- Additional view for changes of direction
- Validation against marker-based motion capture
- Trials with uniforms, body armour and carried loads
- Validated time alignment of video, IMU and EMG

Conclusions

- A portable two-camera workflow provided 2D movement descriptors during military fitness testing.
- The analysis retained 404 push-up cycles and post-contact kinematics for 47 of 57 hops.
- Event definition, limb tracking and quality control determine the reportable data.

Next: validate calibrated 3D and synchronized video/IMU/EMG measurements

Thank you for your attention

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Template: Slidesgo. Icons: Flaticon. Infographics: Freepik.