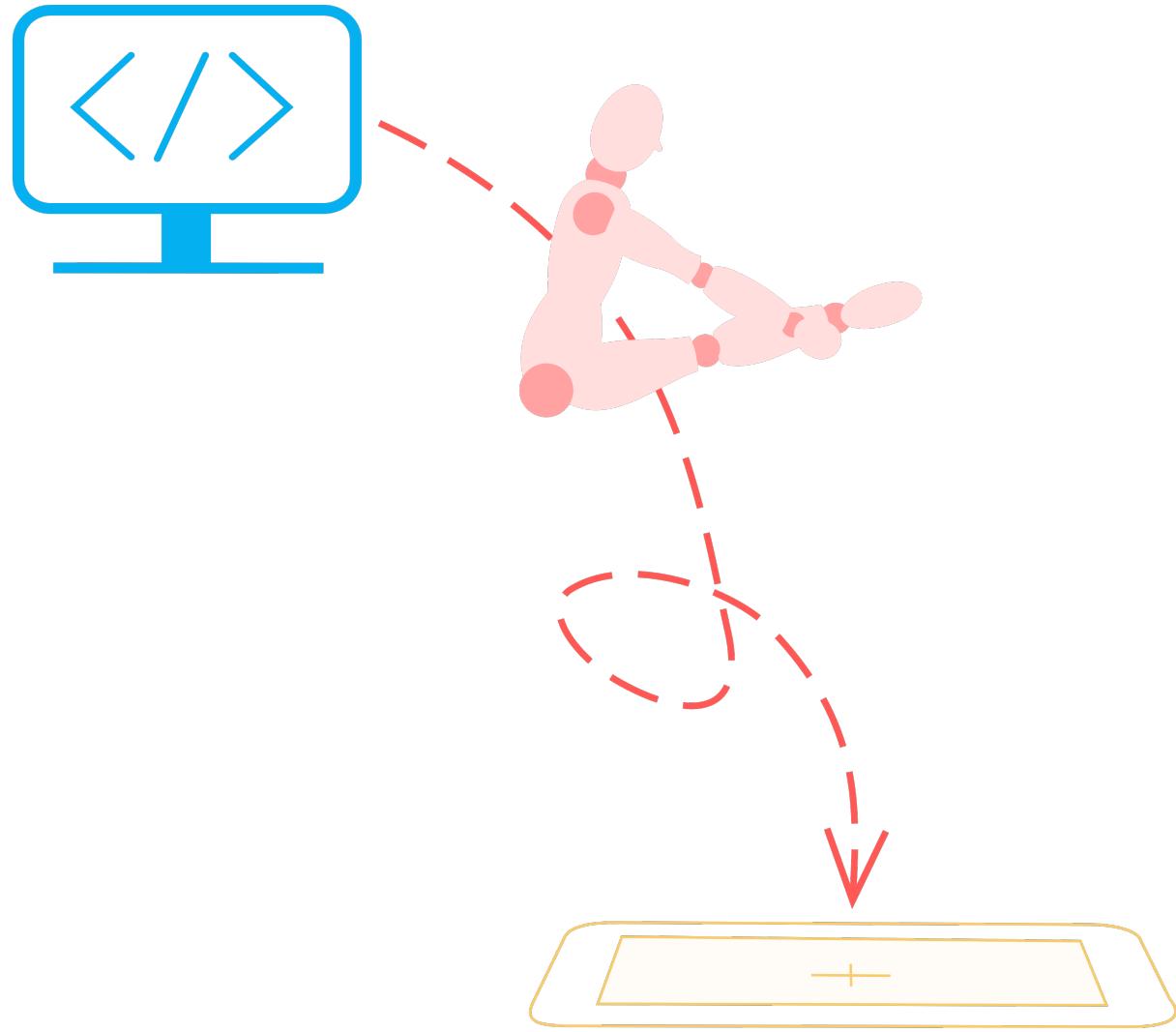


Jumping out of the computer onto the trampoline: what can trampolinists learn from predictive simulations ?

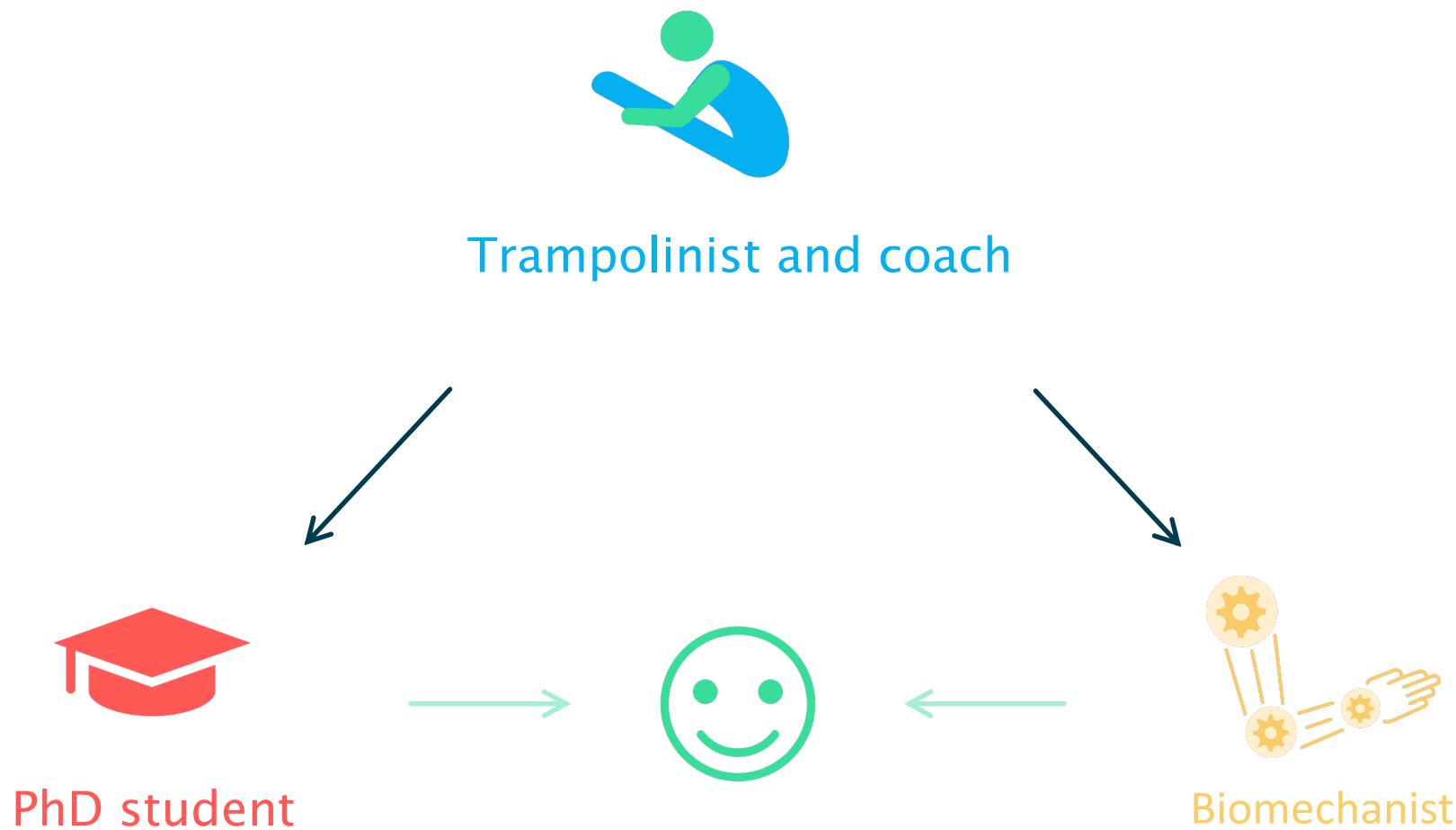


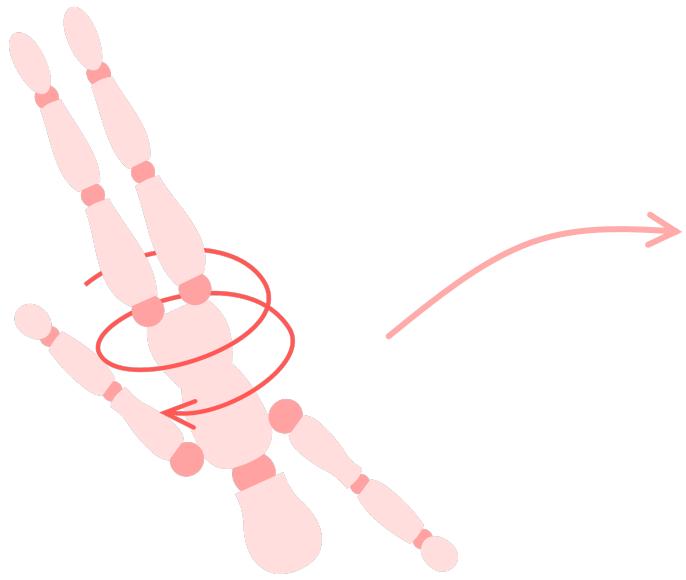
Eve Charbonneau
Université de Montréal
INS Québec
eve.charbonneau.1@umontreal.ca

Thomas Romeas
INS Québec
Université de Montréal

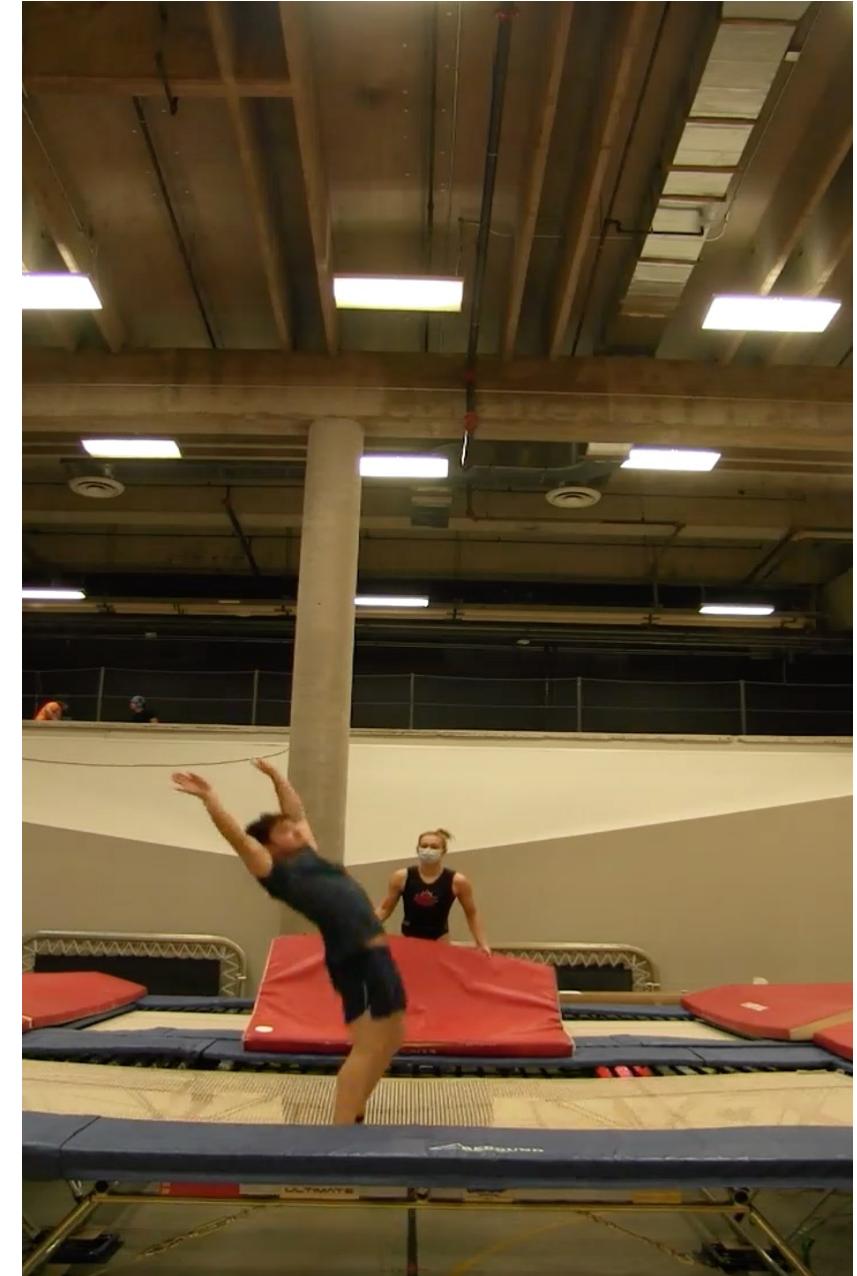
Annie Ross
Polytechnique Montréal

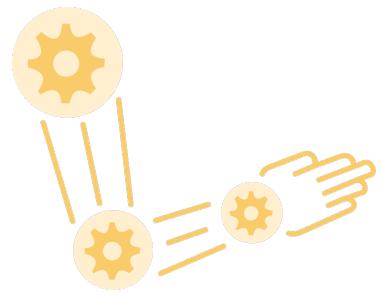
Mickaël Begon
Université de Montréal



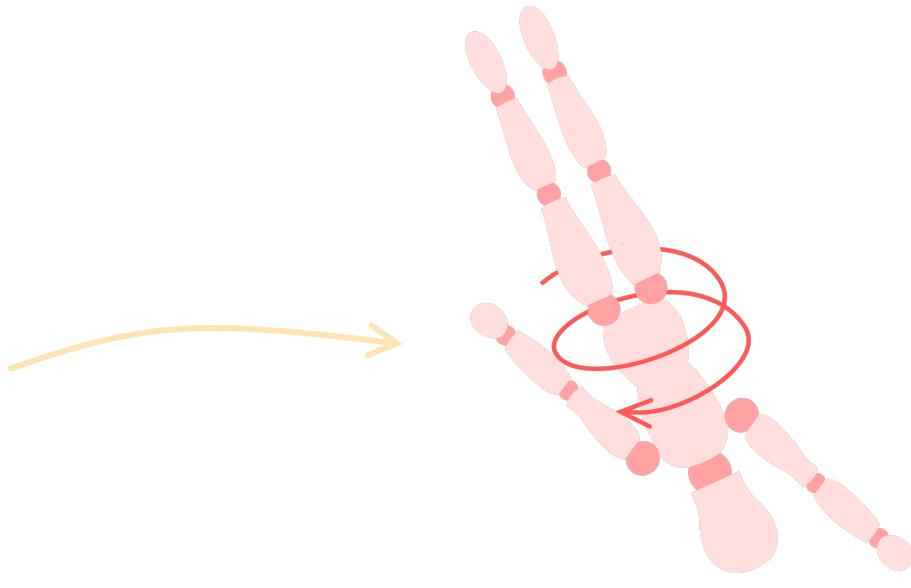


Optimal techniques



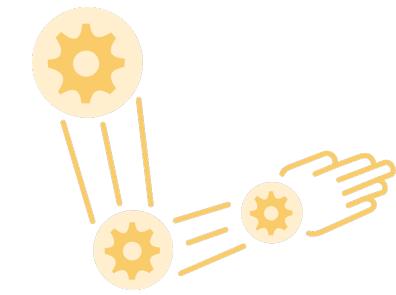


Biomechanical
simulations



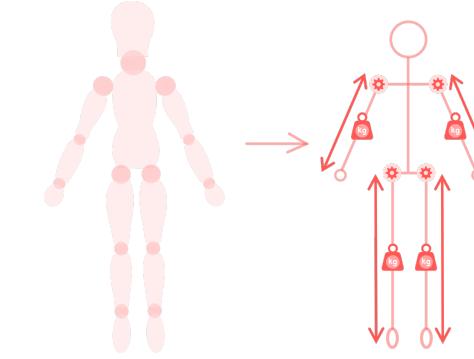
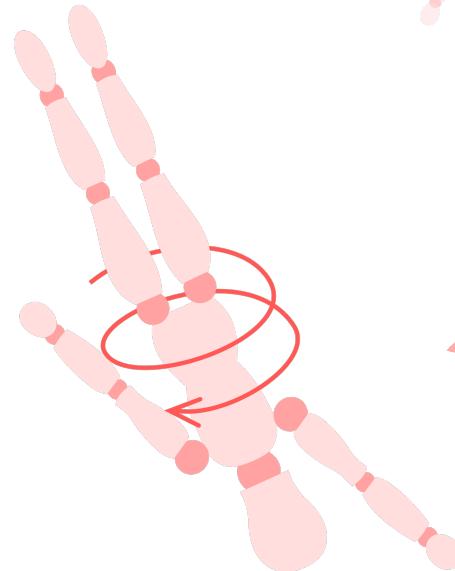
Optimal techniques

Athlete modeling

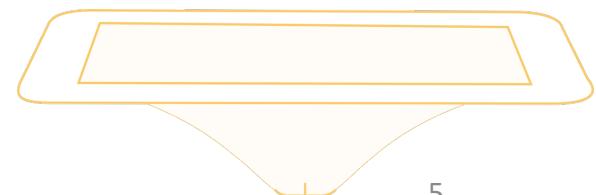


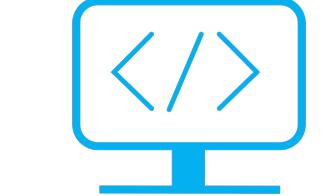
Biomechanical
simulations

Optimal techniques

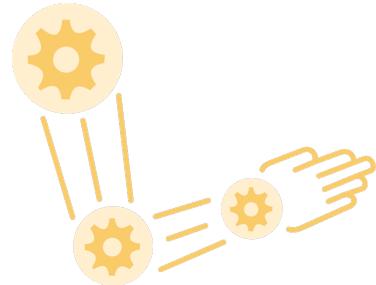


Trampoline modeling



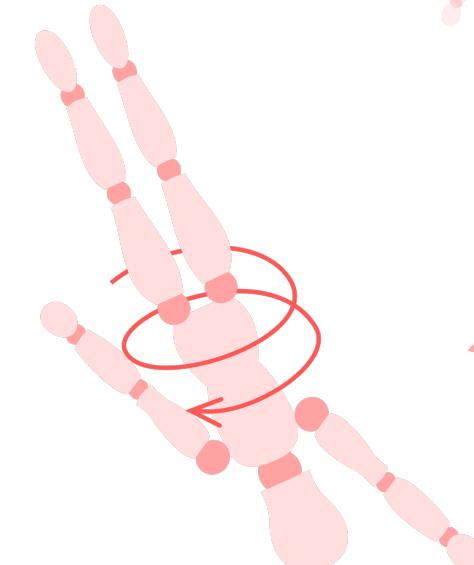
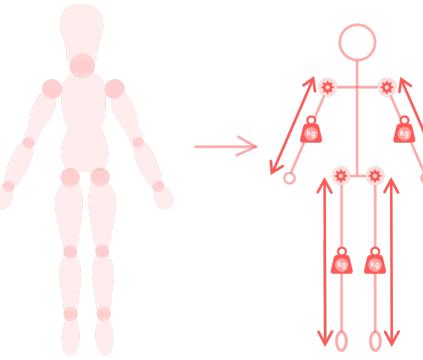


