UNIVERSITÀ DEGLI STUDI DI BRESCIA

Laboratorio di Misure Meccaniche e Termiche

From IMUs to Smartwatches: Measuring Performance in Practical Shooting

Gabriele Pancera, Massimiliano Micheli, Stefano Morzenti, Matteo Lancini

Practical shooting

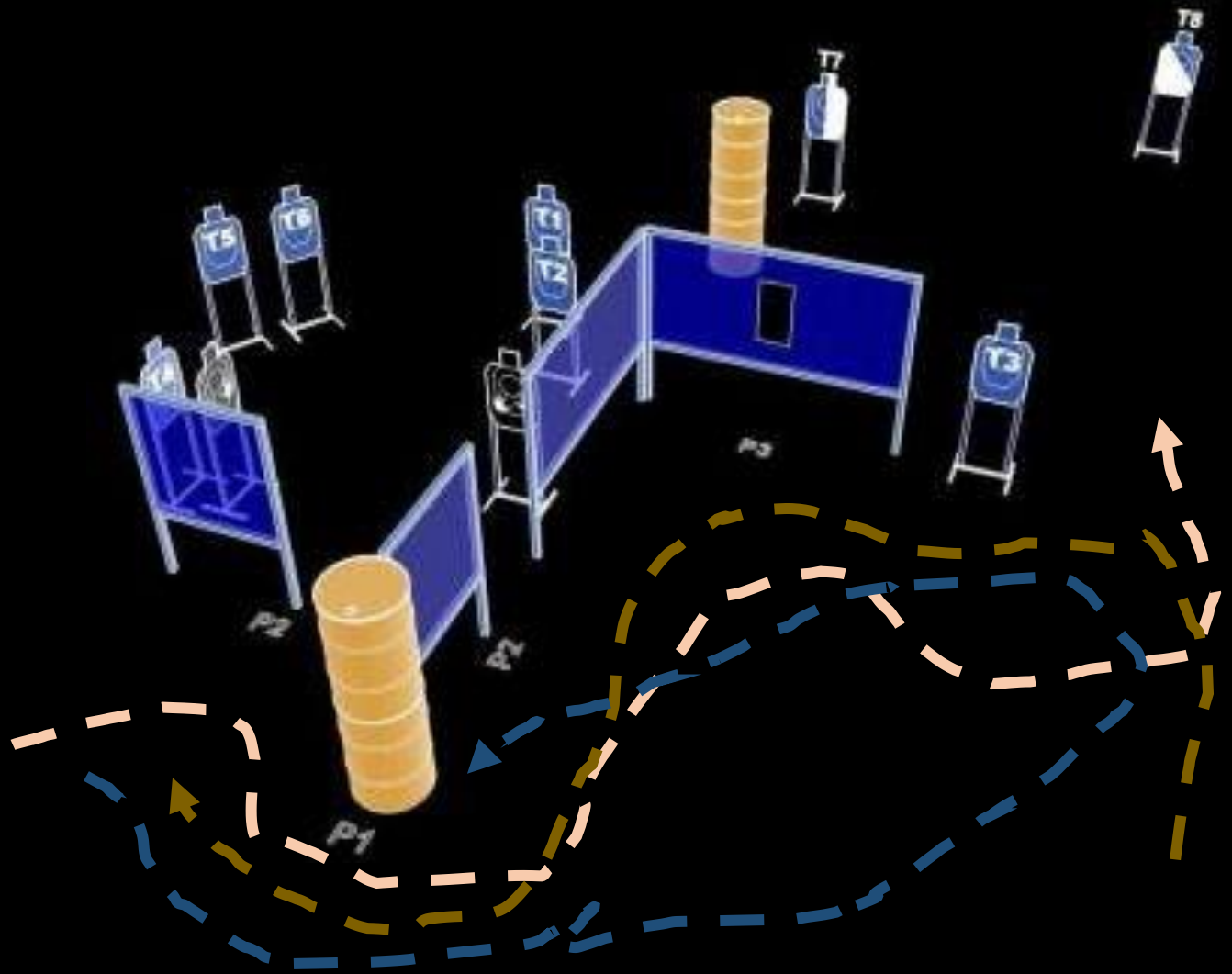
Free path selection

Free target sequence

Free movements combination

Score based on

$$\frac{\text{accuracy}}{\text{time}}$$



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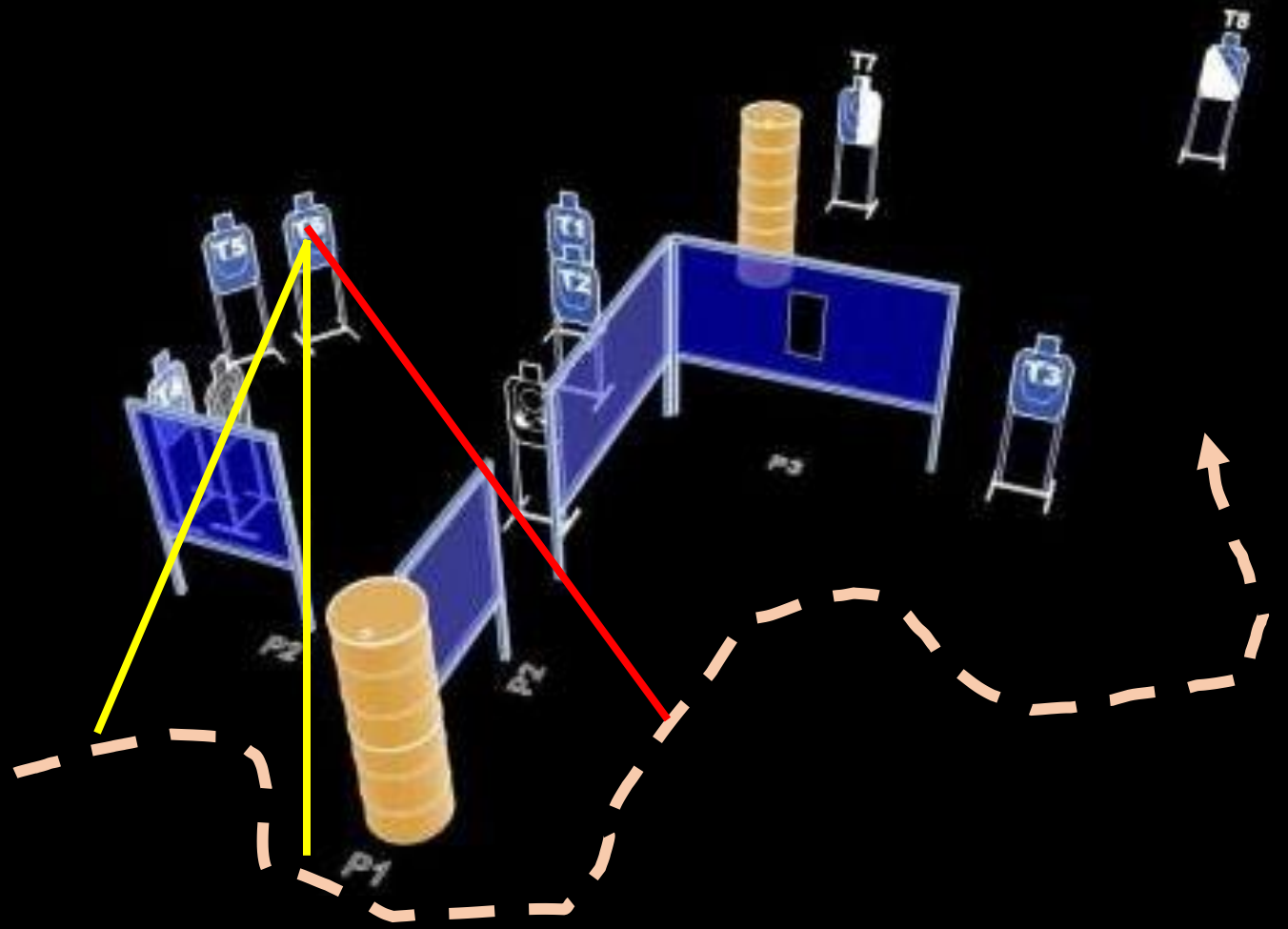


