Exploring biomechanical trampoline strategies through optimal control

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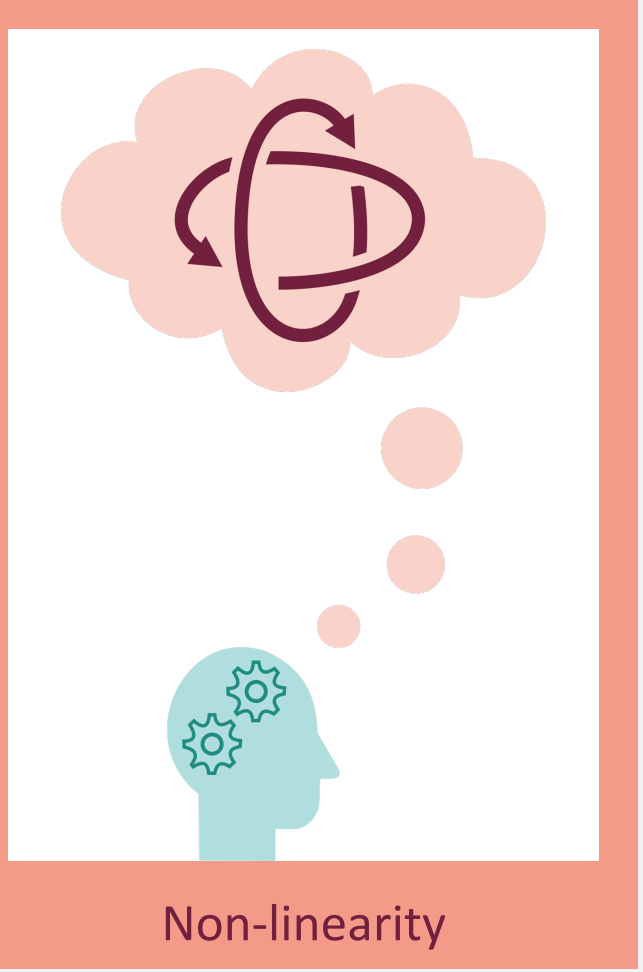
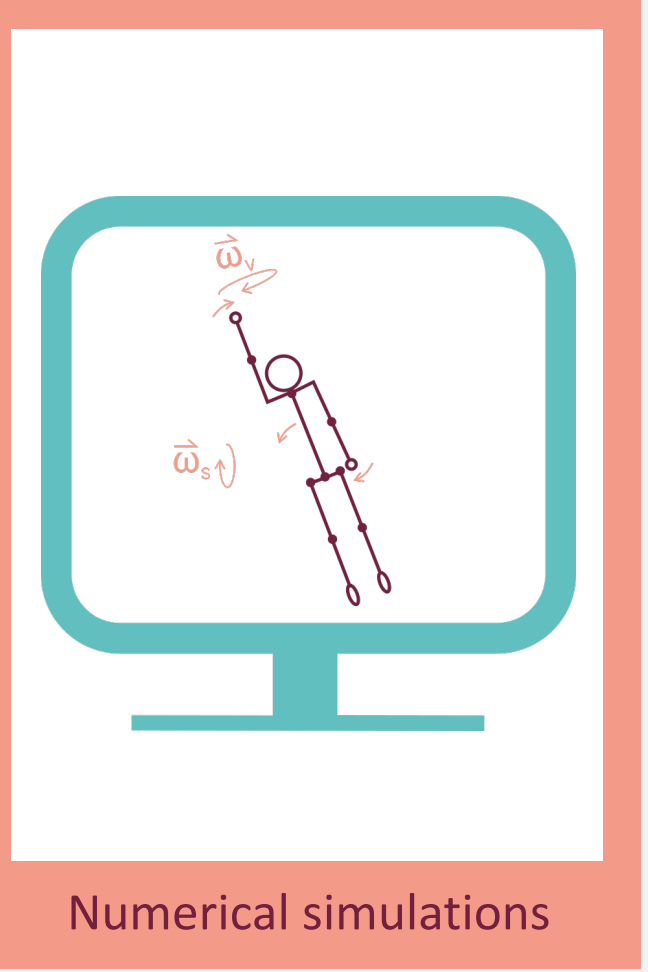