Optimization
procedure



Biomechanical
simulations

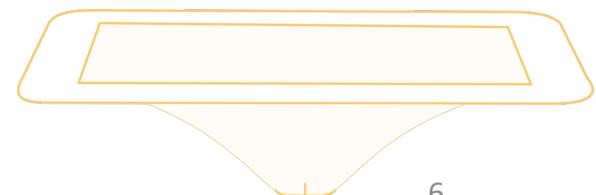
Athlete modeling

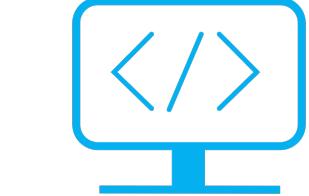


Optimal techniques

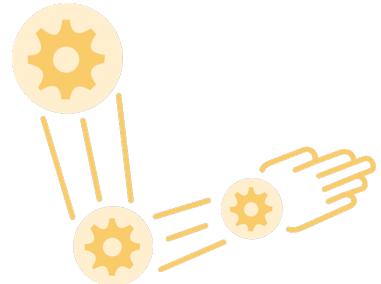


Trampoline modeling





Optimization
procedure

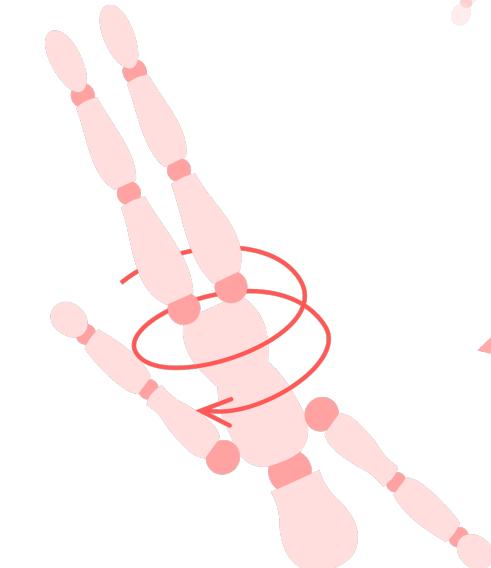
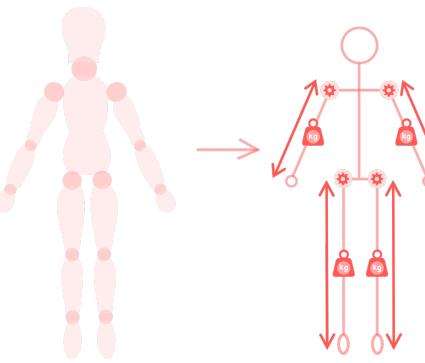


Biomechanical
simulations



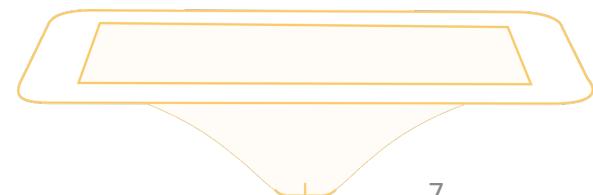
Visual information

Athlete modeling

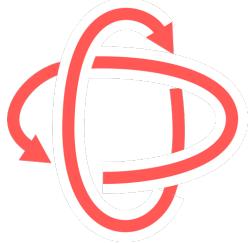


Optimal techniques

Trampoline modeling



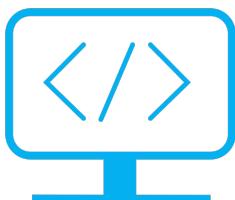
Initial problem



Complex biomechanics

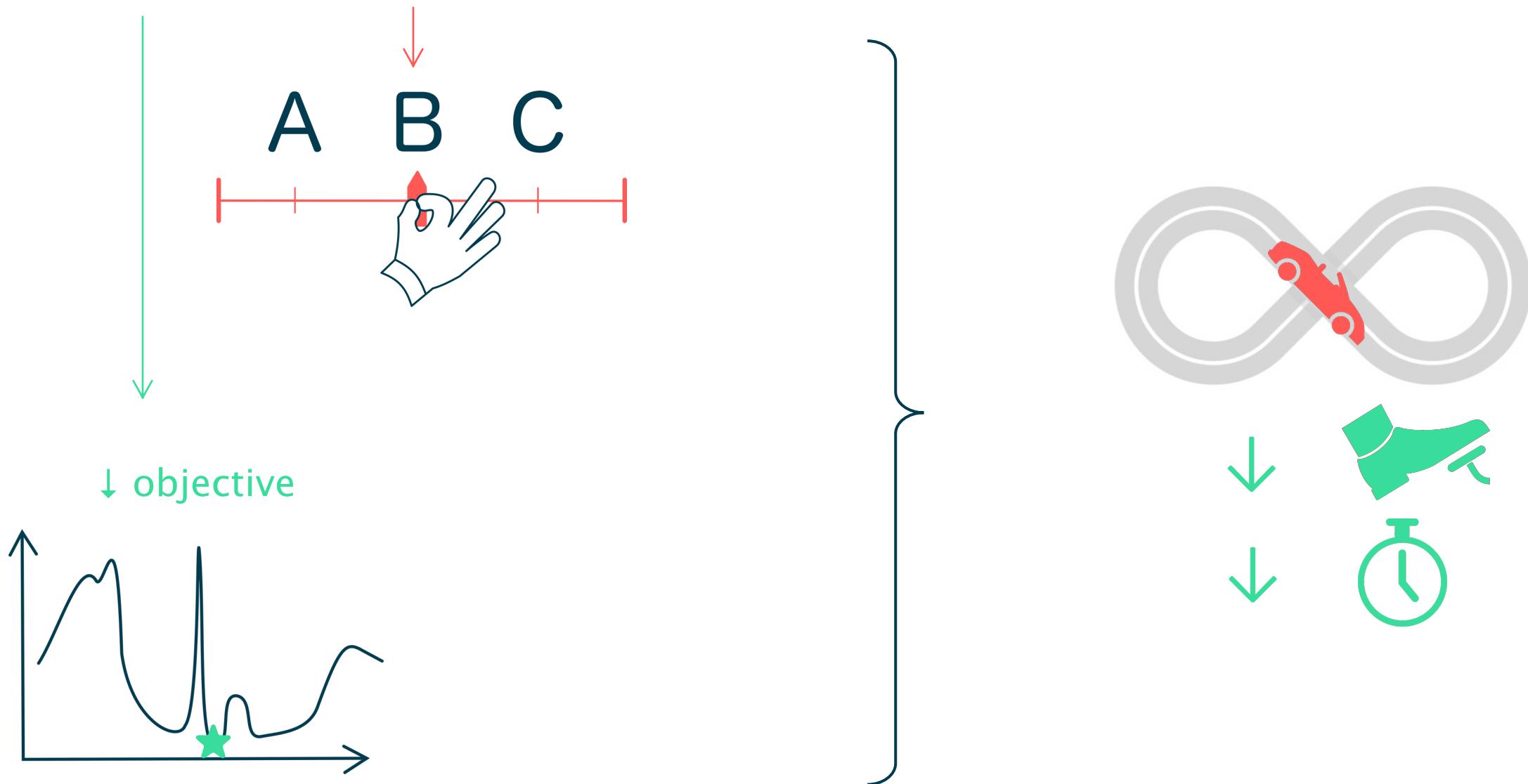


Innovation implies injury risks

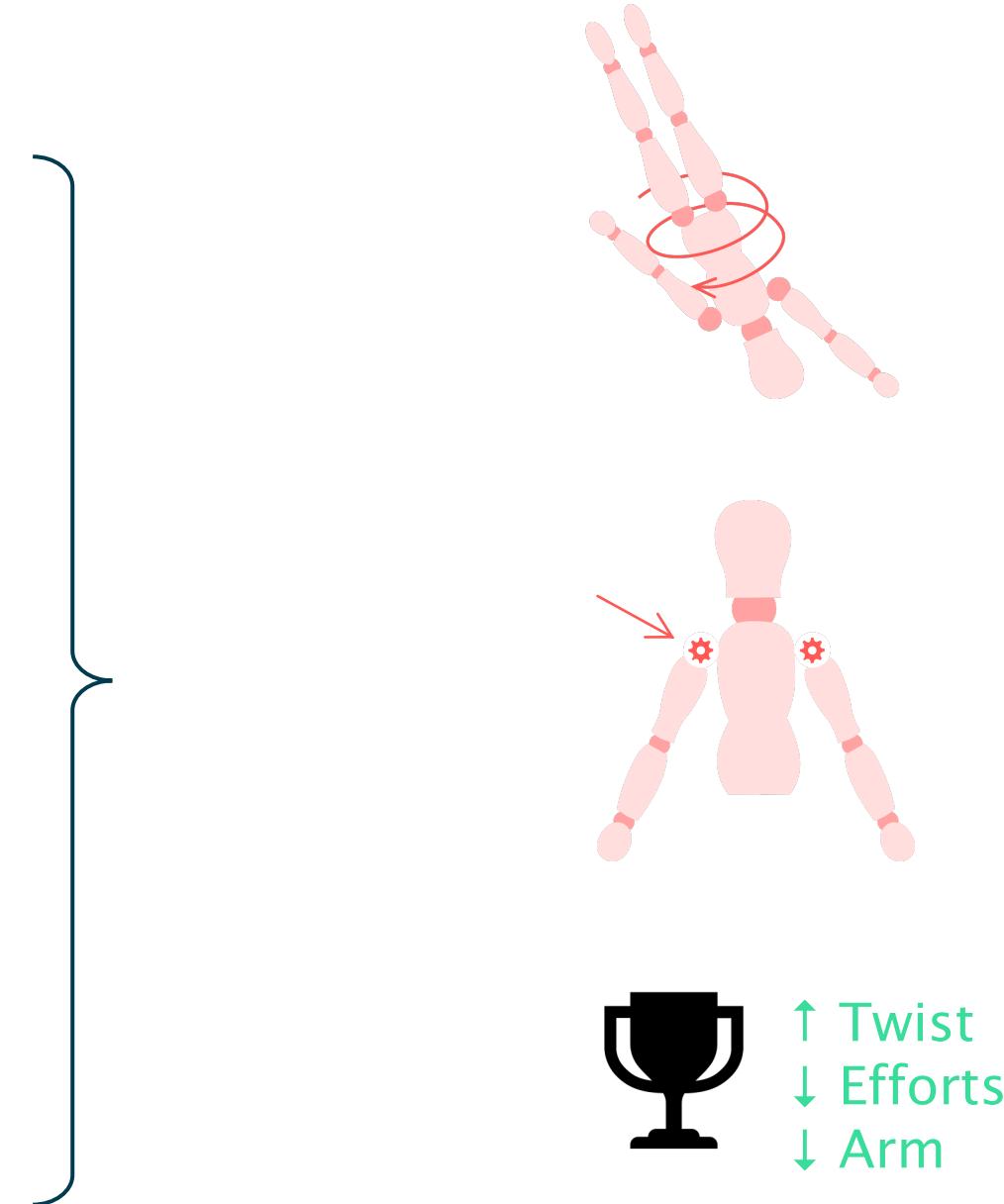
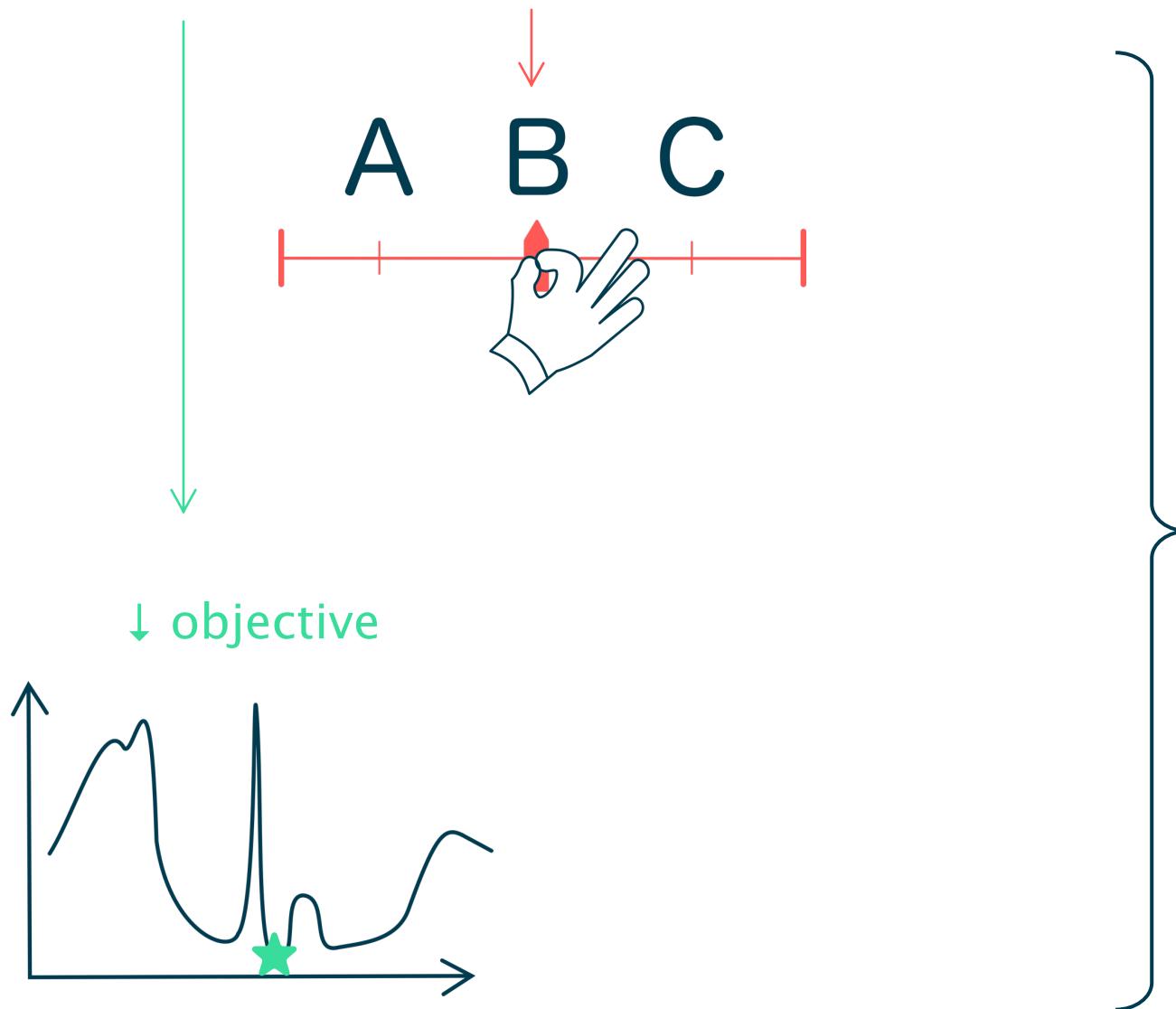