Practical shooting

Free path selection

Free target sequence

Free movements combination

Score based on

$$\frac{\text{points}}{\text{time}}$$

Aim and shoot while running

Aim and shoot while standing

Practical shooting

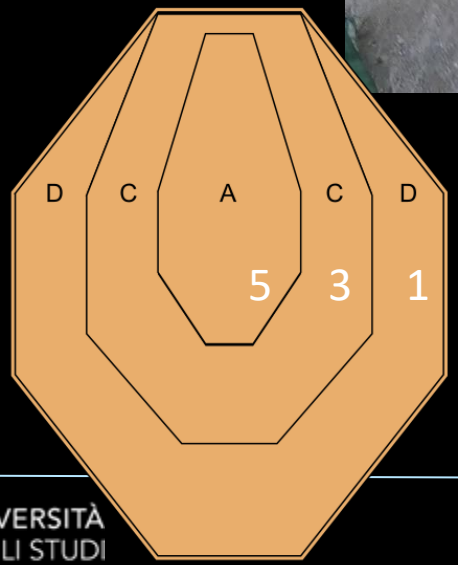
Free path selection

Free target sequence

Free movements combination

Score based on

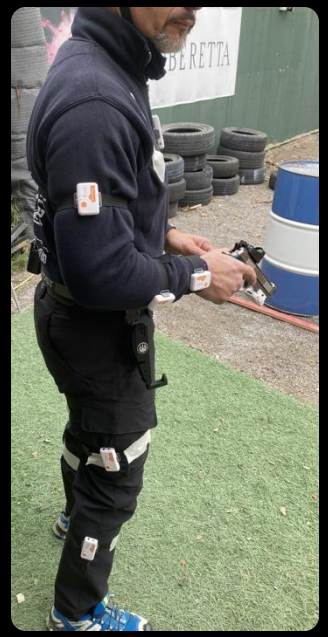
$$\frac{\textbf{points}}{\textbf{time}}$$

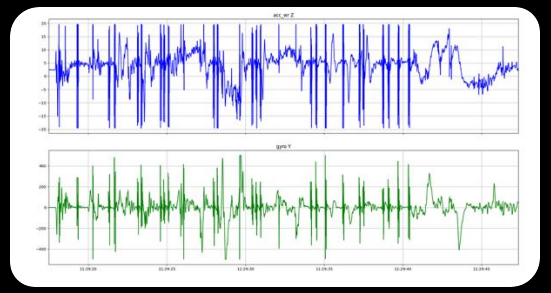


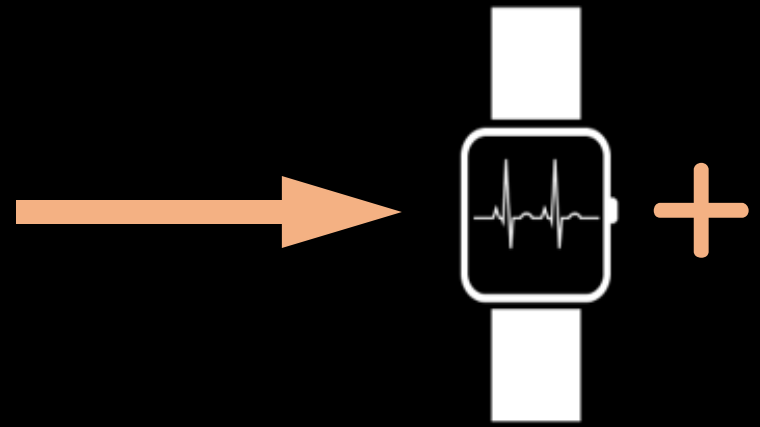
$$\text{HIT RATE} = \frac{\sum points - \sum penalties}{time}$$

Our research question

Can **commercial smartwatches and smartphones** replace **lab-grade IMUs** to monitor performance in *practical shooting*, an outdoor sport involving fast, overlapping actions and many mechanical perturbations?







Critical to make extensive experimentation feasible!

Our approach to Human Action Recognition

ACTIONS	Consensus on the **actions definition**
TRAINING	**Training modality** definition
LAB-TEST	Full-body **lab-grade** sensor system test
POINTS	Measurement **points selection**
SPECIFICS	Minimum **requirements** definition
ALGORITHM	Feature and **algorithm** selection
VALIDATION	Experimental **validation**

Consensus on the **actions definition**

- ACTIONS
- TRAINING
- LAB-TEST
- POINTS
- SPECIFICS
- ALGORITHM
- VALIDATION

While most trainers use the **same names**, a strict definition is not enforced, so they have **different meanings** **NO CONSENSUS**

Successive separate interviews with 12 athletes and trainers

Run – often concurrent with other actions (>3s)

Reload – magazine replacement (5-10s)

Extraction – drawing or picking up the weapon (3-6s)