Non-linearity

Injury risks

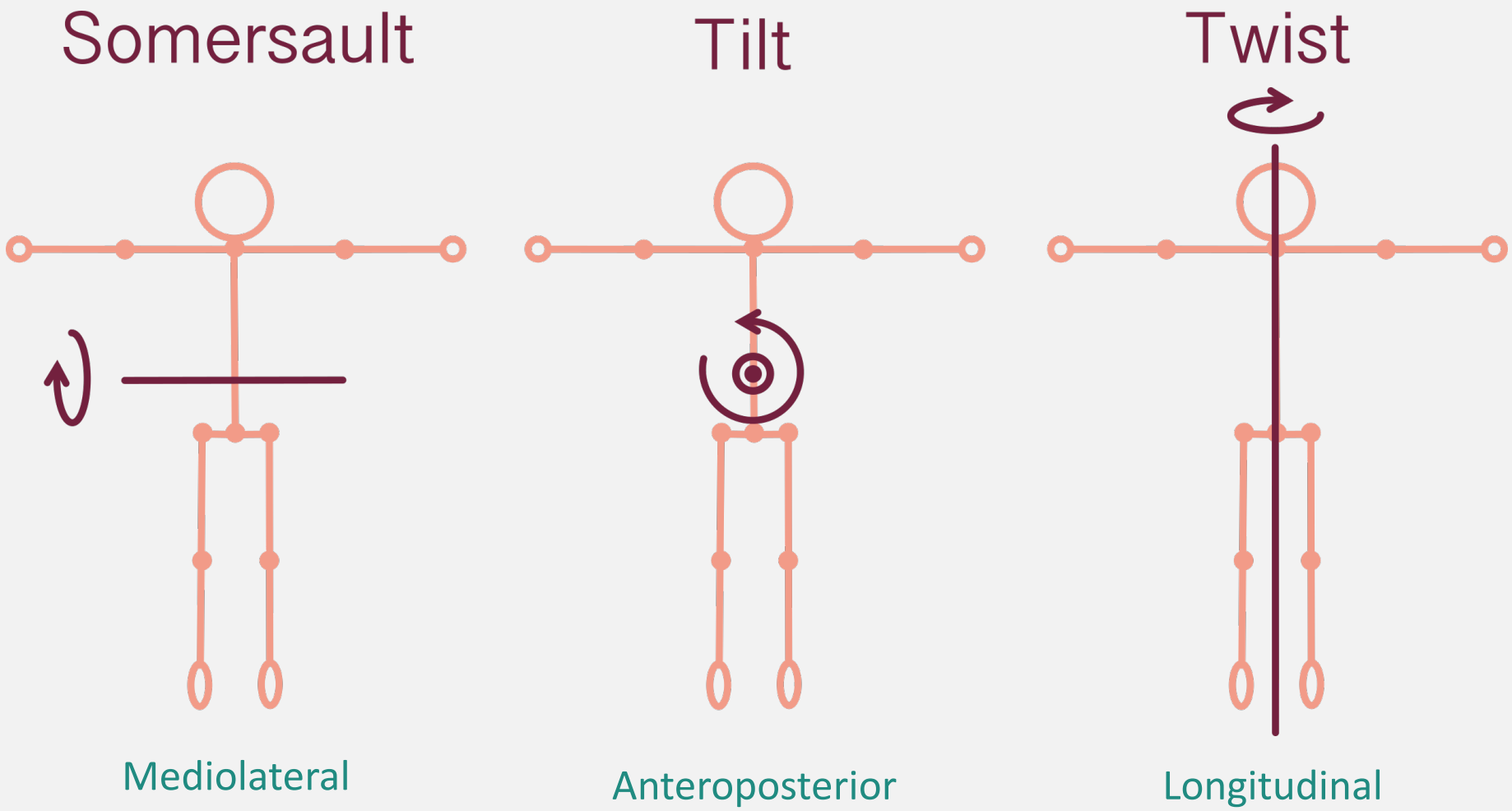


Numerical simulations

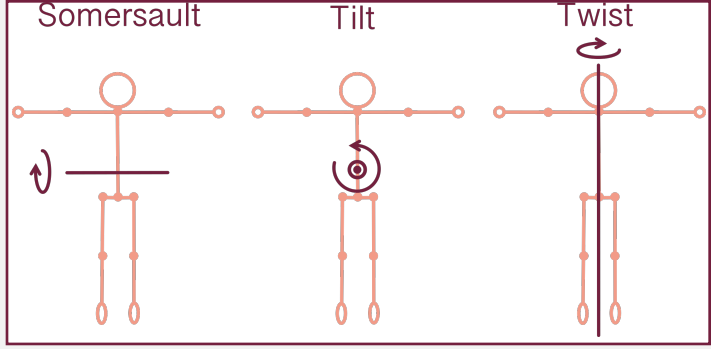
Objective

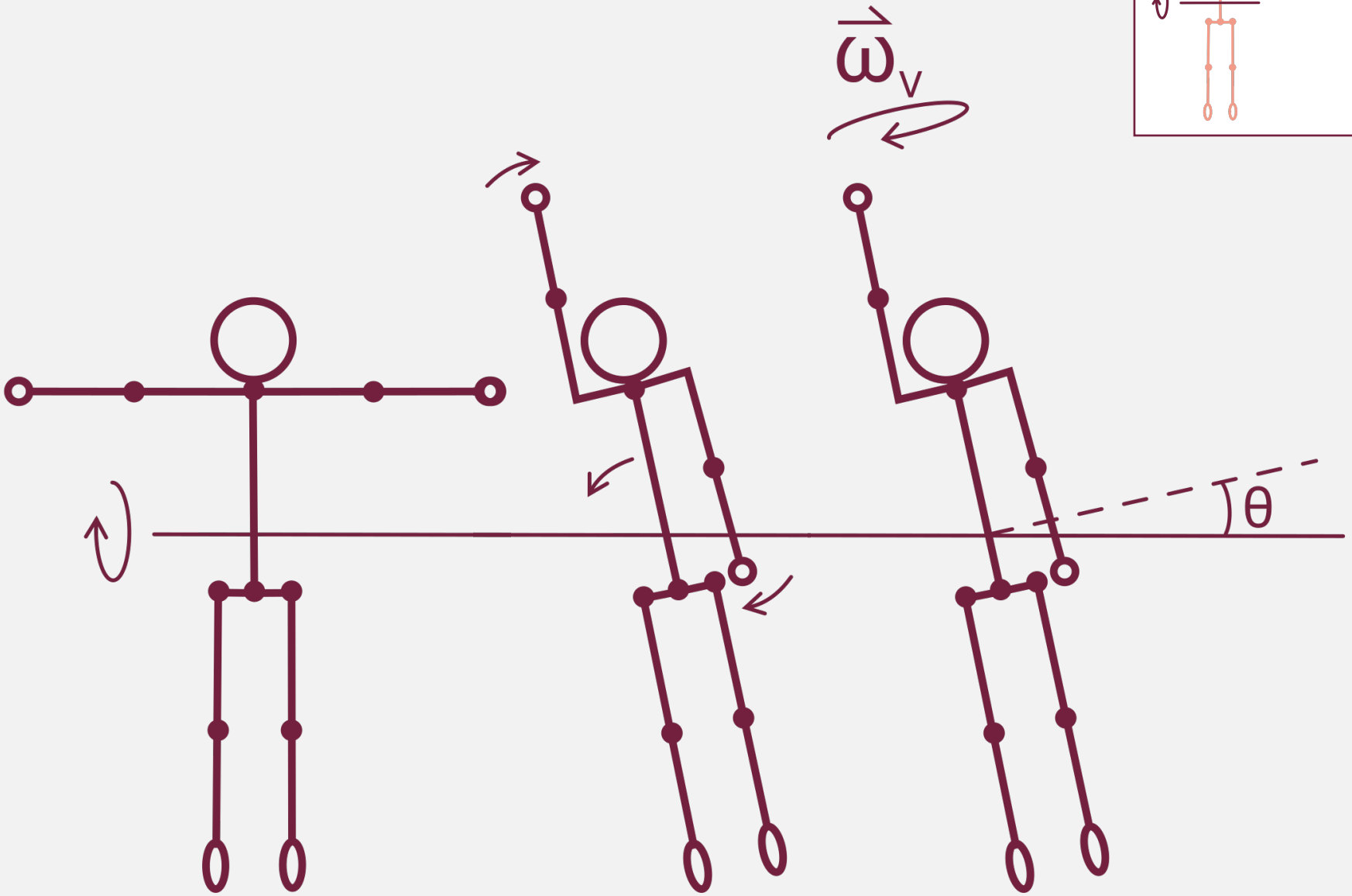
Finding innovative twisting somersault techniques through optimal control to extract efficient biomechanical strategies that can be transferred to the field, to help athletes improve their performance.