Predictive simulation is a good alternative

Optimal control problem



Optimal control problem



Optimal control problem



Dynamics

- $\tau = M(q)\ddot{q} + C(q, \dot{q})\dot{q} + g(q)$

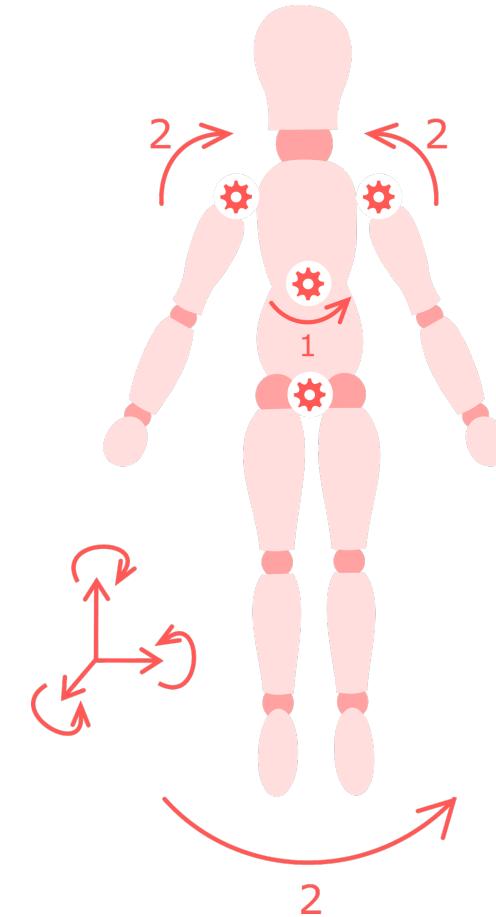


Performance objectives

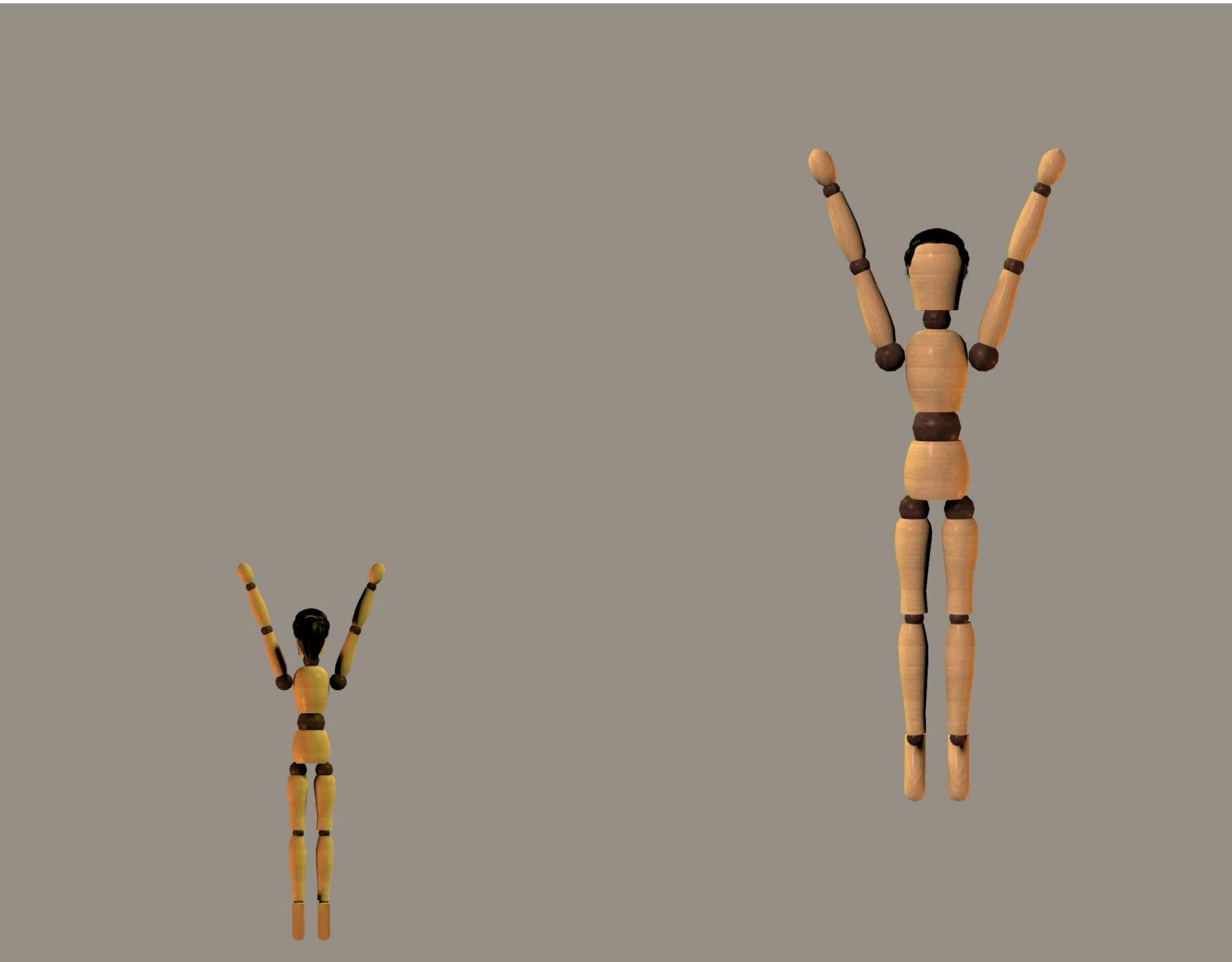


Constraints

- Acrobatics
- Physiological



Optimal solutions

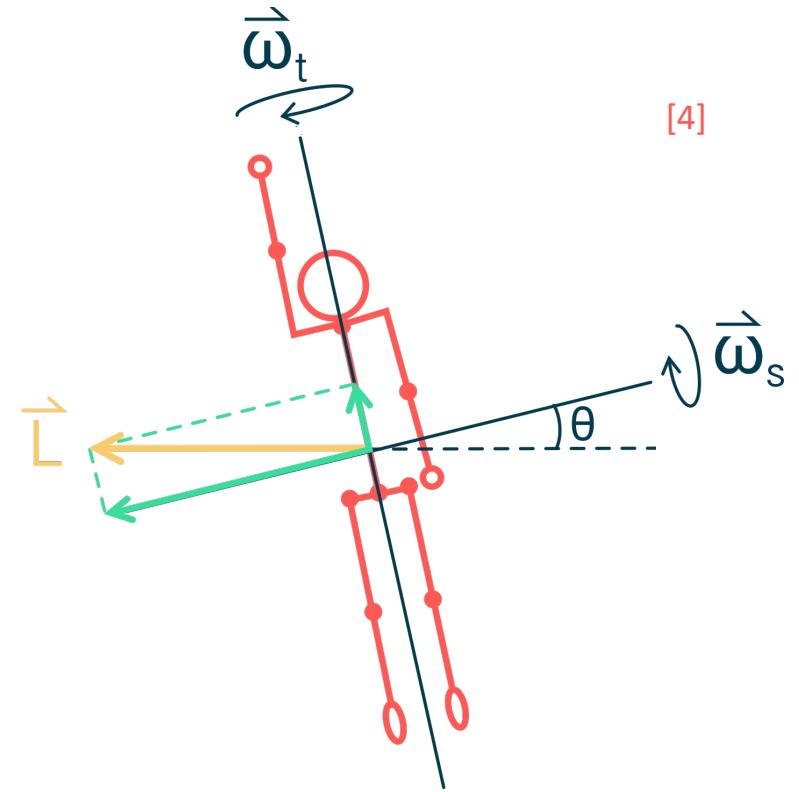
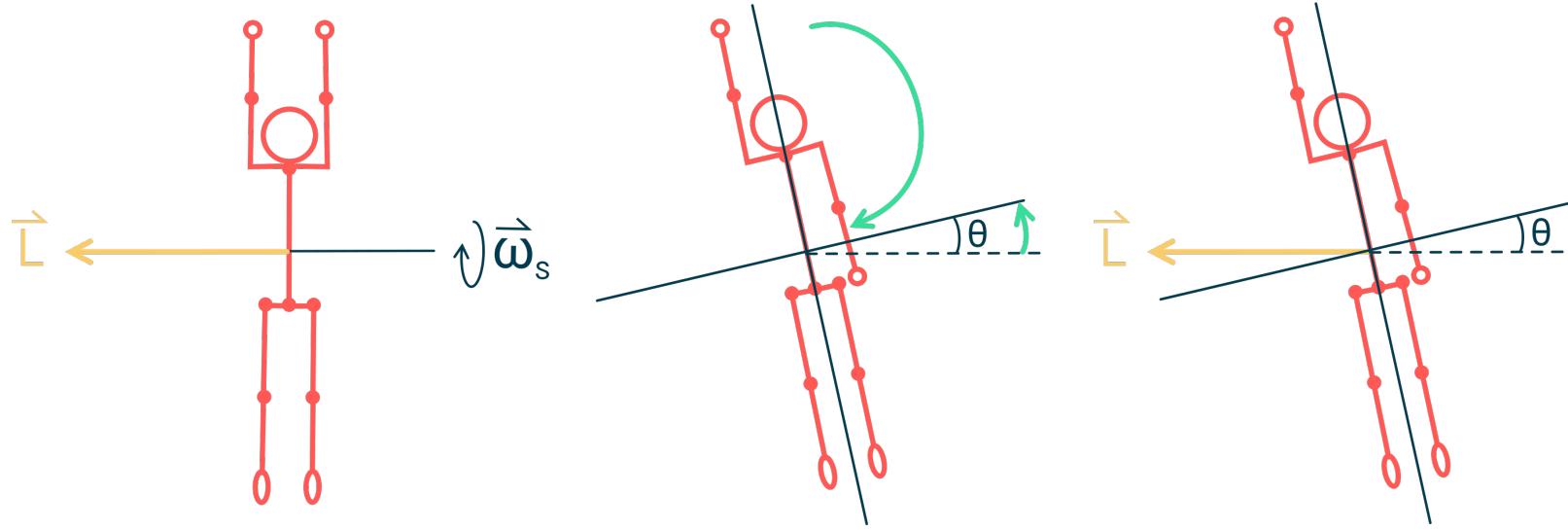


Optimal strategies

Optimal control taught us:

- 1 Moving segments in the best tilting plane^[2]
- 2 Circular motion of the hips^[3]
- 3 Adjustments might be needed^[3]

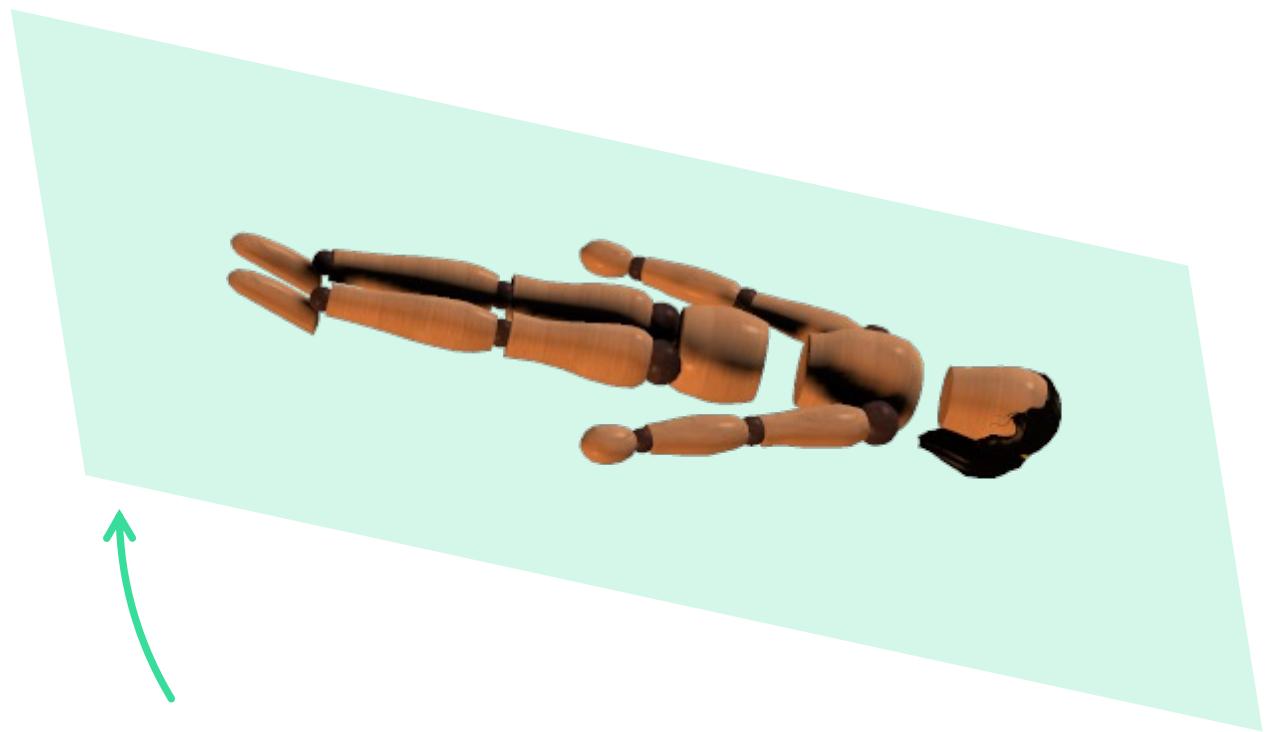
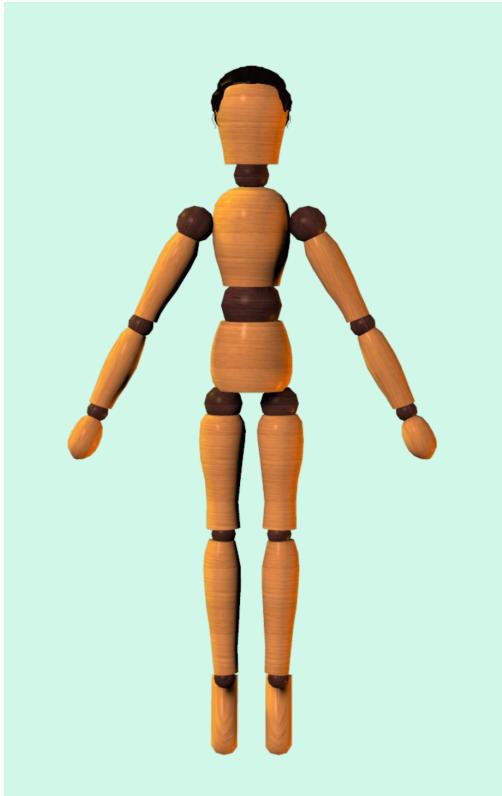
Aerial twist



1

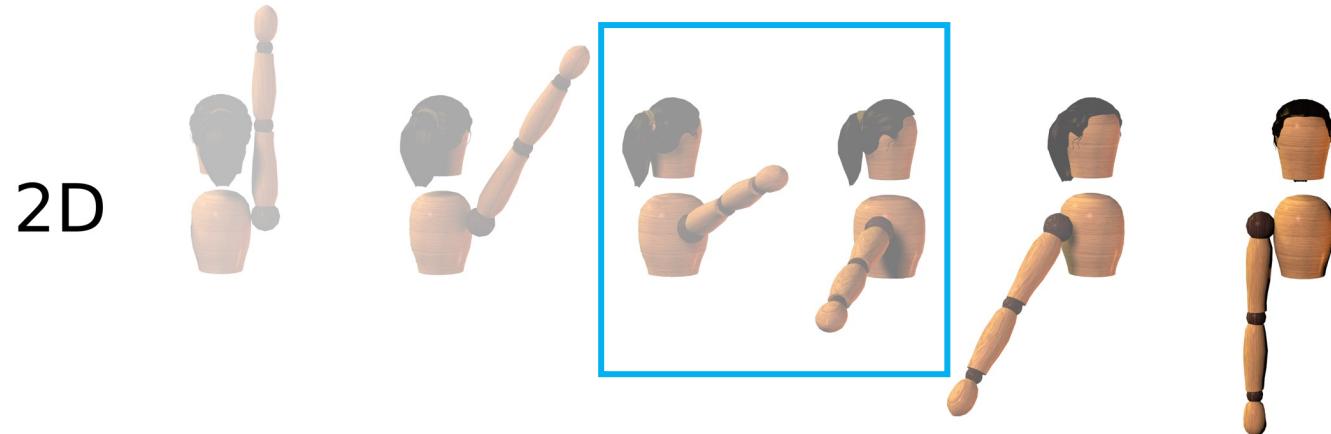
Moving segments in the best tilting plane