Shot – complex movement (0.3 - 2s) including:

aiming, firing (at least twice),

recoil management

NOT ONLY THE EXPLOSION EVENT

Training modality definition

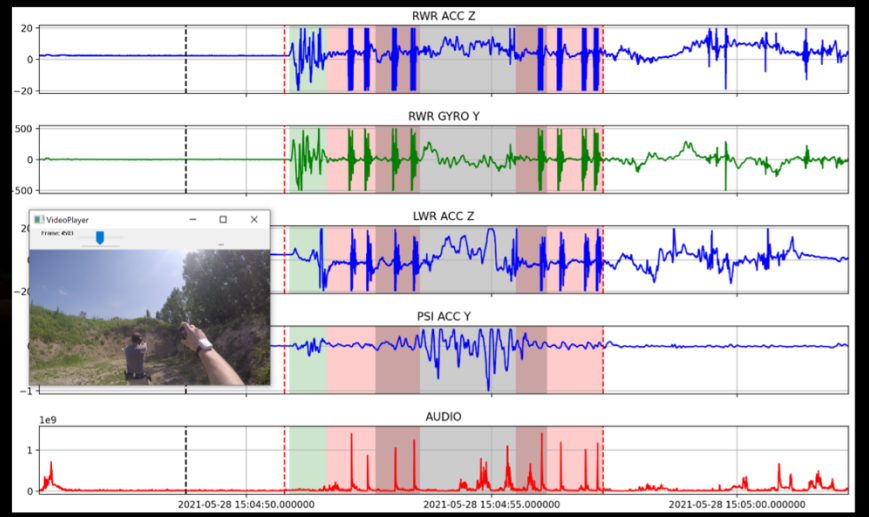
- ACTIONS
- TRAINING
- LAB-TEST
- POINTS
- SPECIFICS
- ALGORITHM
- VALIDATION

Single action recording

- Athlete is instructed
- Easier to label
  (random recorded instruction)

Whole exercise recording

- Athlete is free
- Labeling is time consuming
  (ex post review by operators)



Training modality definition

ACTIONS

TRAINING

LAB-TEST

POINTS

SPECIFICS

ALGORITHM

VALIDATION

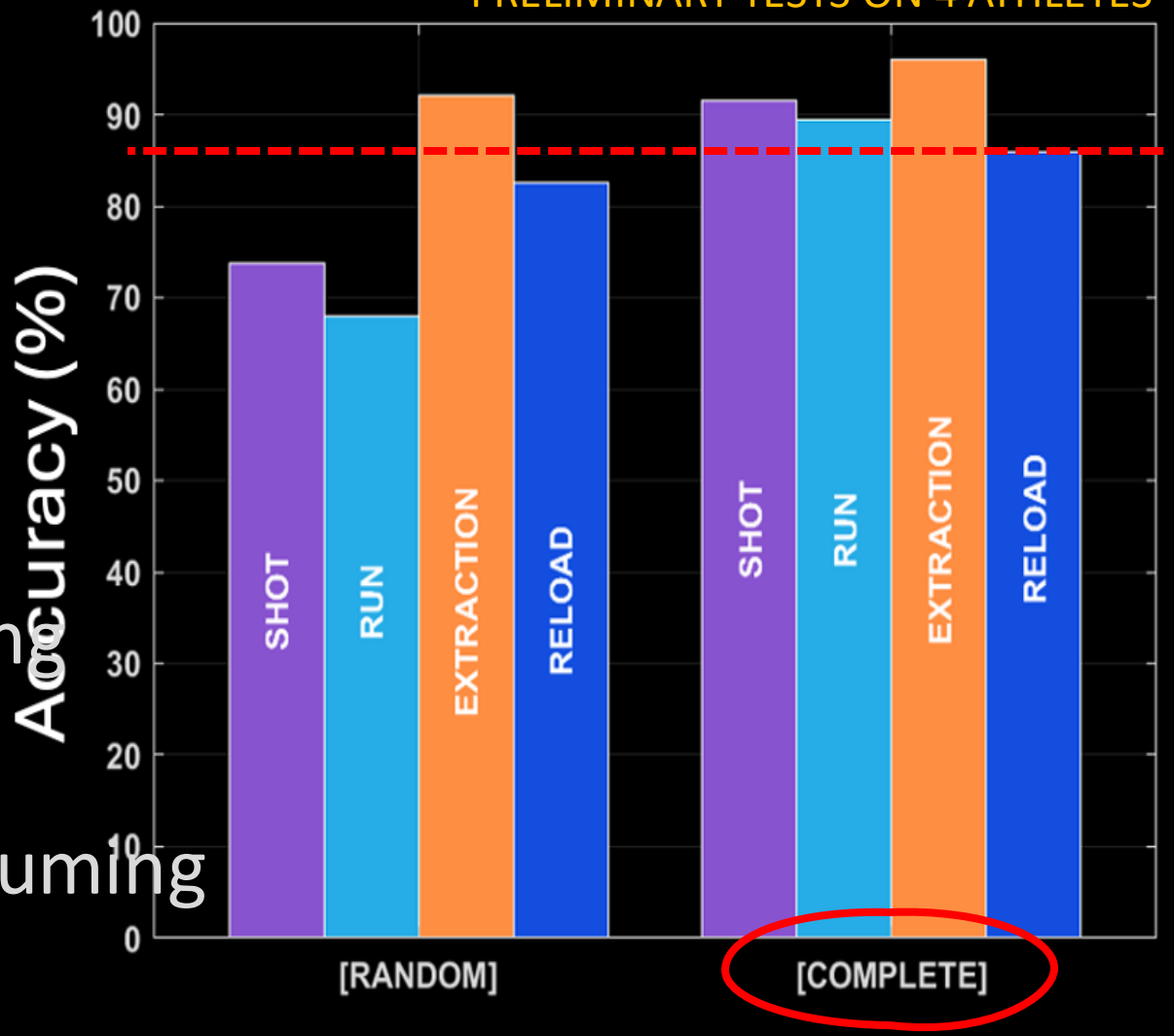
Single action recording

- Athlete is instructed
- Easier to label

Whole exercise recording

- Athlete is free
- Labeling is time consuming

PRELIMINARY TESTS ON 4 ATHLETES



Full-body **lab-grade** sensor system test

ACTIONS

TRAINING

LAB-TEST

POINTS

SPECIFICS

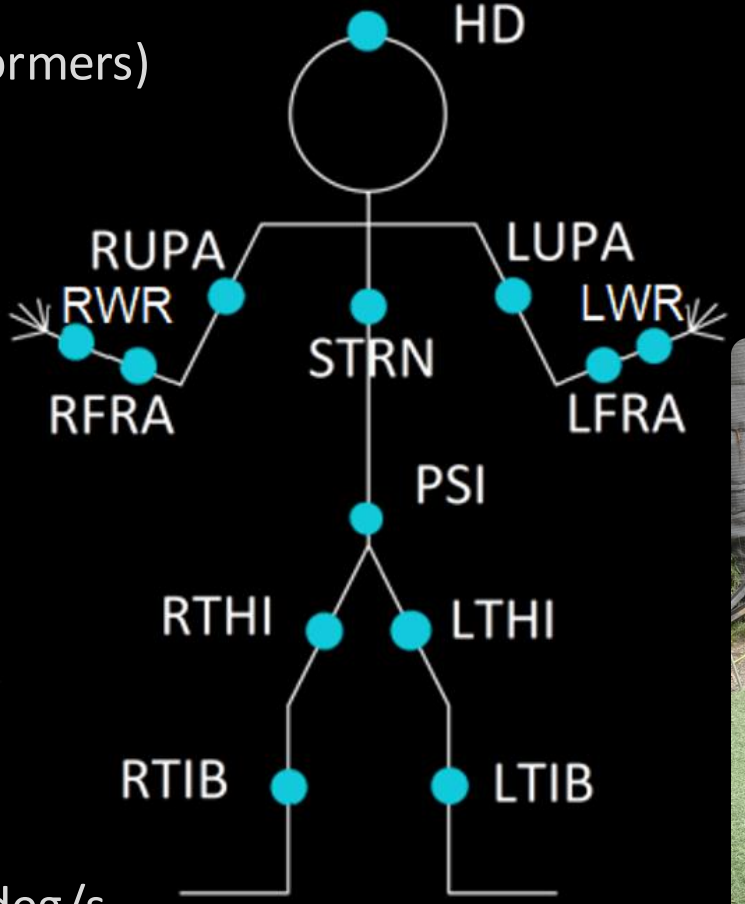
ALGORITHM

VALIDATION

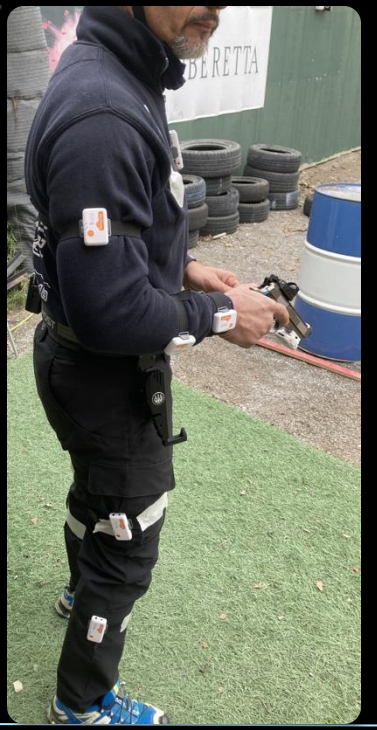
- 12 athletes (intermediate and top-performers)
- 3 training sessions per athlete
- 20 targets per session
- 36 recordings, ~1500 shots

- Whole body setup*
- 14 Shimmer3 IMU unit