Best tilting plane



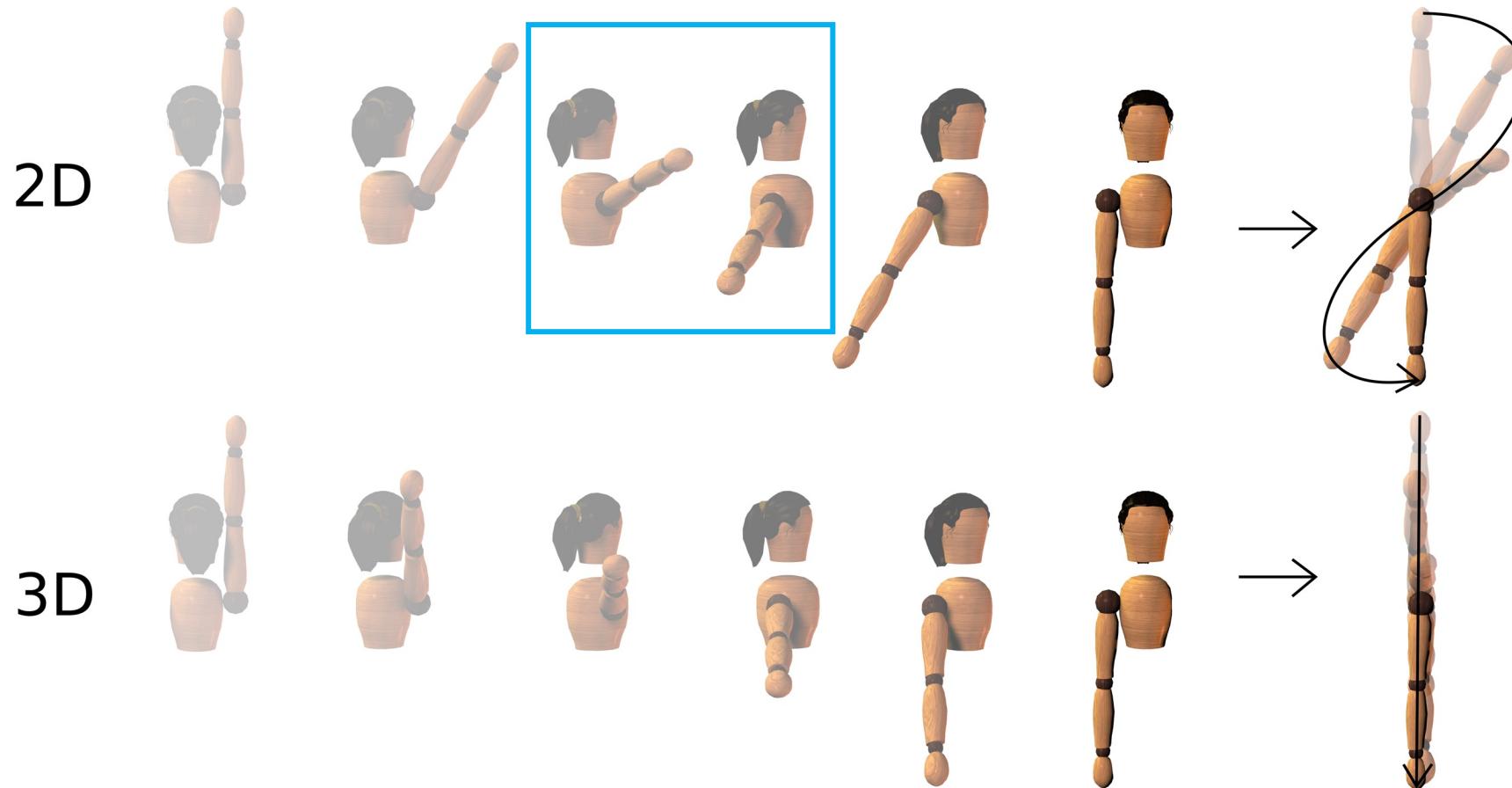
1

Moving segments in the best tilting plane



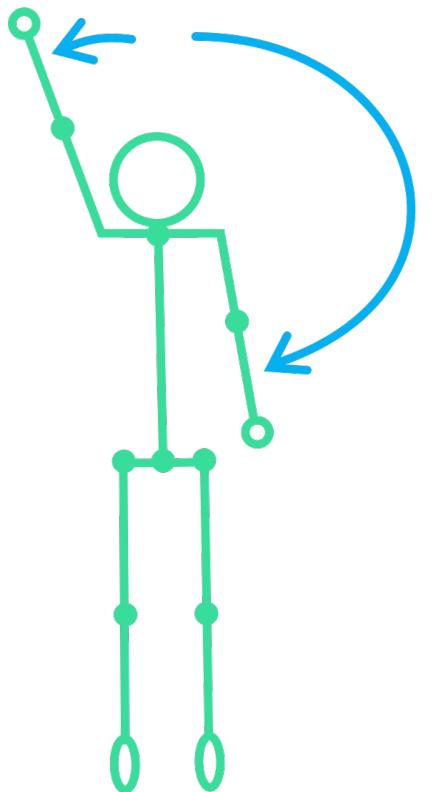
1

Moving segments in the best tilting plane

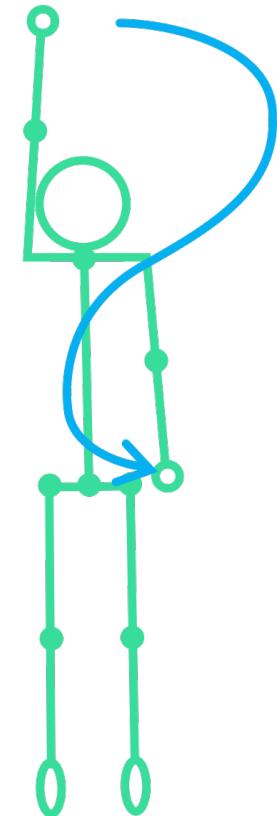


1

Moving segments in the best tilting plane



Coach instructions



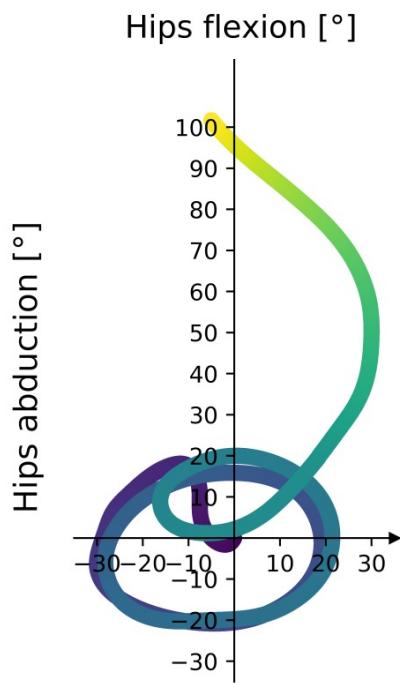
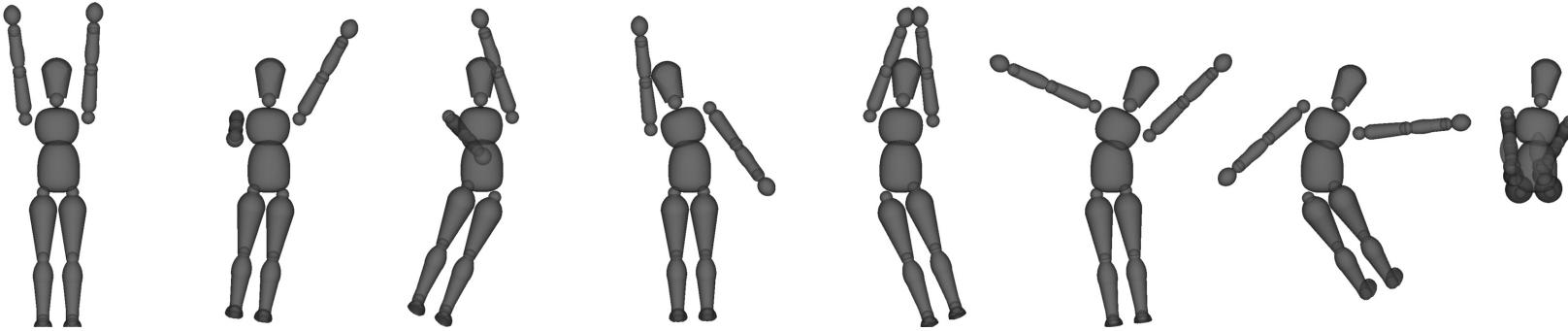
Athlete modifications

1

Moving segments in the best tilting plane



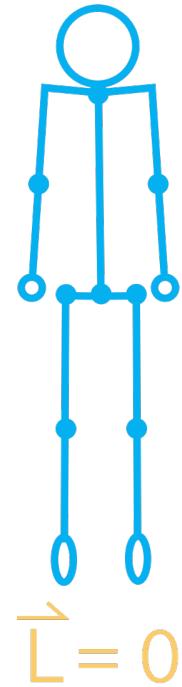
Circular motion of the hips



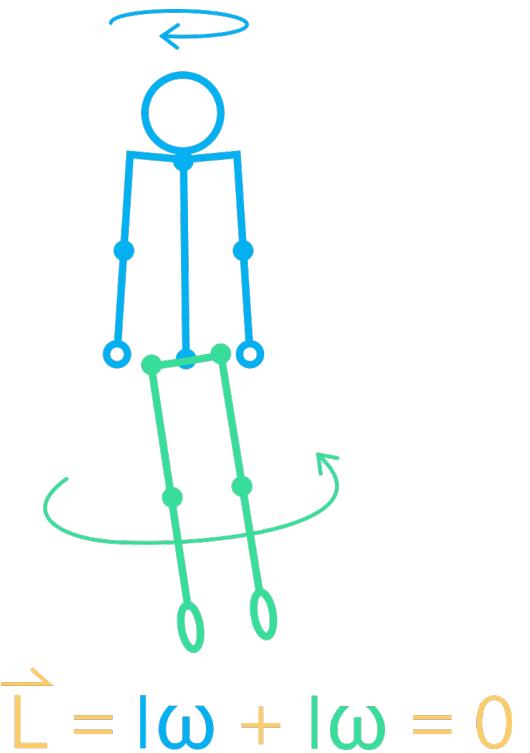
2

Circular motion of the hips

Cat twist

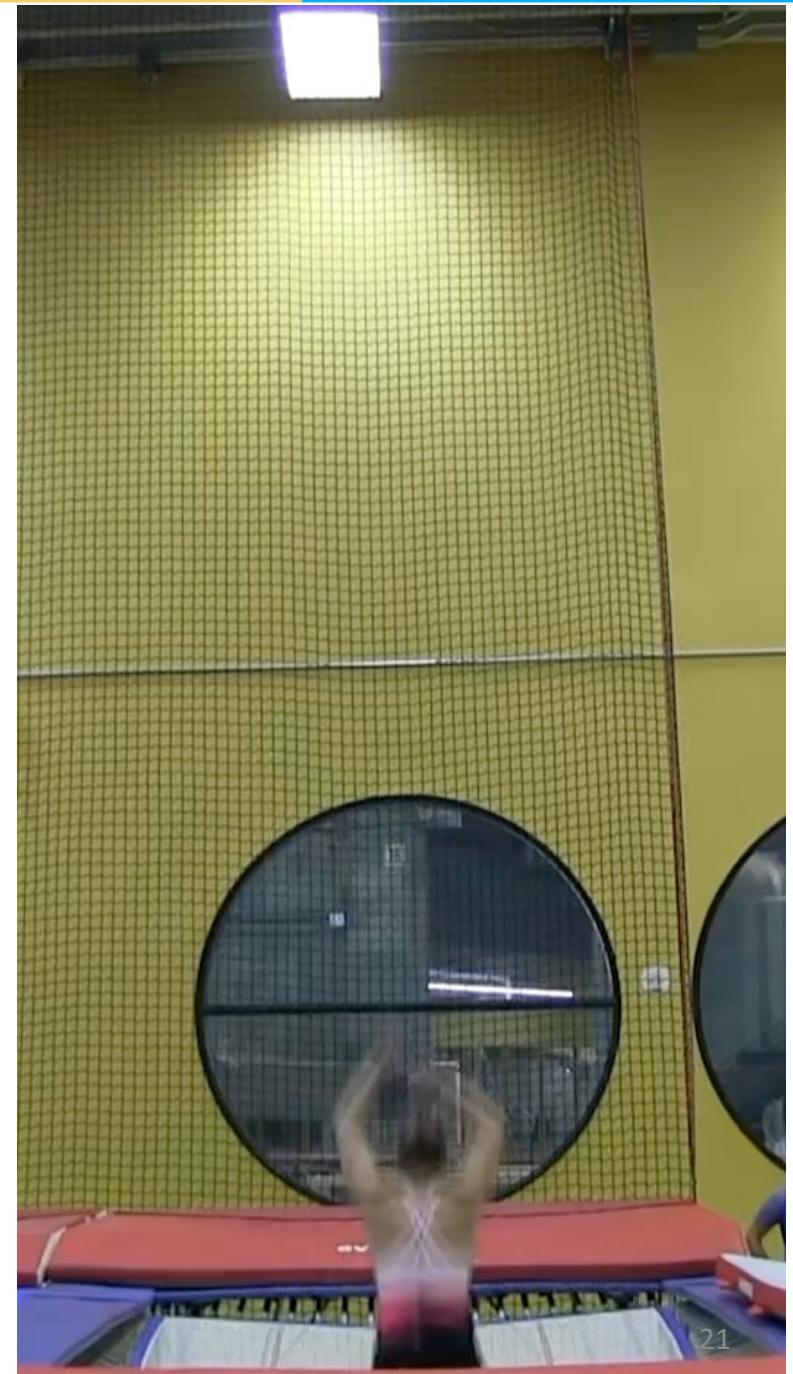


$$\vec{L} = 0$$



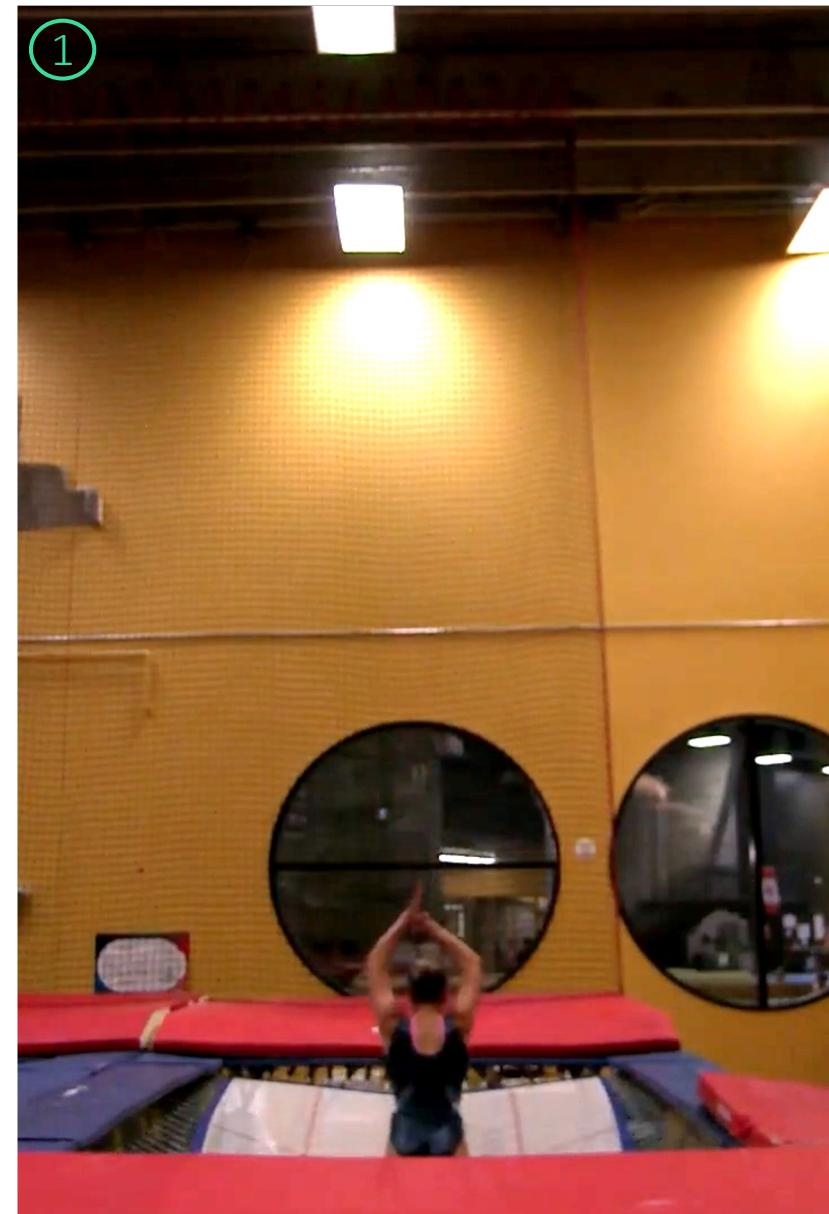
$$\vec{L} = |\omega + | \omega = 0$$

+ aerial twist contributions



3

Adjustments might be needed

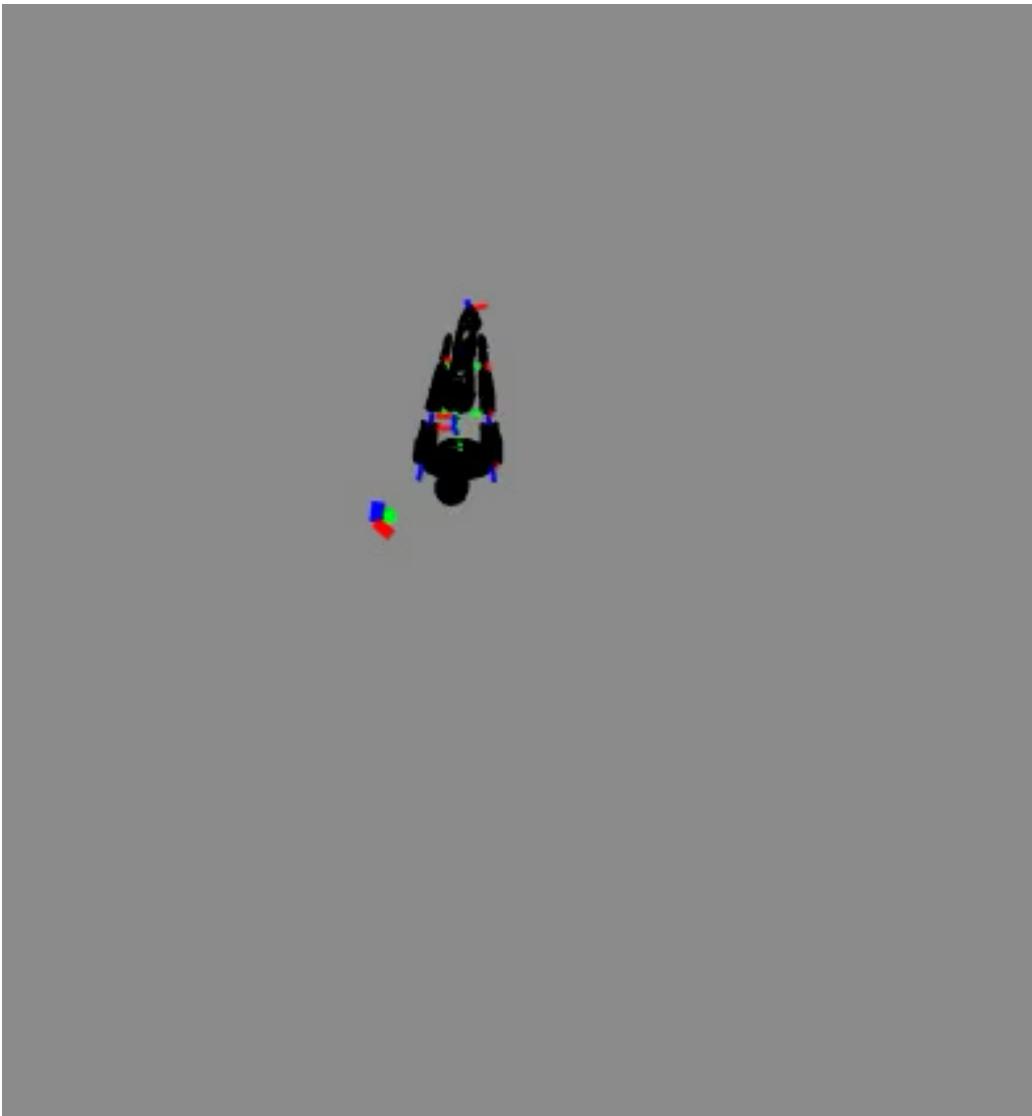


① Twisting phase

- Rotation: somersault & twist
- Oscillations: tilt

② Somersaulting phase

- Rotation: somersault
- Oscillations: tilt & twist



Why is that problematic ?

- Not in line with sport regulations
- Harder to keep track of their orientation

How to transfer from twist to somersault ?

- Rotation velocities
- Relative moment of inertia

$$\cos^2 \alpha_0 = A(B - C)/B(A - C)^{[5]}$$

Up to this point...