- Sampling frequency of 1000 Hz
- Full-scale range of ± 2 g ± 500 deg/s
- Uncertainty (P=99%) ± 0.003 g ± 0.063 deg/s



GUN



** Huang et al. 2018 - Foletti et al, 2021*

Measurement **points selection**

ACTIONS

TRAINING

LAB-TEST

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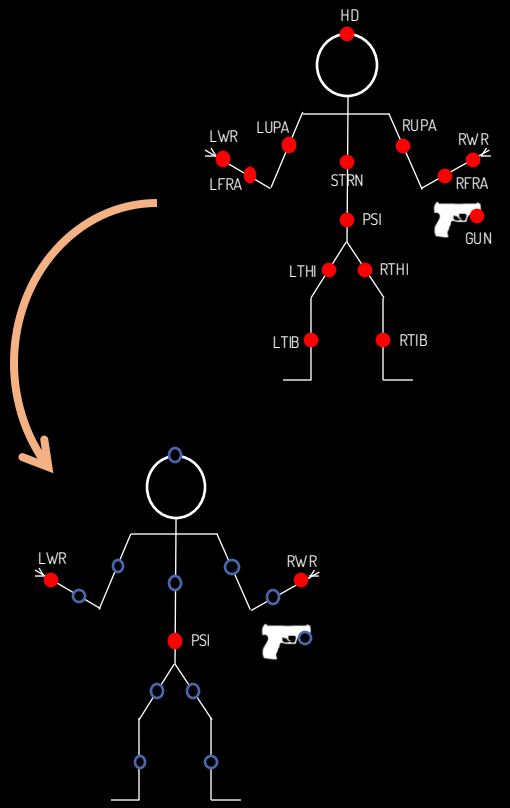
VALIDATION

- Extract any 1-2-3 sensors combination
- Compare best performing algorithms
- Avoid gun (competion rules)
- Focus on wrists + phone-holder spots



Best configuration: PSI + both wrists

Try to reduce to two

Measurement **points selection**

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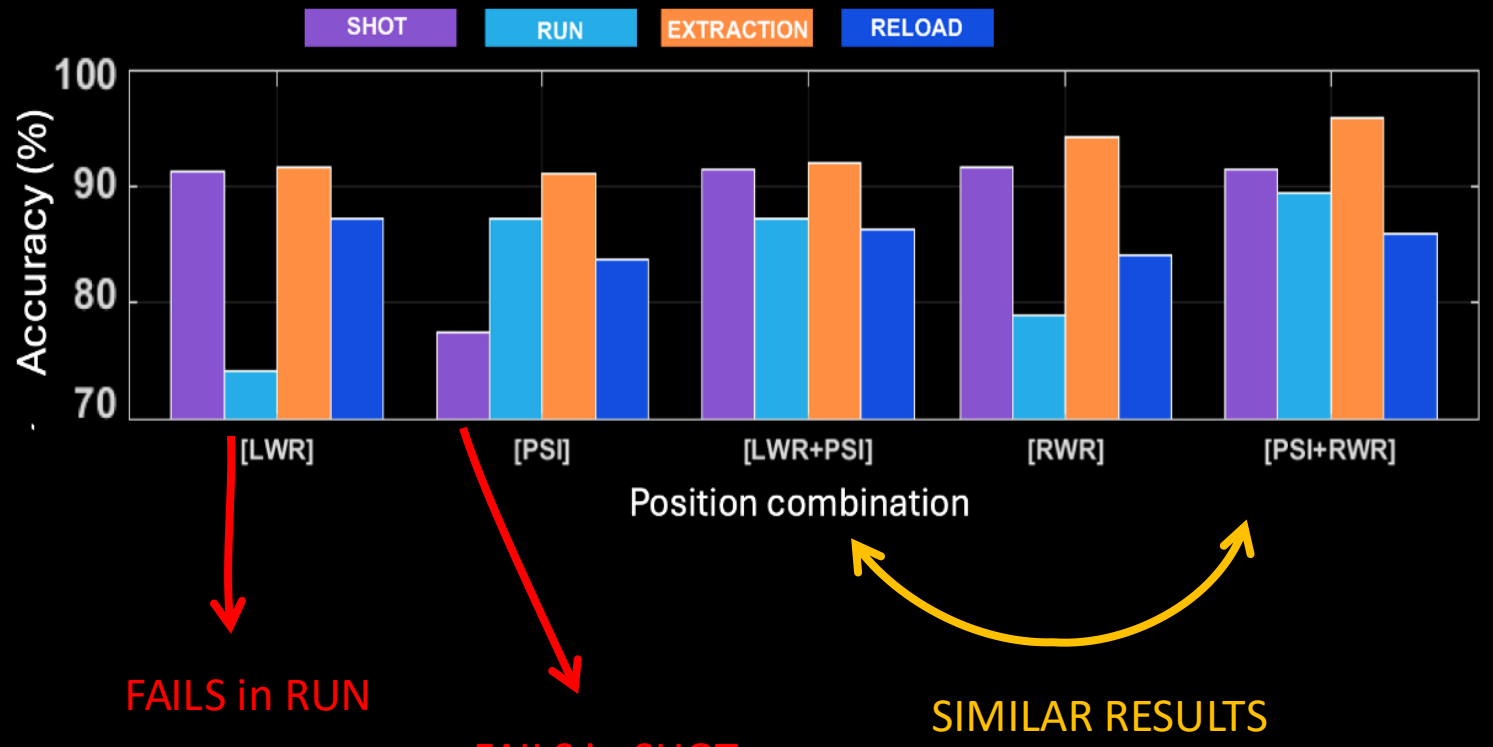