Practical advices to coaches

~~2D arm
Arms
Rush to pike~~



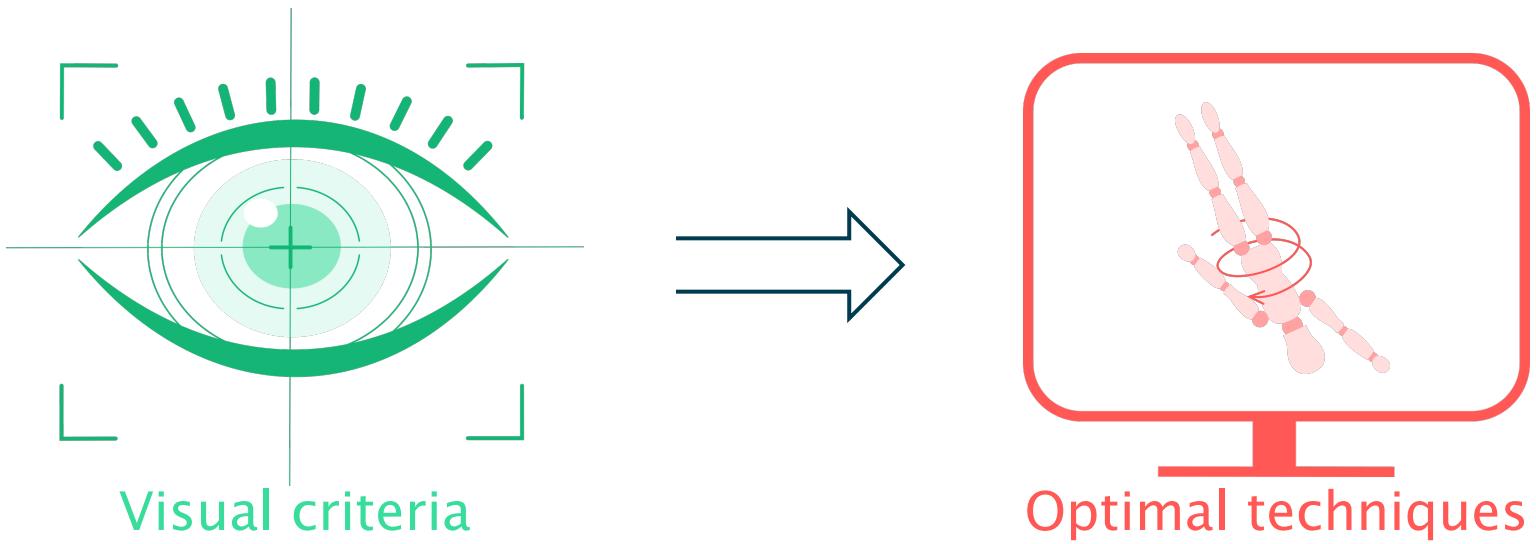
3D arm
Arms + Hips
Take time to adjust



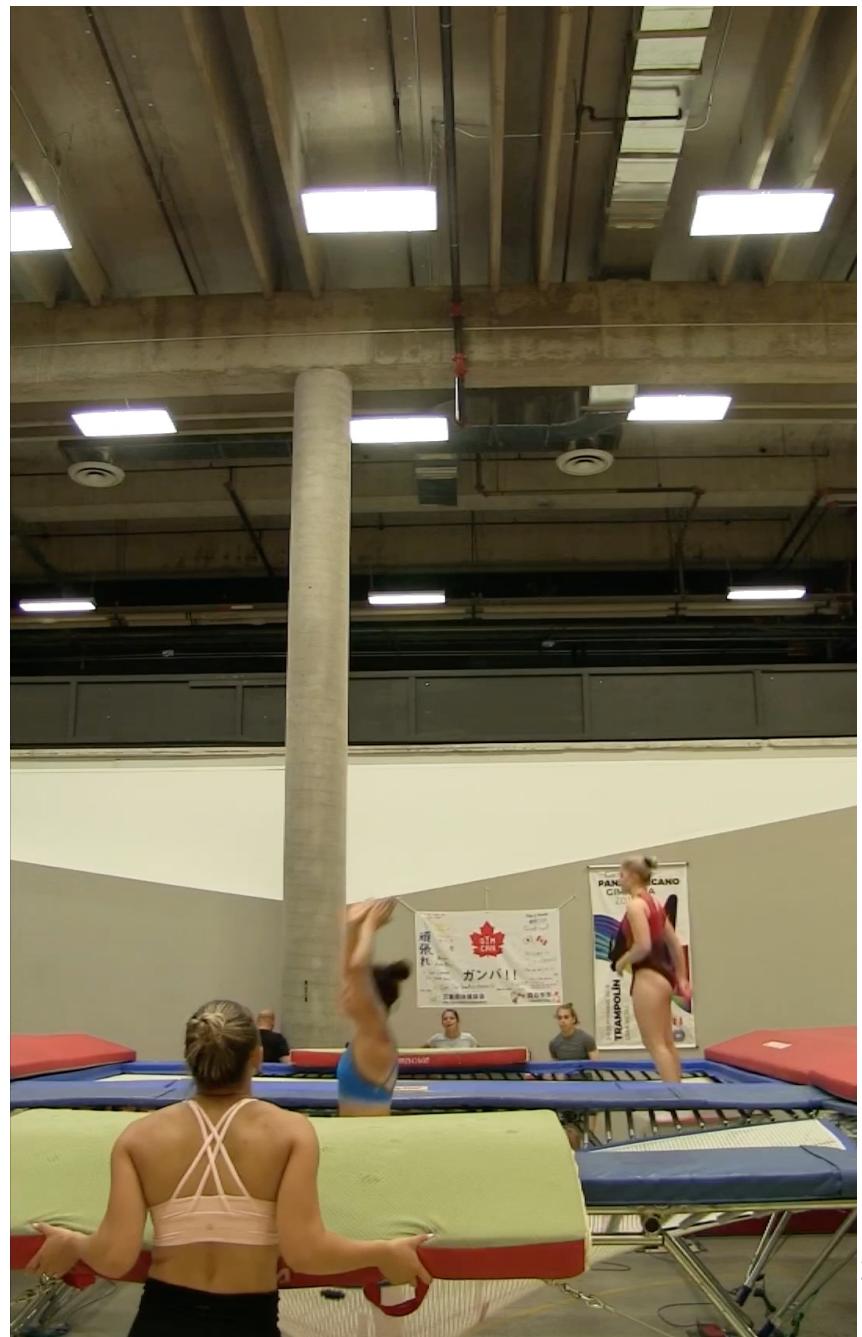
Could not prescribe techniques

- Visual needs
- Propulsion phase

Improvements



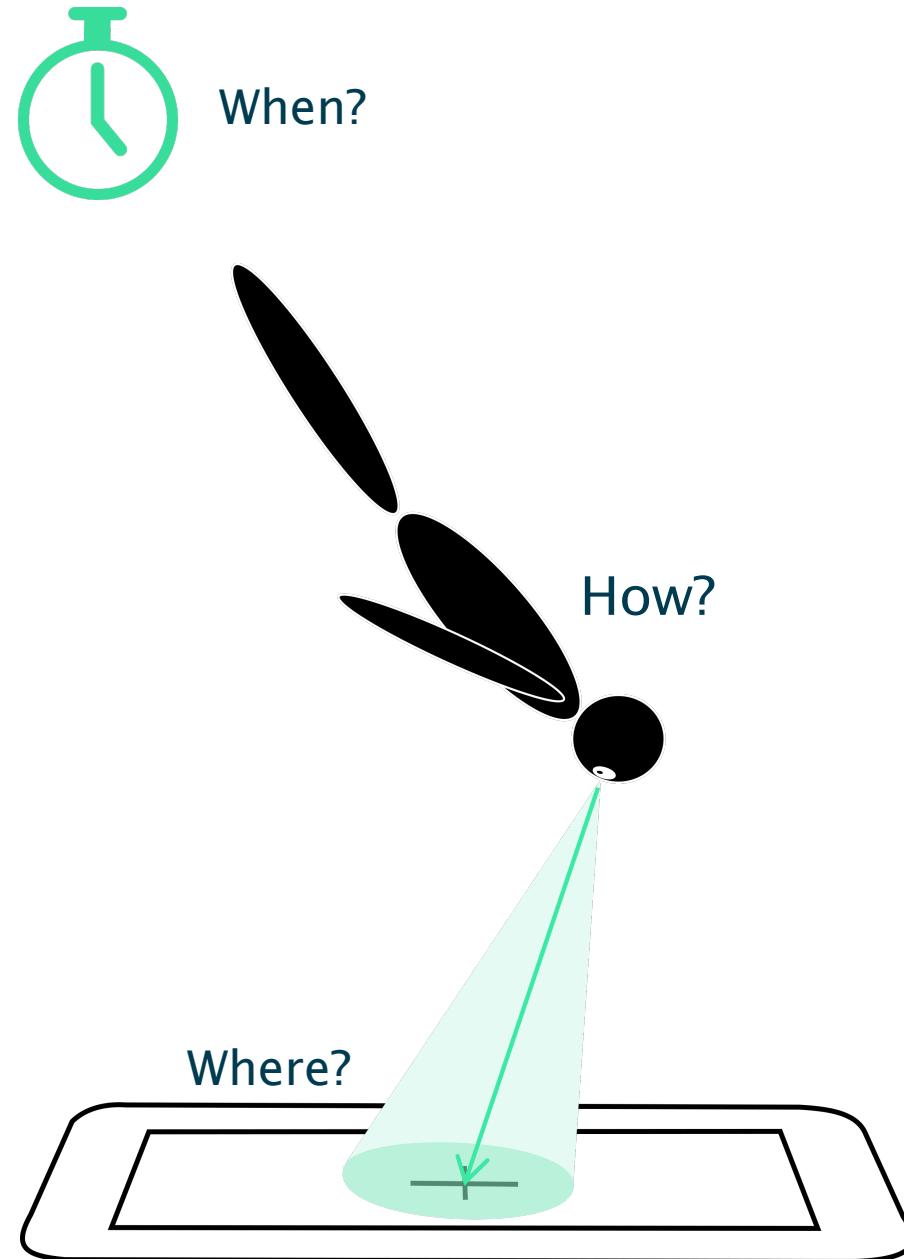
Visual needs



Problem

Lack of literature

- Important part of the sport



Eye-tracking data collection



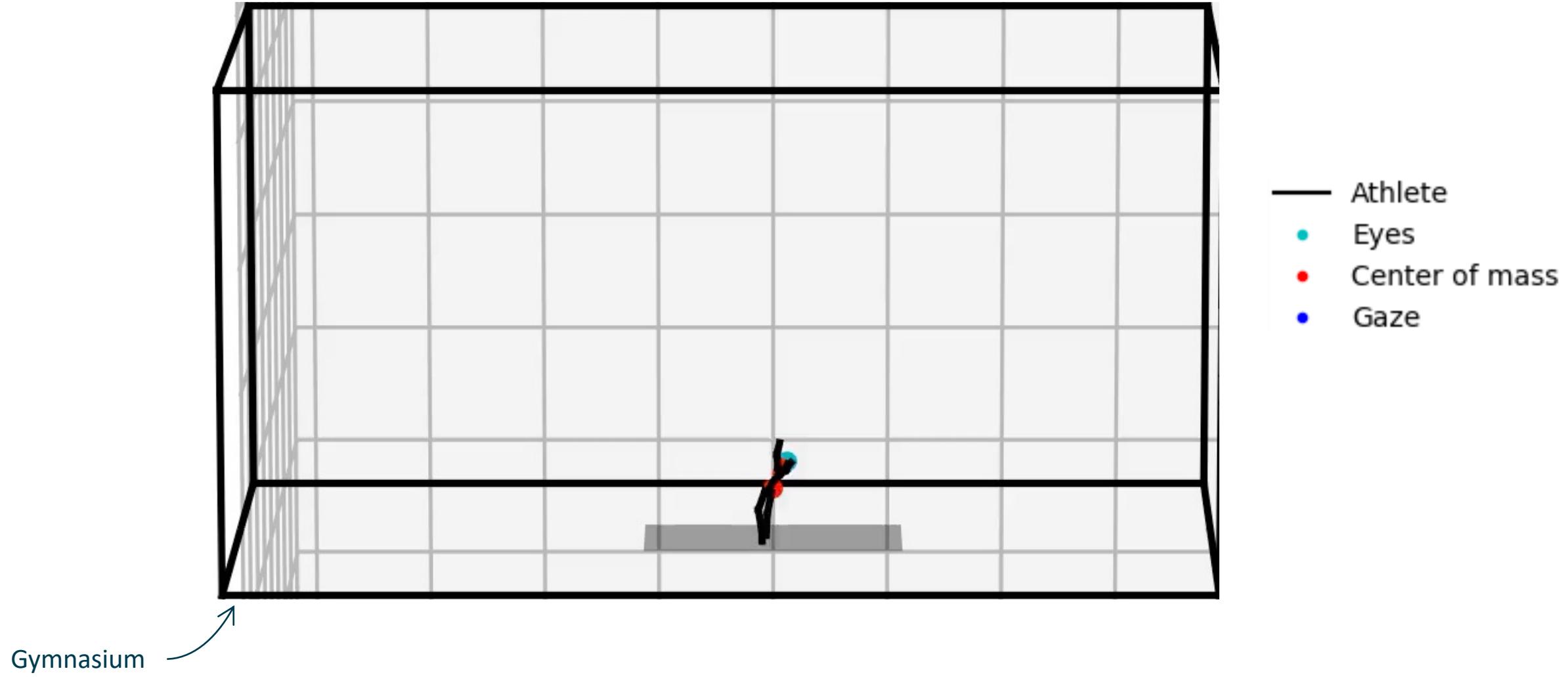
8 elites vs 9 subelites



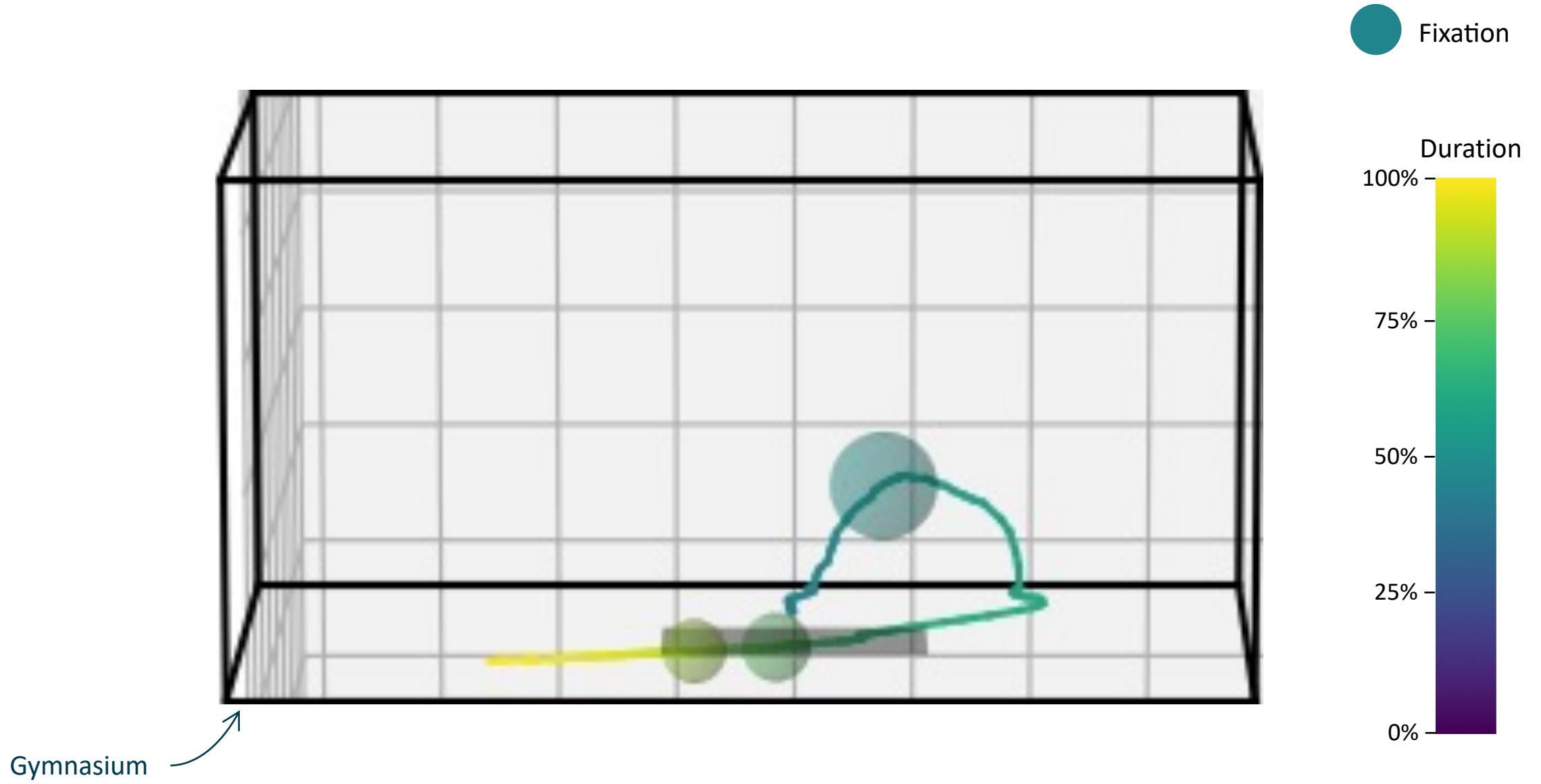
Eye-tracking data collection



Data analysis

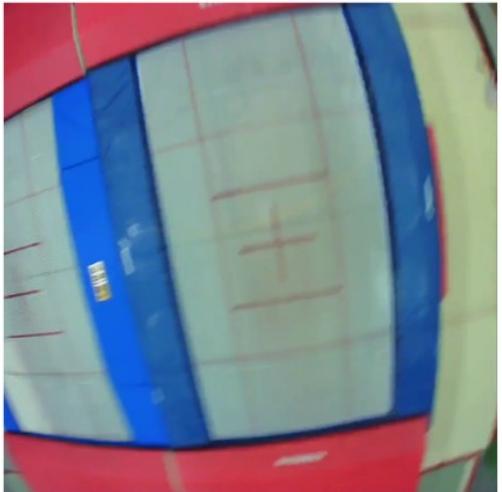


Data analysis

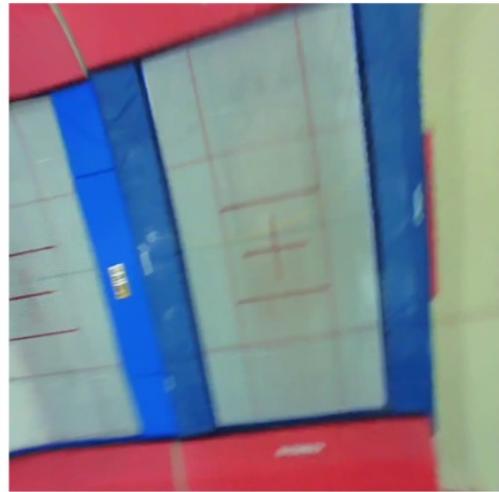


Data analysis

Input video



①



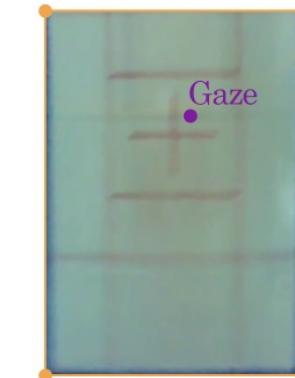
Revert lens distortion

②



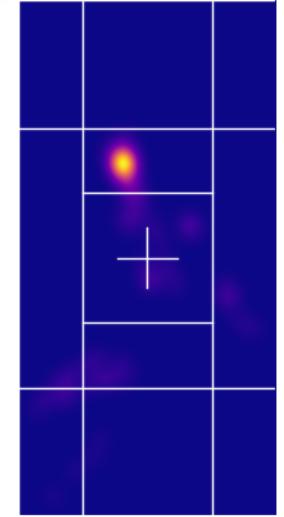