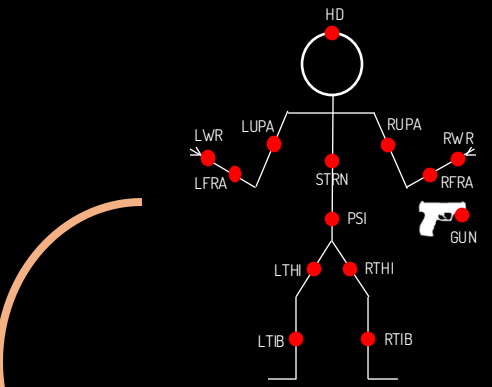

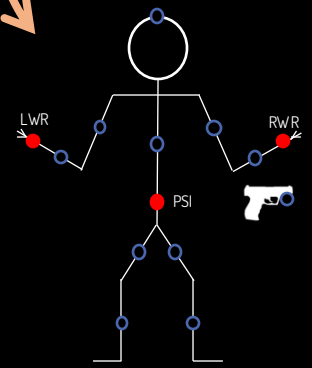

Measurement **points selection**

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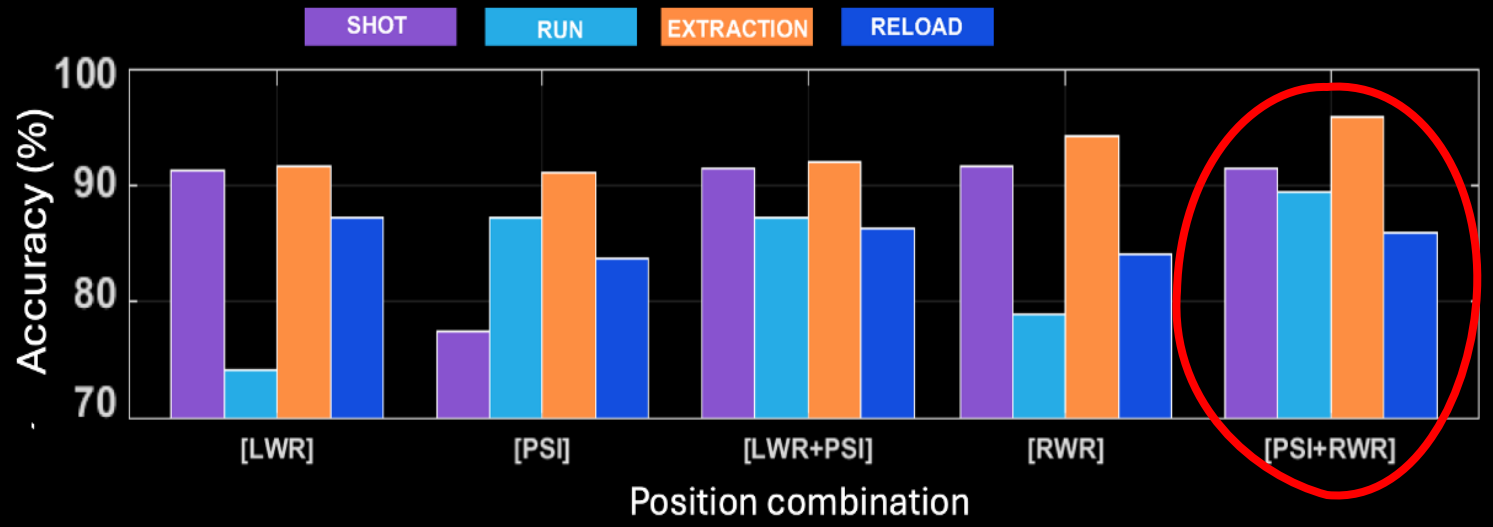

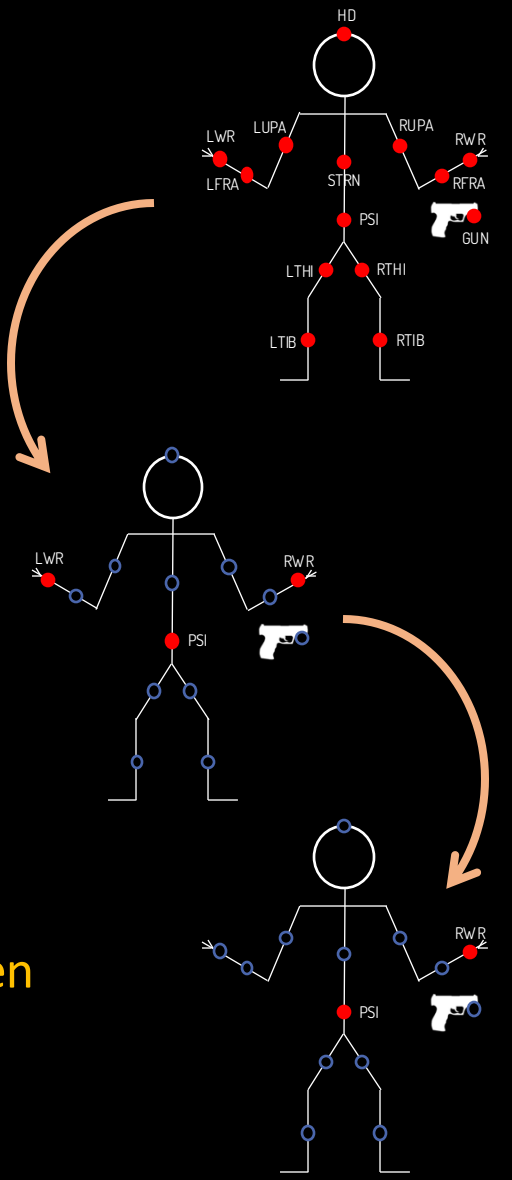

Dominant wrist and the back using the belt holder are chosen

Some athletes could have issues with the dominant hand

Minimum **requirements** definition

ACTIONS

TRAINING

LAB-TEST

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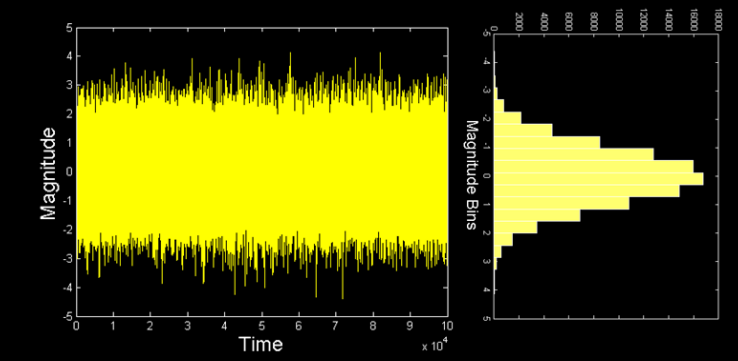
VALIDATION