Manually label
key points

③



Change view
point

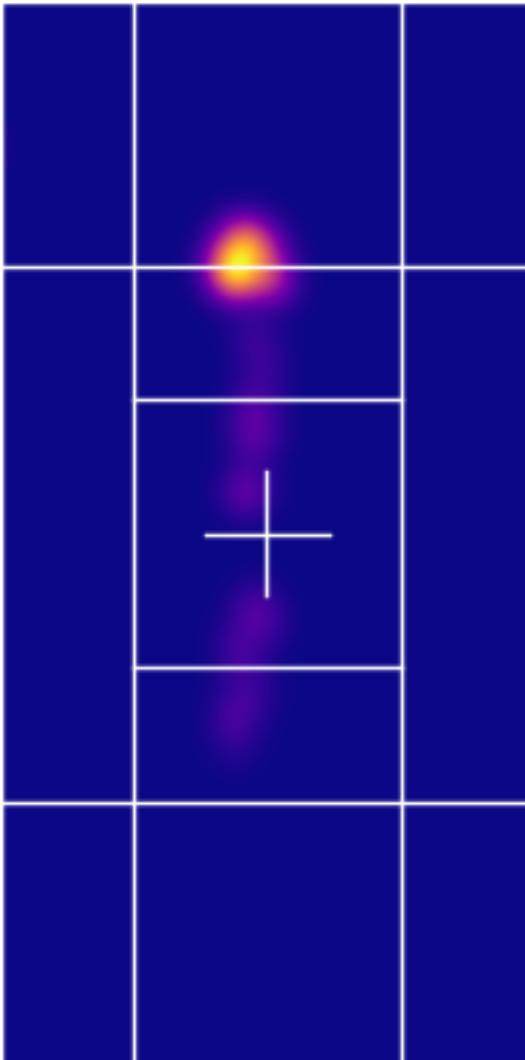
④



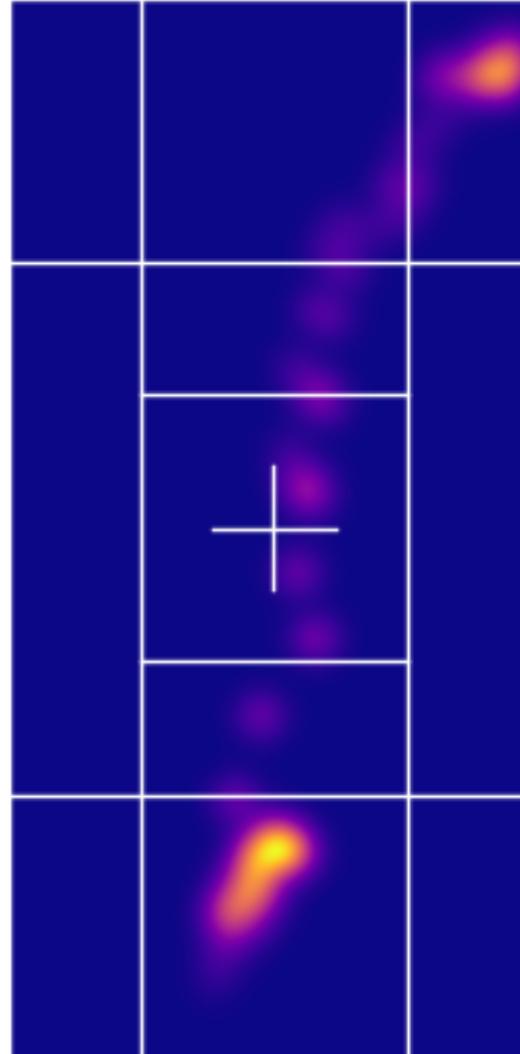
Gaussian
heatmap

Data analysis

Continuous gaze

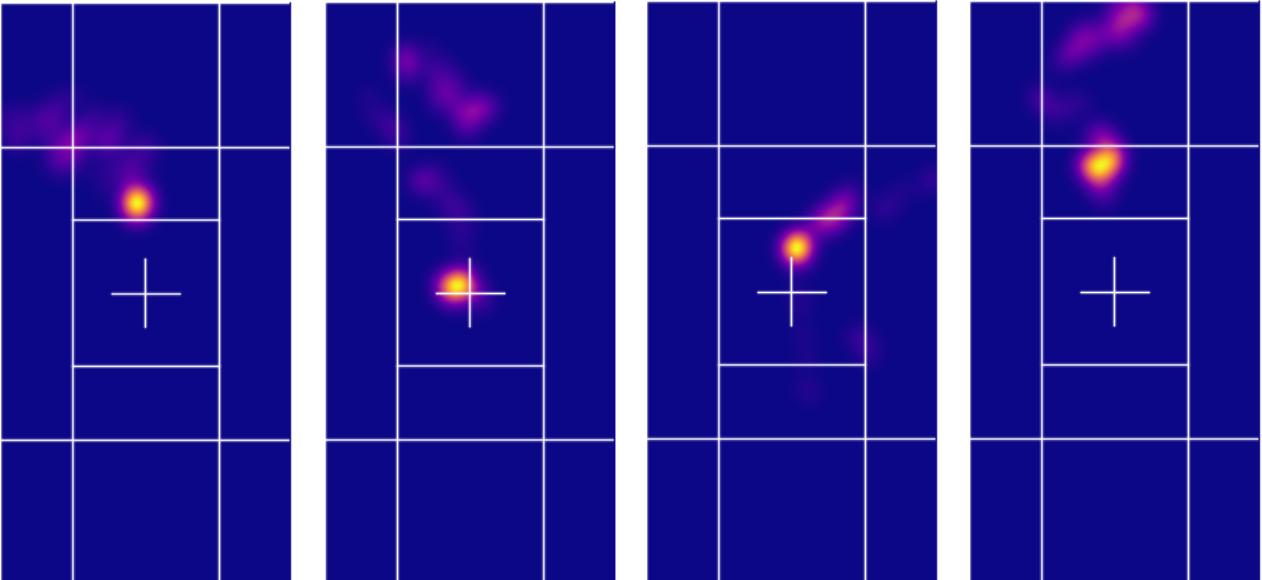


Fixations / saccades

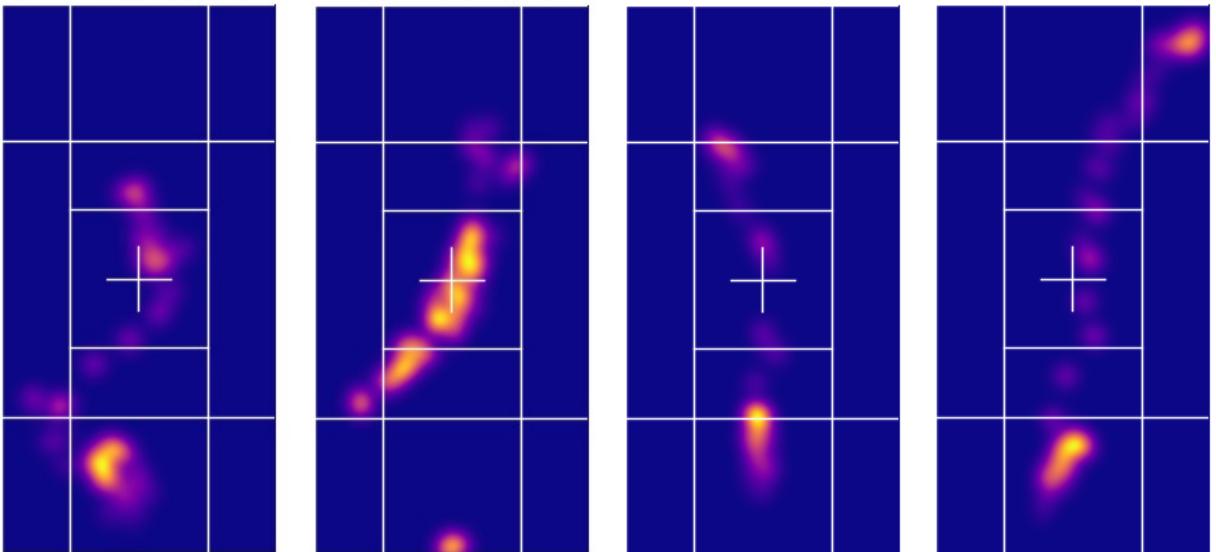


Data analysis

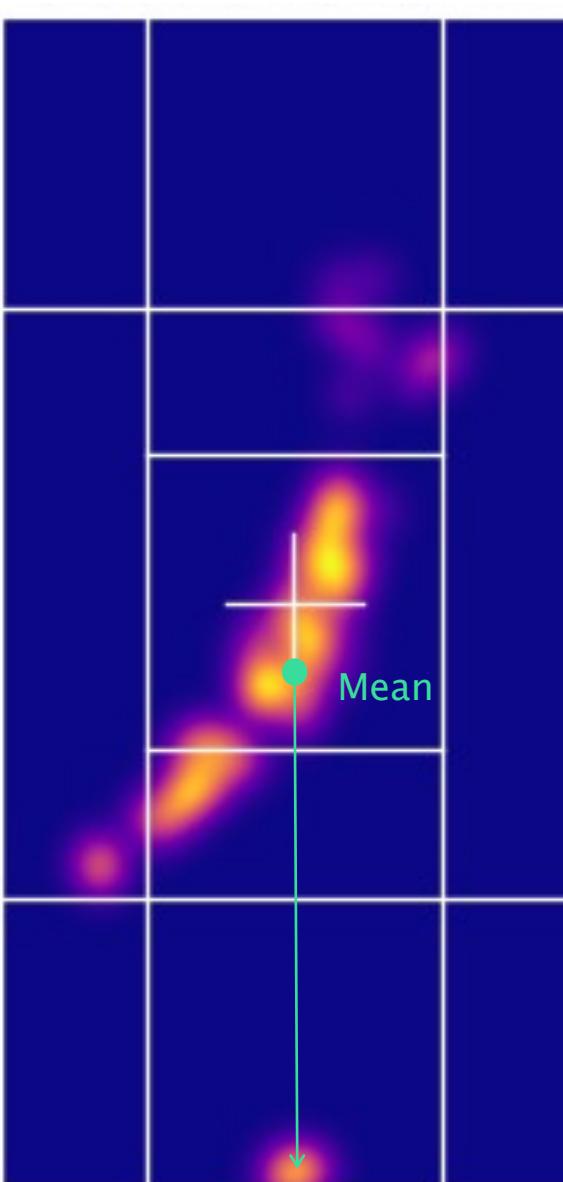
Elites



Subelites

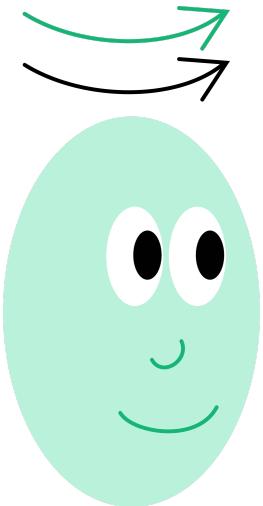


Data analysis

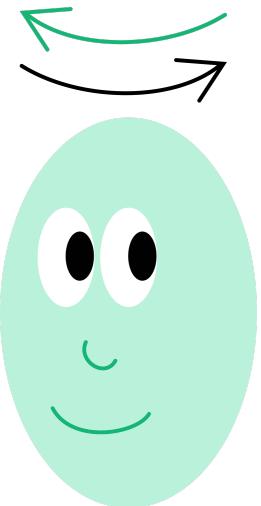


Data analysis

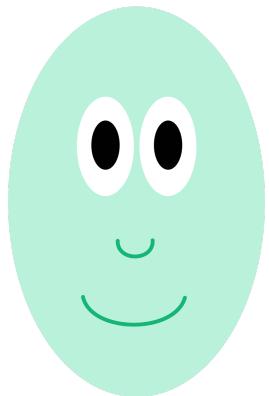
Head & eyes movements



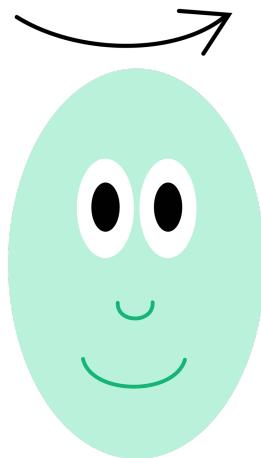
Anticipatory movements



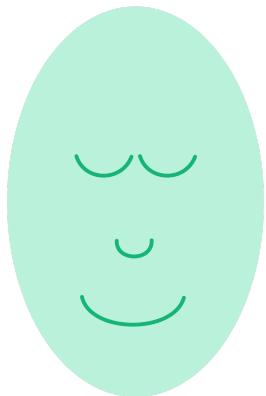
Compensatory movements



Spotting

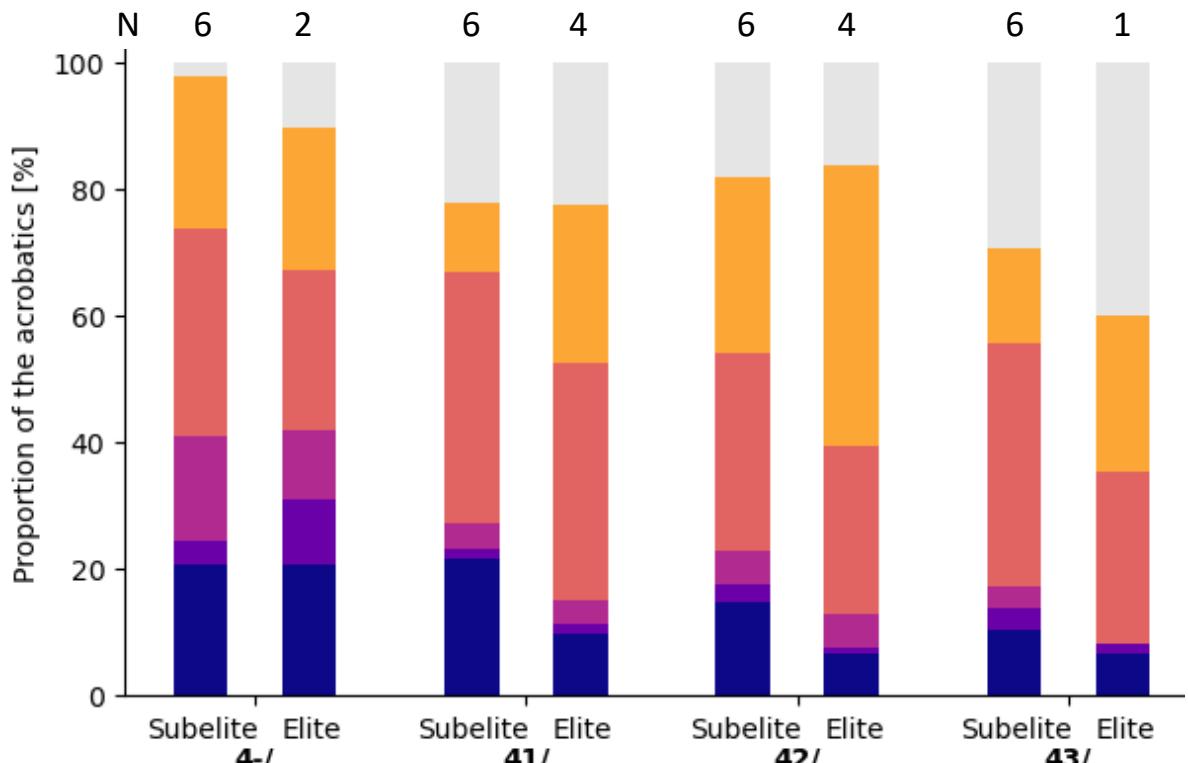
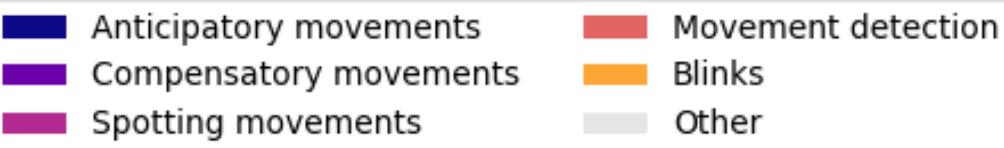


Movement detection



Blinks

Preliminary results



Anticipatory movements



Compensatory movements



Spotting

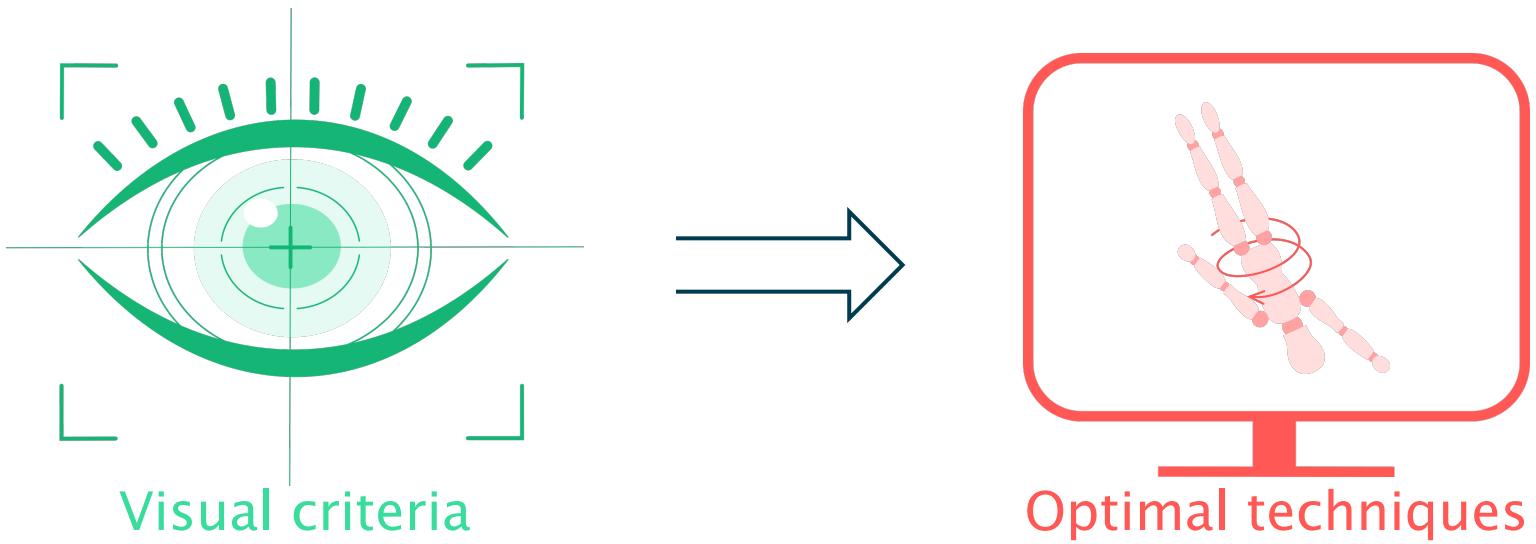


Movement detection



Blinks
37

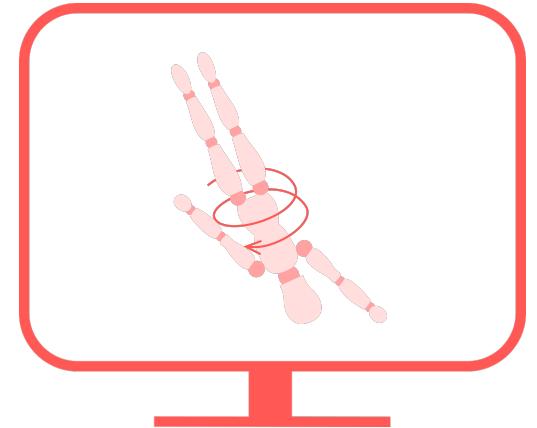
Improvements



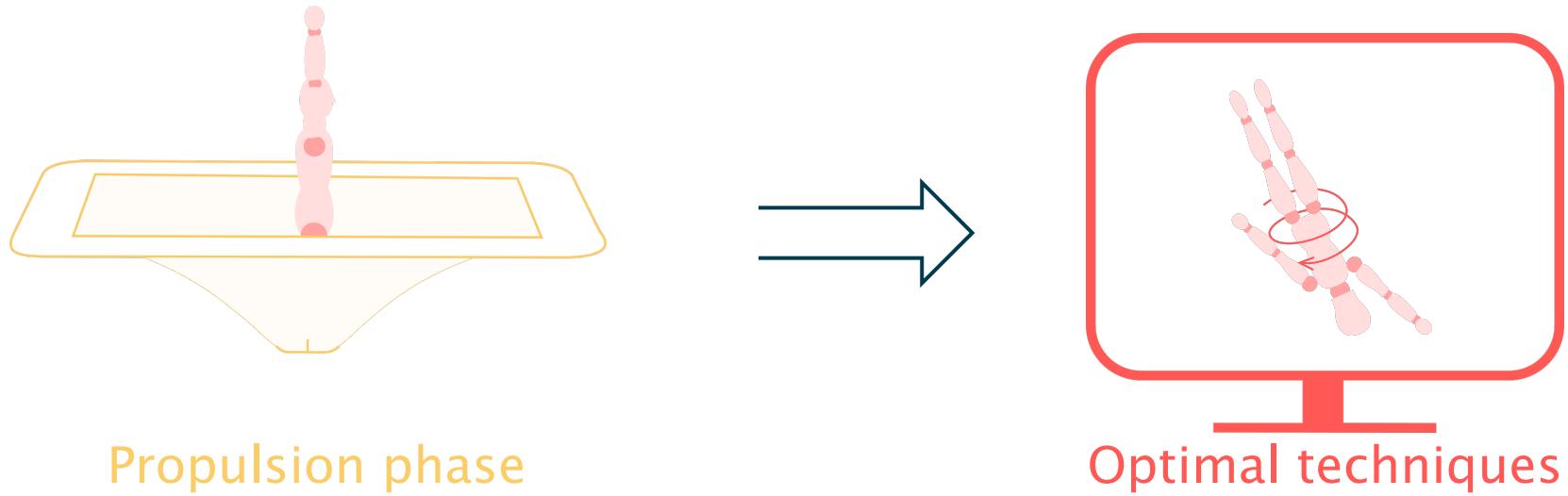
Improvements



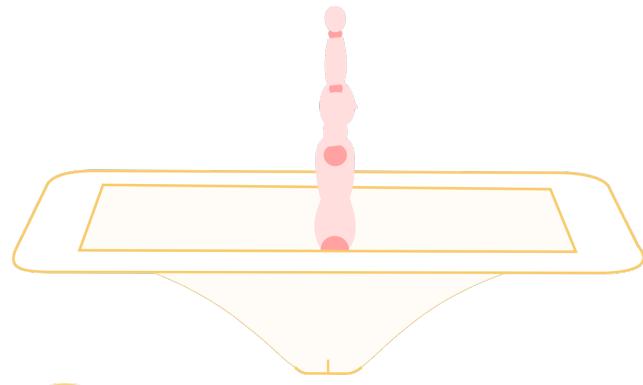
$\min_{q,\dot{q},u,t}$ kinematic and visual objectives
s.t. kinematic and visual constraints



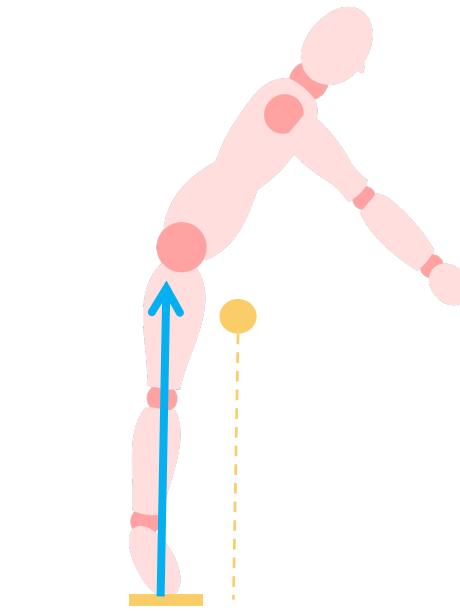
Improvements



Optimal propulsion techniques

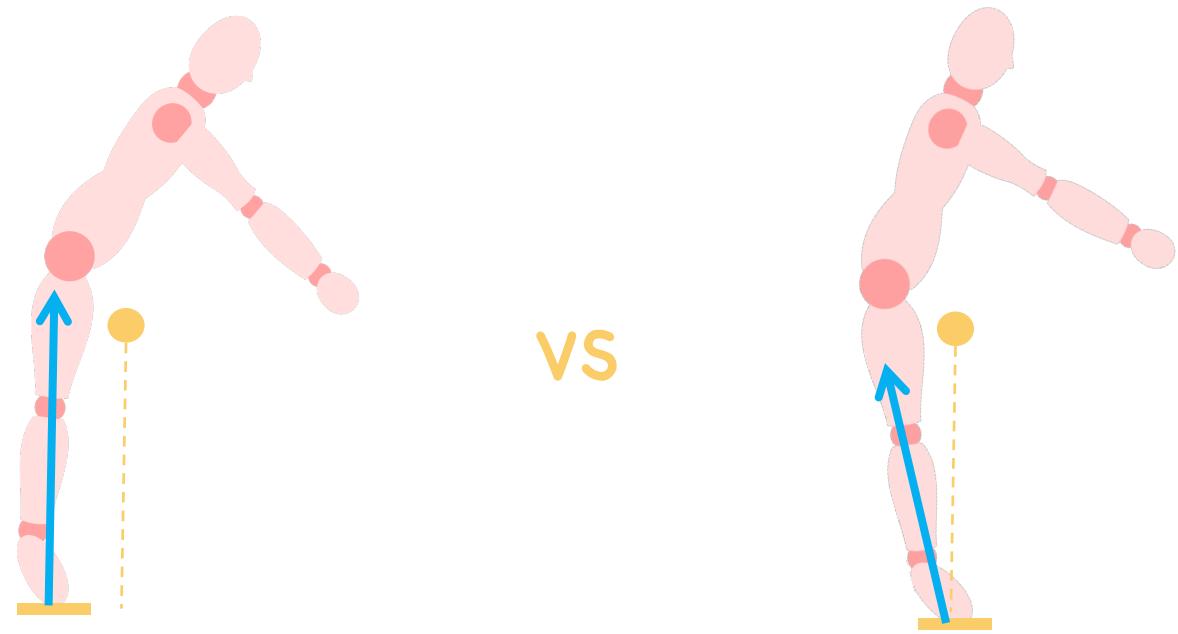


? Linear AND angular momentum



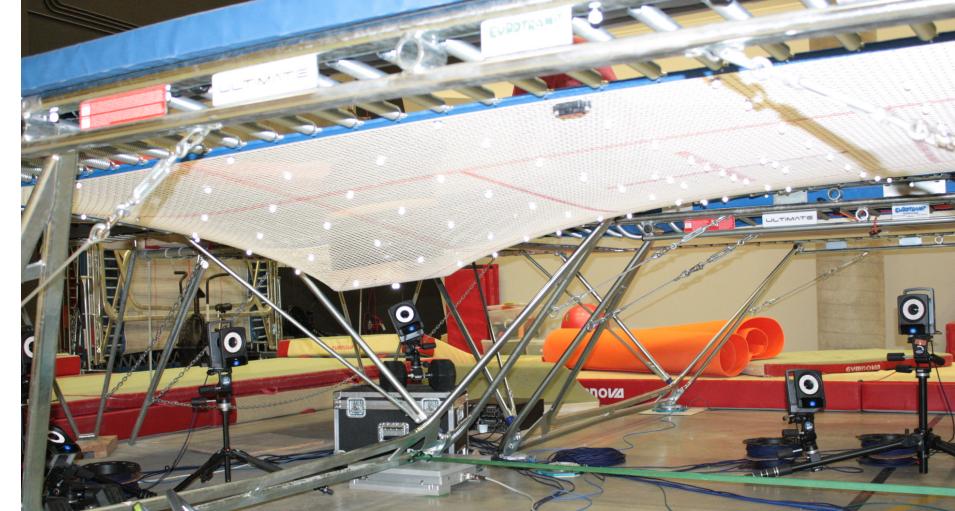
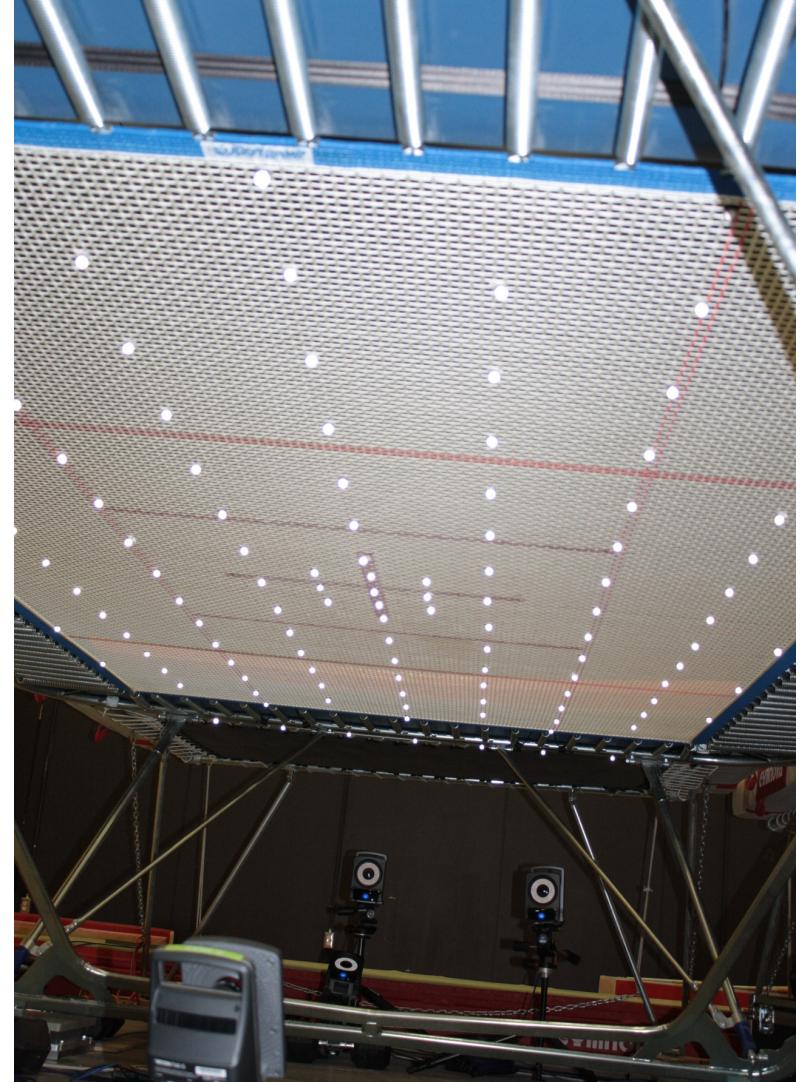
Move CoM