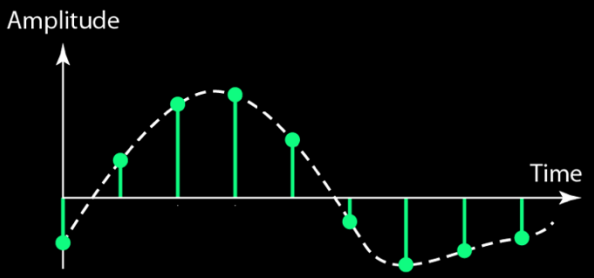
Simulate a lower signal-to-noise ratio

- Perturbate the IMU raw signal
- Normal distributed random noise
- Sigma from literature on commercial smart devices



Simulate a lower sampling frequency

- Undersample the IMU raw signal
- Frequency ratio based on common smart devices



Minimum **requirements** definition

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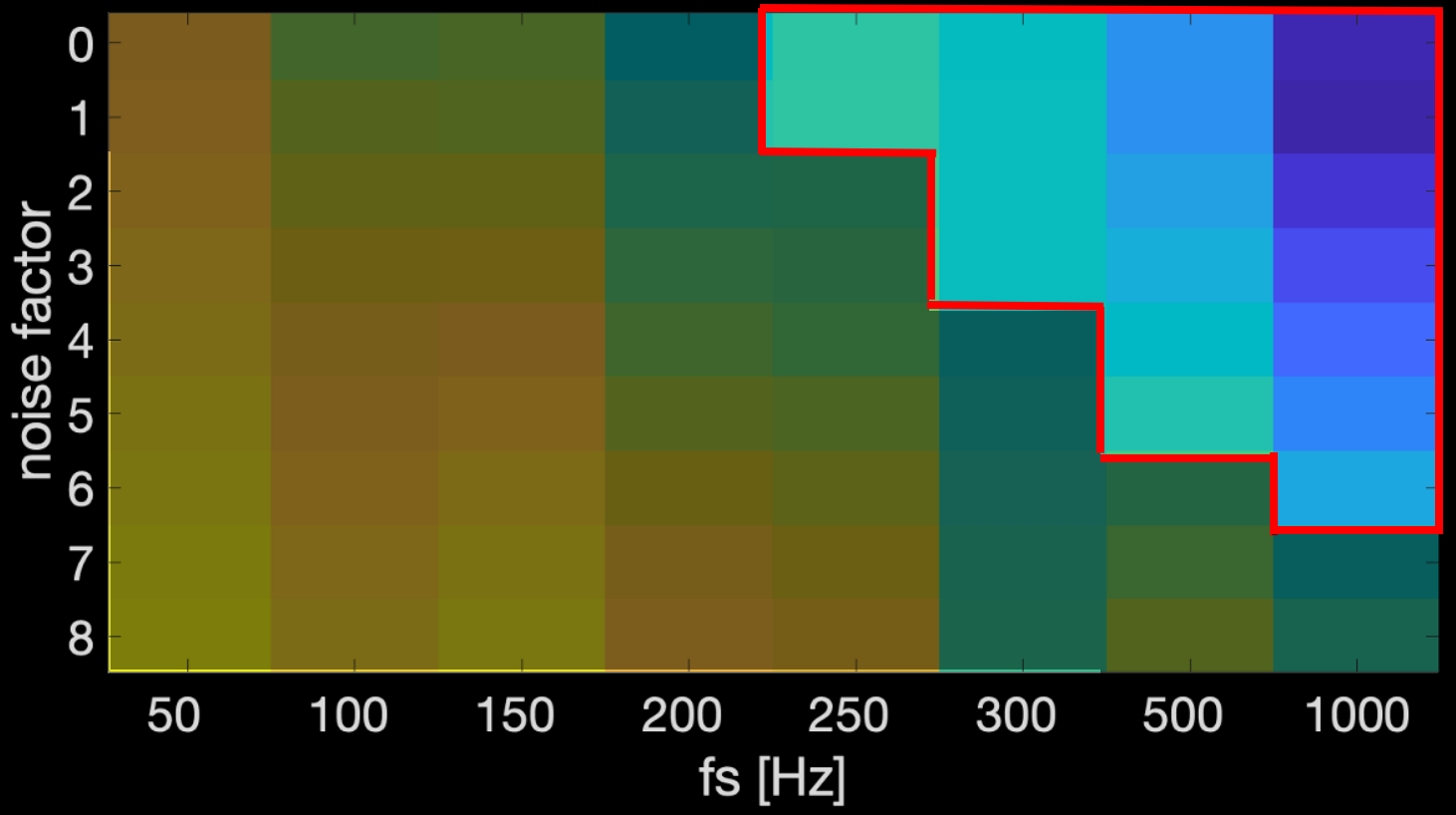

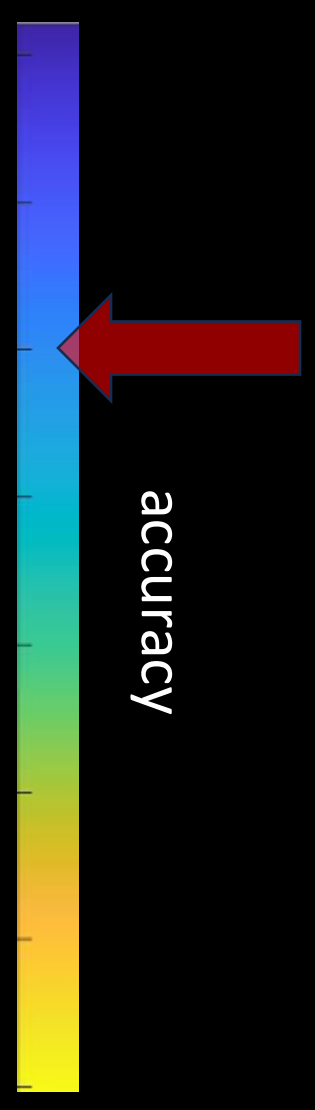

Frequency and sensor noise specifications >> hardware choice

Feature and **algorithm** selection

ACTIONS

TRAINING

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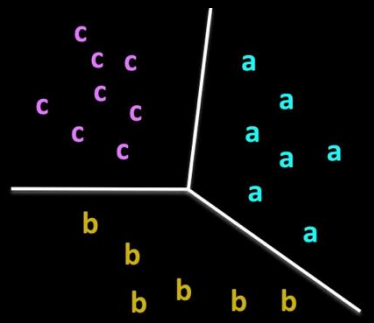
VALIDATION

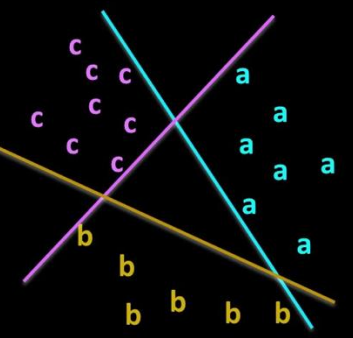
- Standard HAR feature selection*
- Limited portion of the experimental dataset
- 11 classifier of the KNN and SVM families
- 6 different time windows: 50 to 2000 ms



multiclass classificator

vs

multiple binary classificators

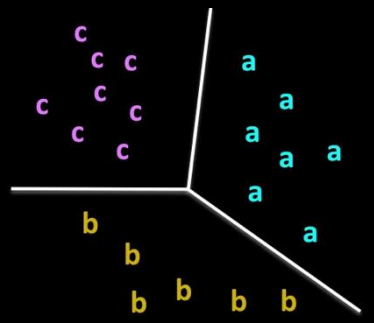


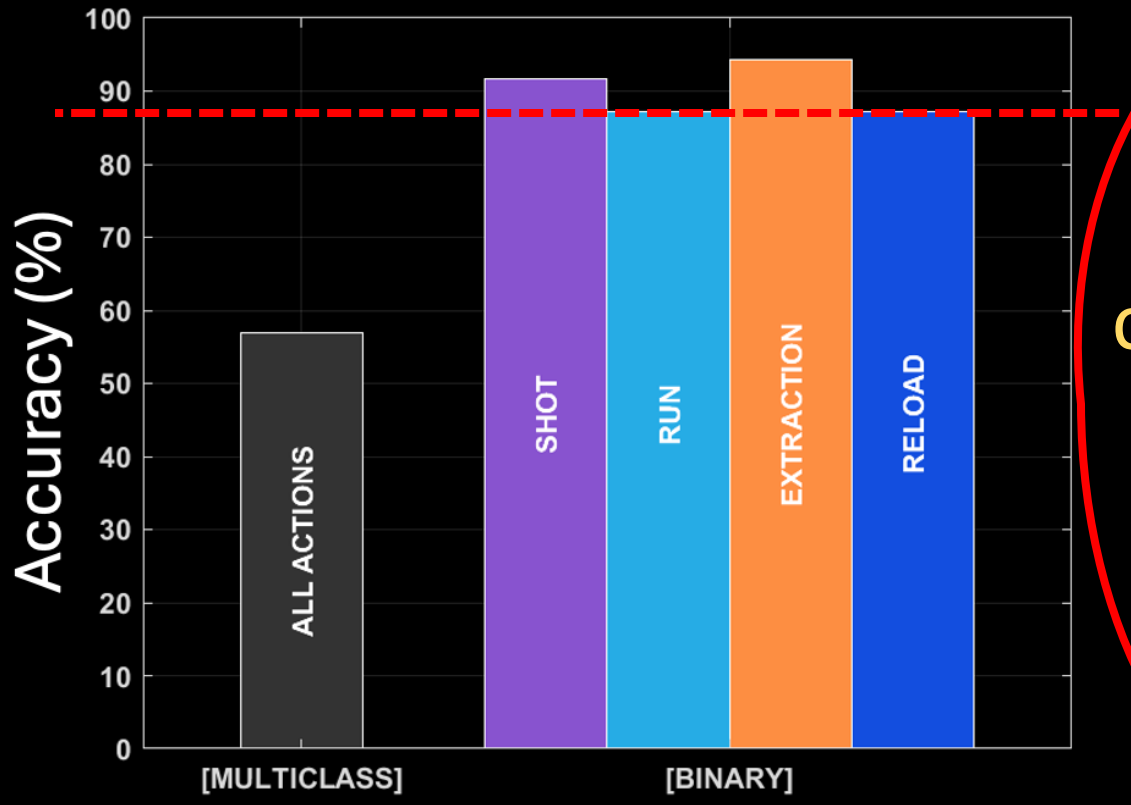
* Zhang et al. 2021

Feature and **algorithm** selection

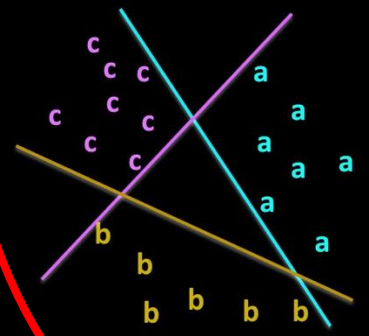
- ACTIONS
- TRAINING
- LAB-TEST
- POINTS
- SPECIFICS
- ALGORITHM
- VALIDATION

multiclass classificator





multiple binary classificators



Experimental **validation**

ACTIONS

TRAINING

LAB-TEST

POINTS

SPECIFICS

ALGORITHM

VALIDATION

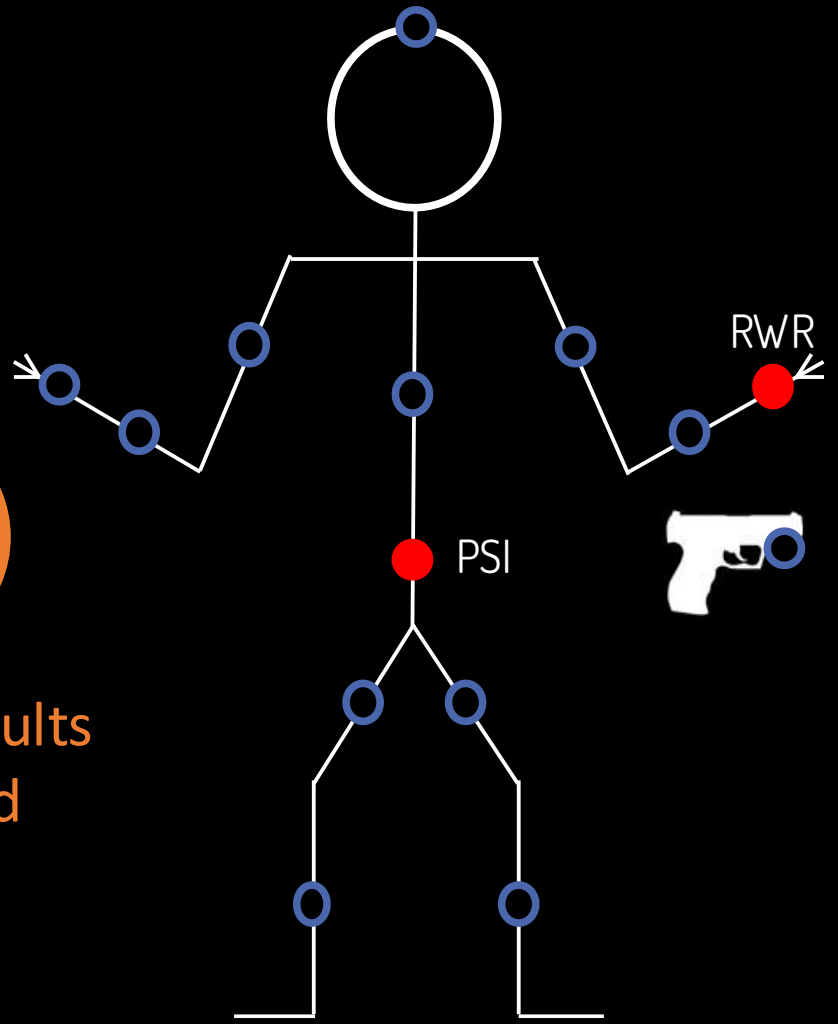
FIRST ROUND

- 12 athletes (intermediate and top-performers)
- 9 training sessions per athlete
- 20 targets per session
- 108 recordings, >4000 shots

- PSI+RWR setup*
- 2 Shimmer3 IMU

- Sampling frequency of 1000 Hz
- Full-scale range of ± 2 g ± 500 deg/s
- Uncertainty (P=99%) ± 0.003 g ± 0.063 deg/s

Previous results confirmed



** Foletti et al, 2021*

Experimental **validation**

ACTIONS

TRAINING

LAB-TEST

POINTS

SPECIFICS

ALGORITHM

VALIDATION

SECOND ROUND

- >8 athletes (intermediate)
- >10 training sessions per athlete
- **Self administered tests**
- Selected hardware smartphone+smartwatch

Results and final design
are cover by nda

Conclusions

Can **commercial smartwatches and smartphones** replace **lab-grade IMUs** to monitor performance in *practical shooting*?

Yes, depending on the target accuracy we can choose the right hardware/software solution

Limitations:

- Action definition is still not a consensus
- Manual labelling is time consuming
- Tradeoff between optimal setup and comfort/rules

4th IEEE INTERNATIONAL WORKSHOP ON

IEEE STAR Trento2025 | Sport Technology and Research

Thanks for your attention

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Measurement **points selection**

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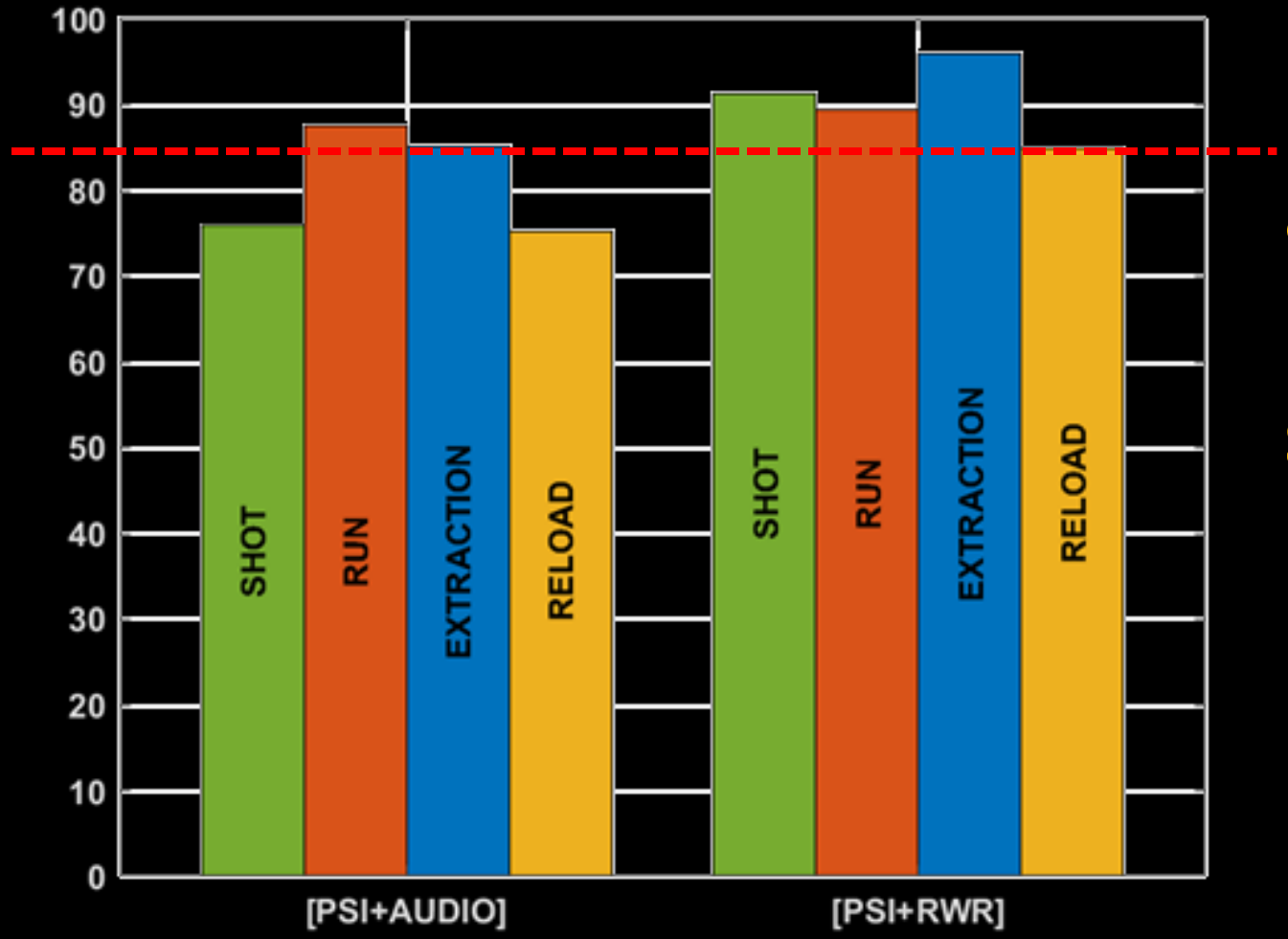

Can we use the **audio signal** to improve **single-point** measurement?

not likely

Example of a data ex