vs

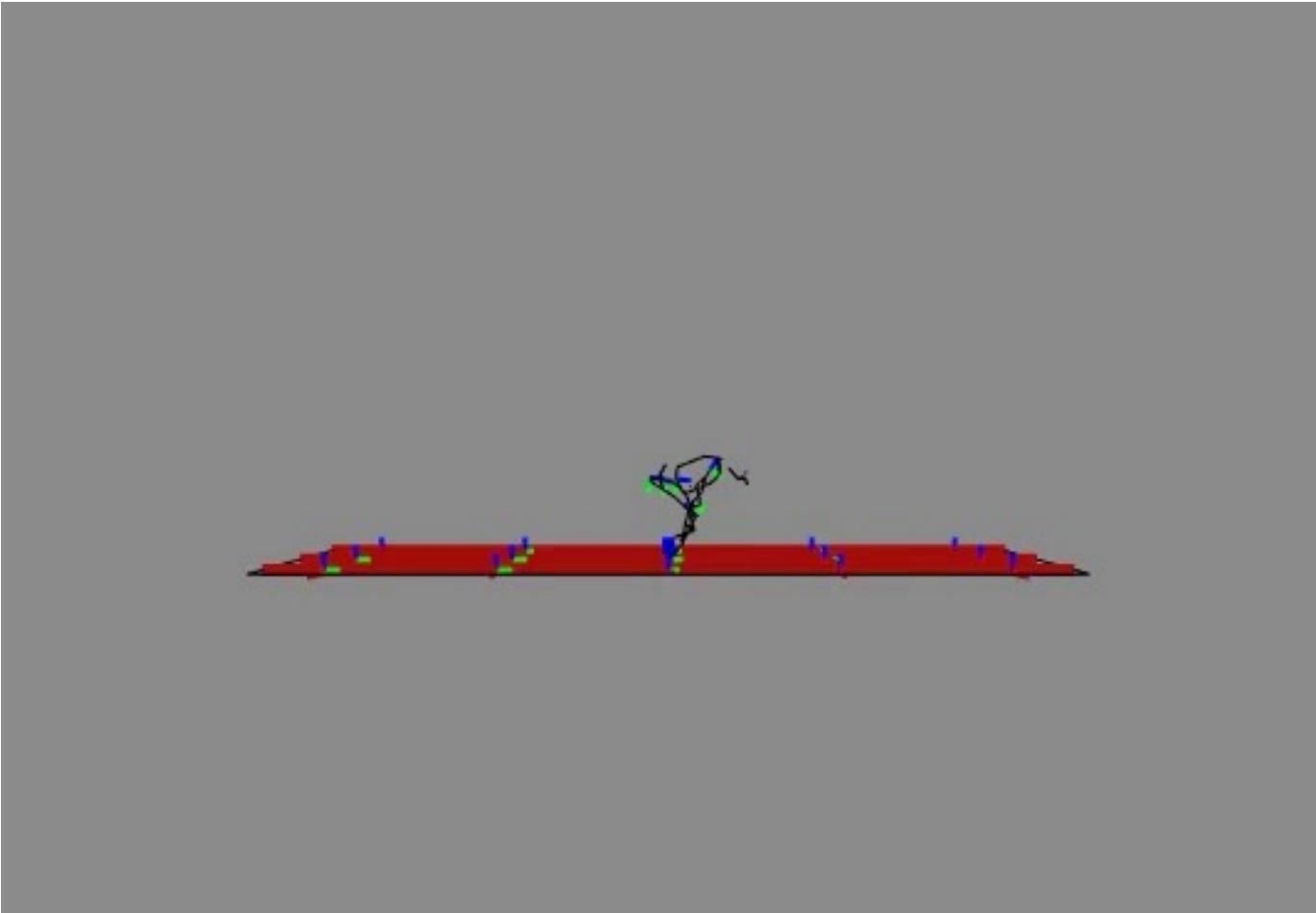


Horizontal deformation

Trampoline data collection



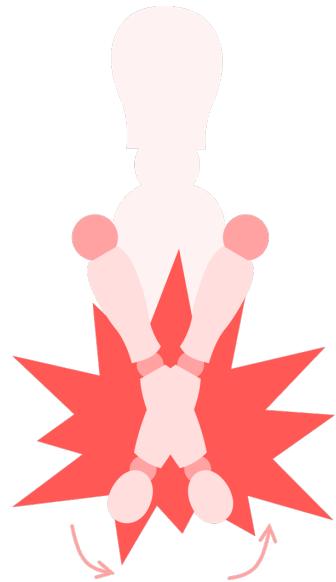
Propulsion phase



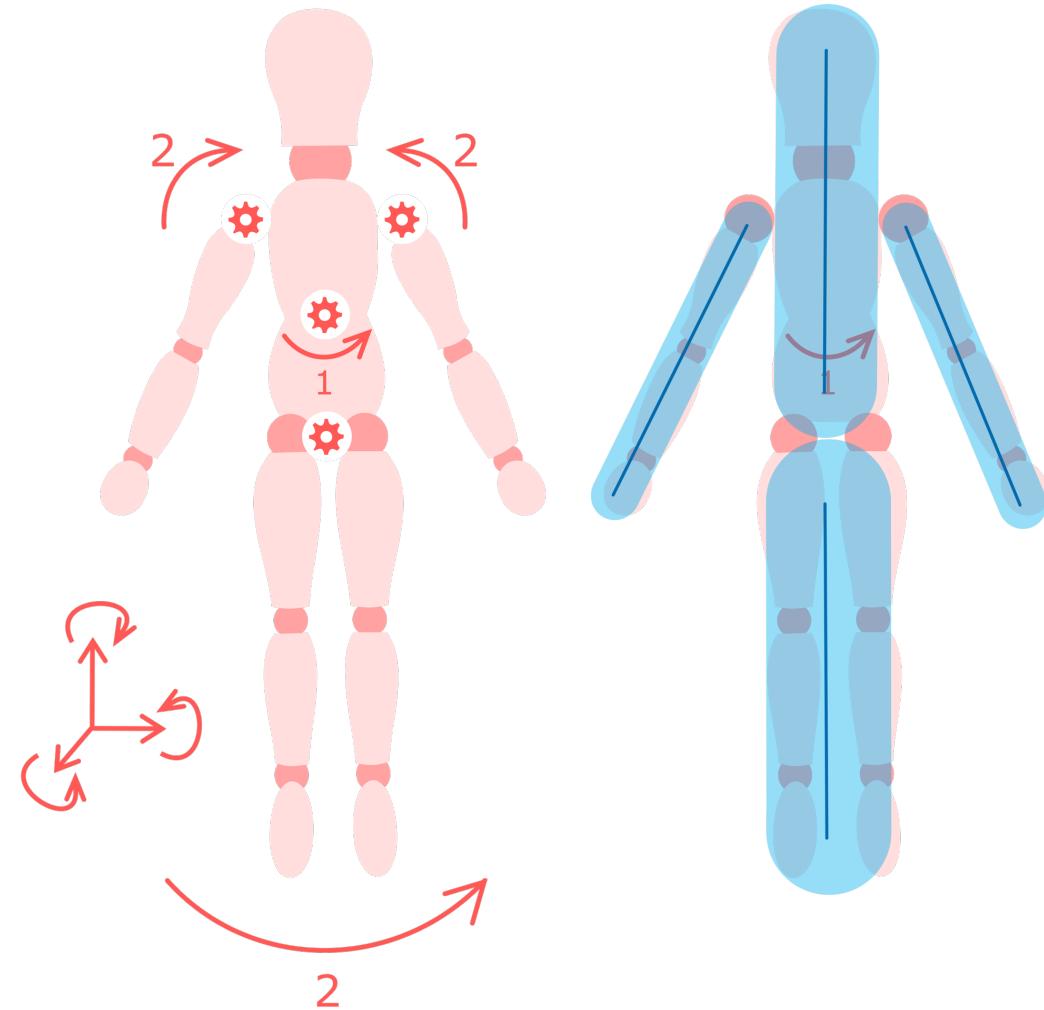
Computational bonus

Computational bonus

1. Self-collision constraint³



Collision



Spherocylinders

Computational bonus

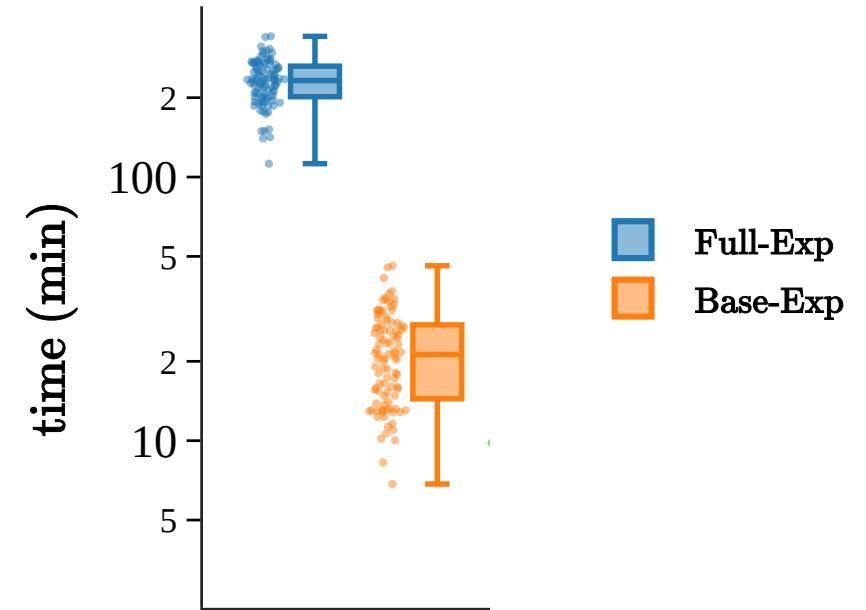
2. Free-floating base dynamics⁶

$$\begin{bmatrix} M_{BB}(\mathbf{q}) & M_{BJ}(\mathbf{q}) \\ M_{JB}(\mathbf{q}) & M_{JJ}(\mathbf{q}) \end{bmatrix} \begin{pmatrix} \ddot{\mathbf{q}}_B \\ \ddot{\mathbf{q}}_J \end{pmatrix} + \begin{pmatrix} N_B(\mathbf{q}, \dot{\mathbf{q}}) \\ N_J(\mathbf{q}, \dot{\mathbf{q}}) \end{pmatrix} = \begin{pmatrix} \mathbf{0}_{6 \times 1} \\ \boldsymbol{\tau}_J \end{pmatrix}$$

Jerk actuated degrees of freedom⁶

$$\mathbf{x} = [\mathbf{q} \ \dot{\mathbf{q}} \ \ddot{\mathbf{q}}]^\top$$

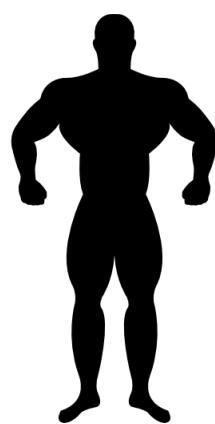
$$\mathbf{u} = \dddot{\mathbf{q}}$$



Future work

Future work

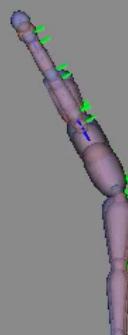
1. Assessing the impact of the athlete's anthropometry on the optimal techniques



VS

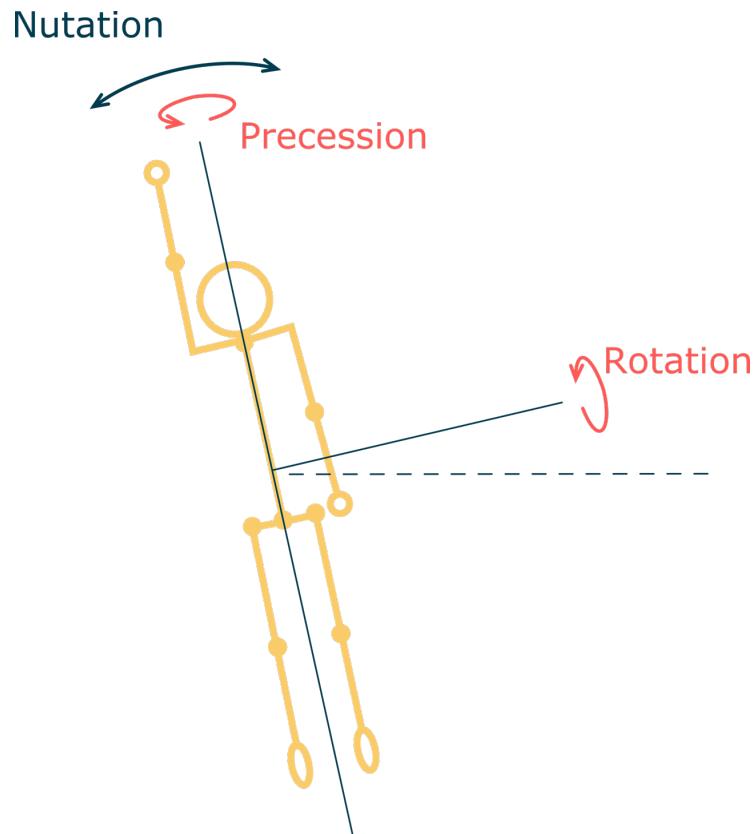


17 athletes
trampoline, diving, gymnastics, artistic swimming

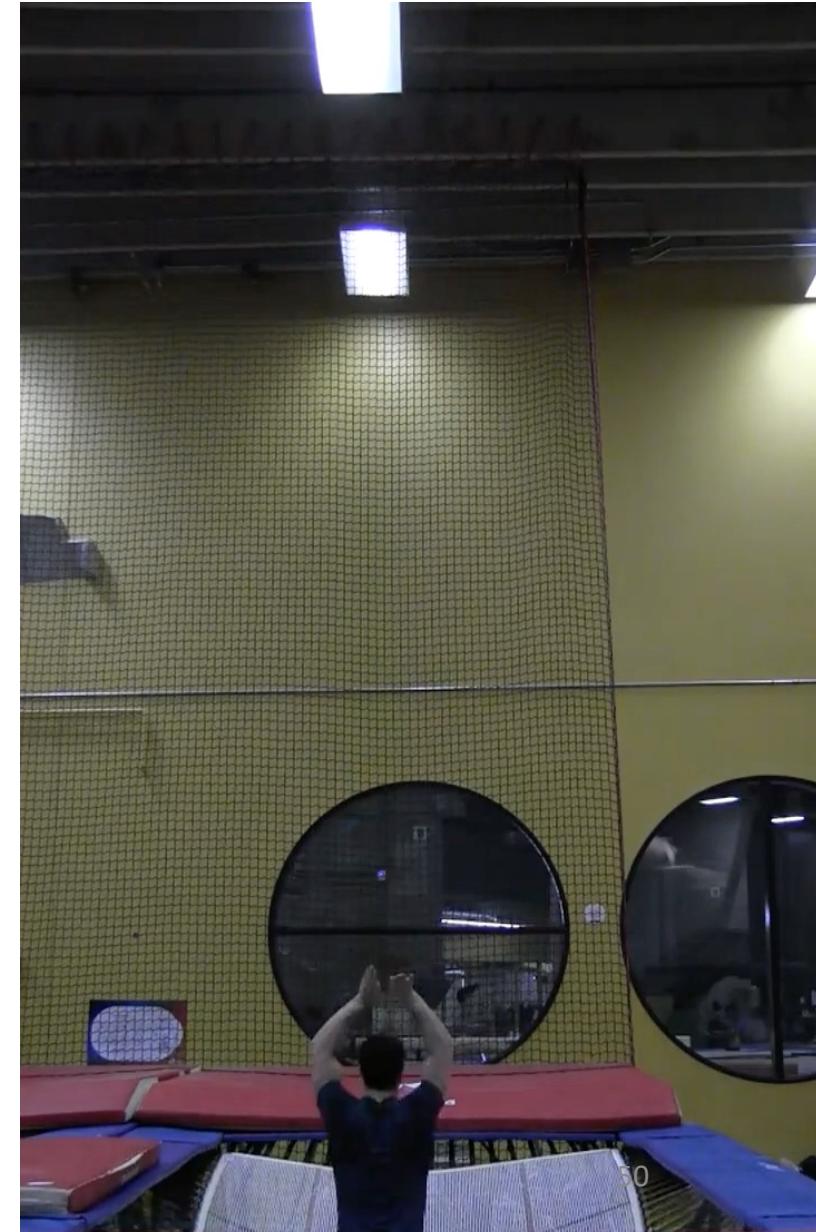
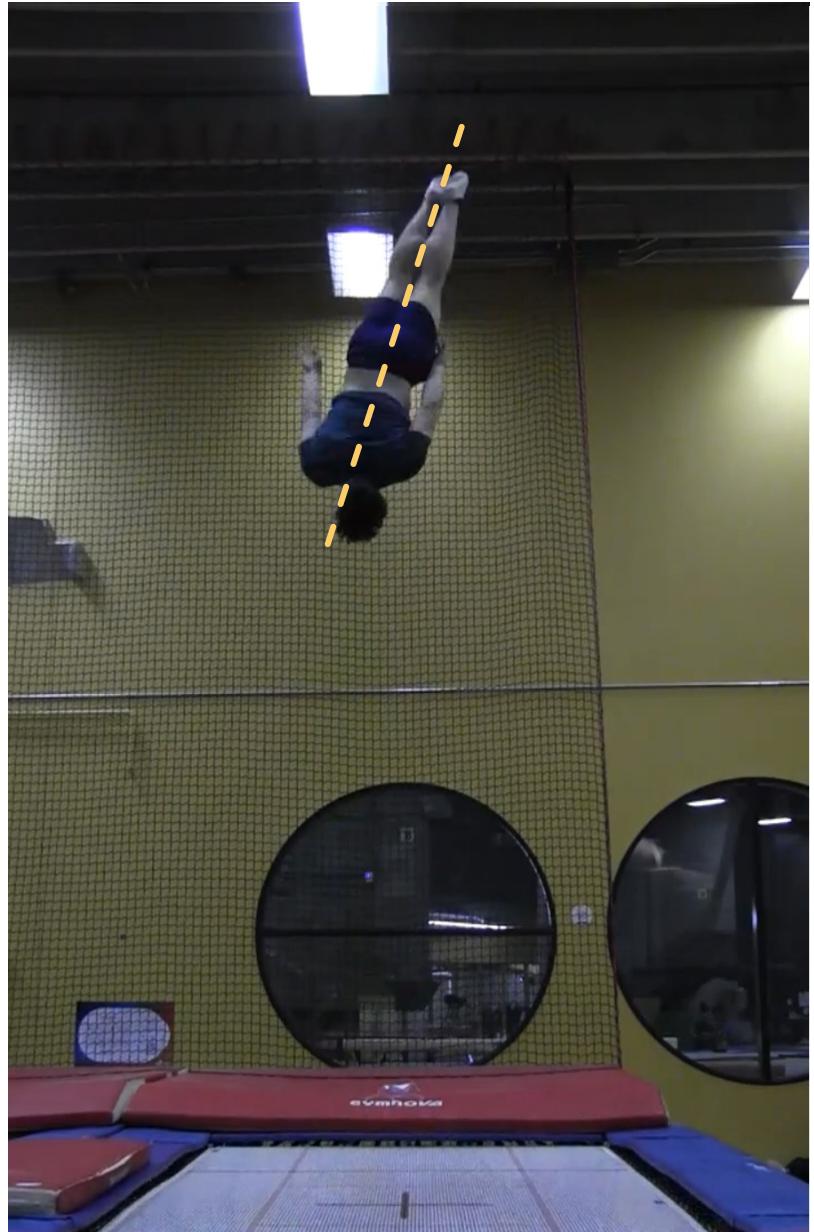


Future work

2. Measure the benefits of the nutation twist technique

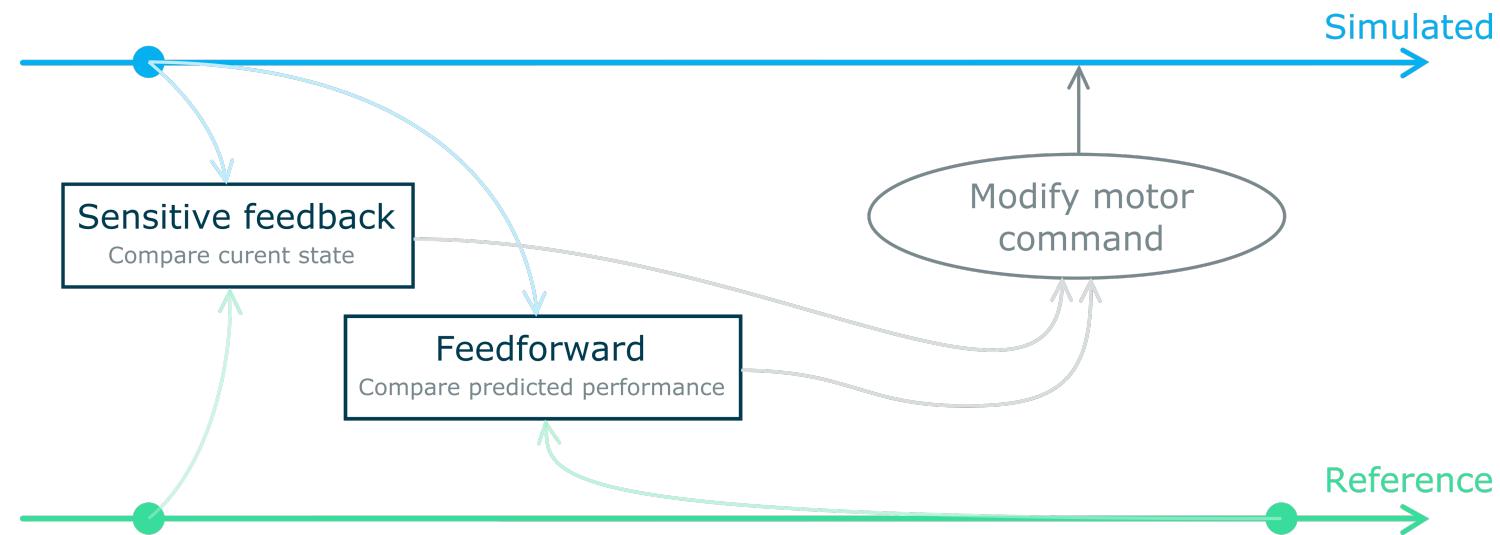


Future work



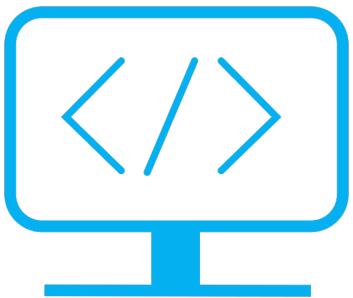
Future work

3. Including feedbacks



Future work

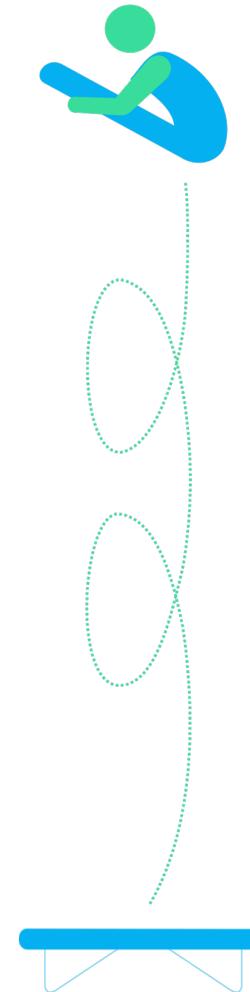
4. Transfer to the field



Case study →

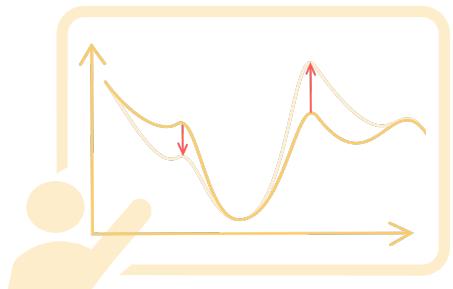


Kinematic differences

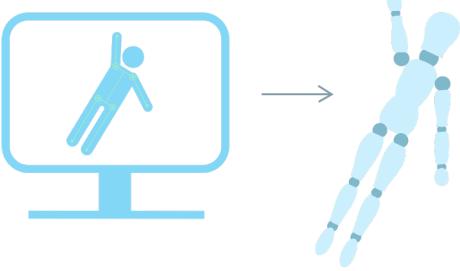


$$\vec{L} = I\vec{\omega}$$
$$\vec{F} = m\vec{a}$$

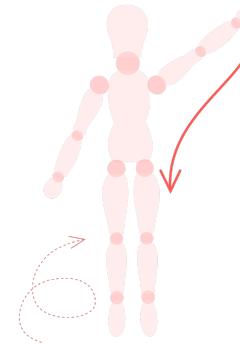
↗ Understanding



Modify athlete's techniques



Increase realism



Appropriate techniques



Performance improvement

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