Rotation axes



Aerial twists





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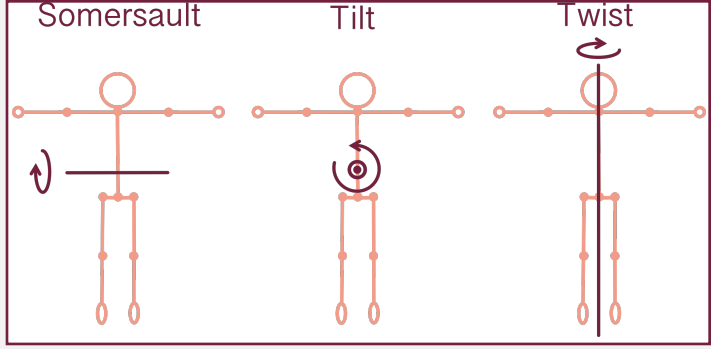

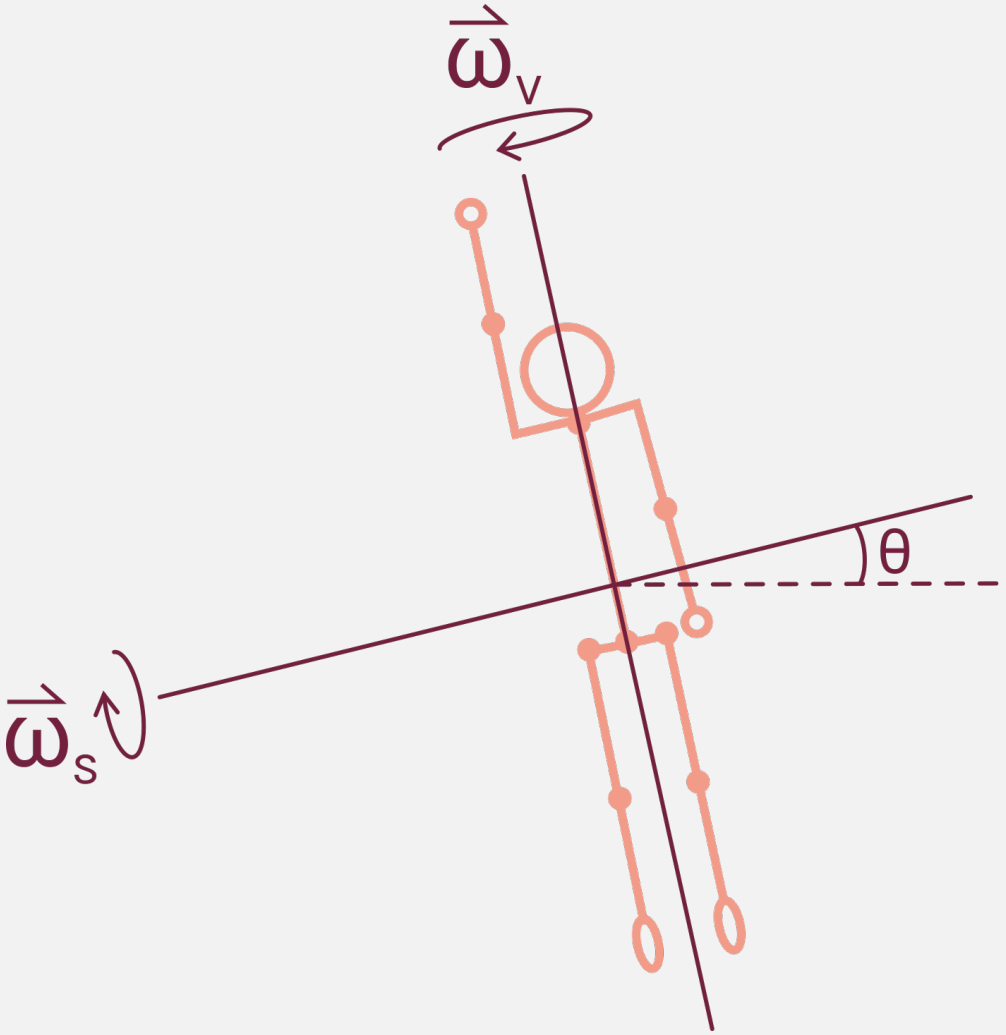

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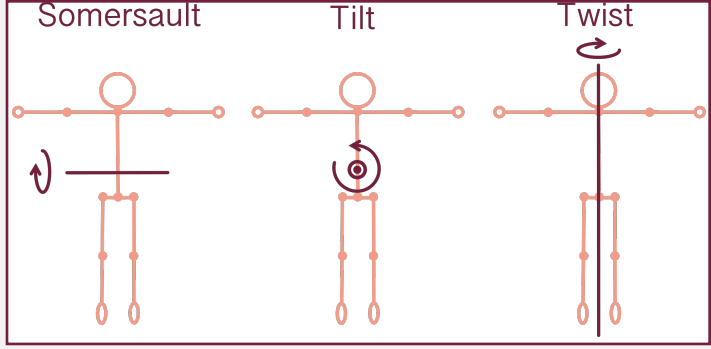

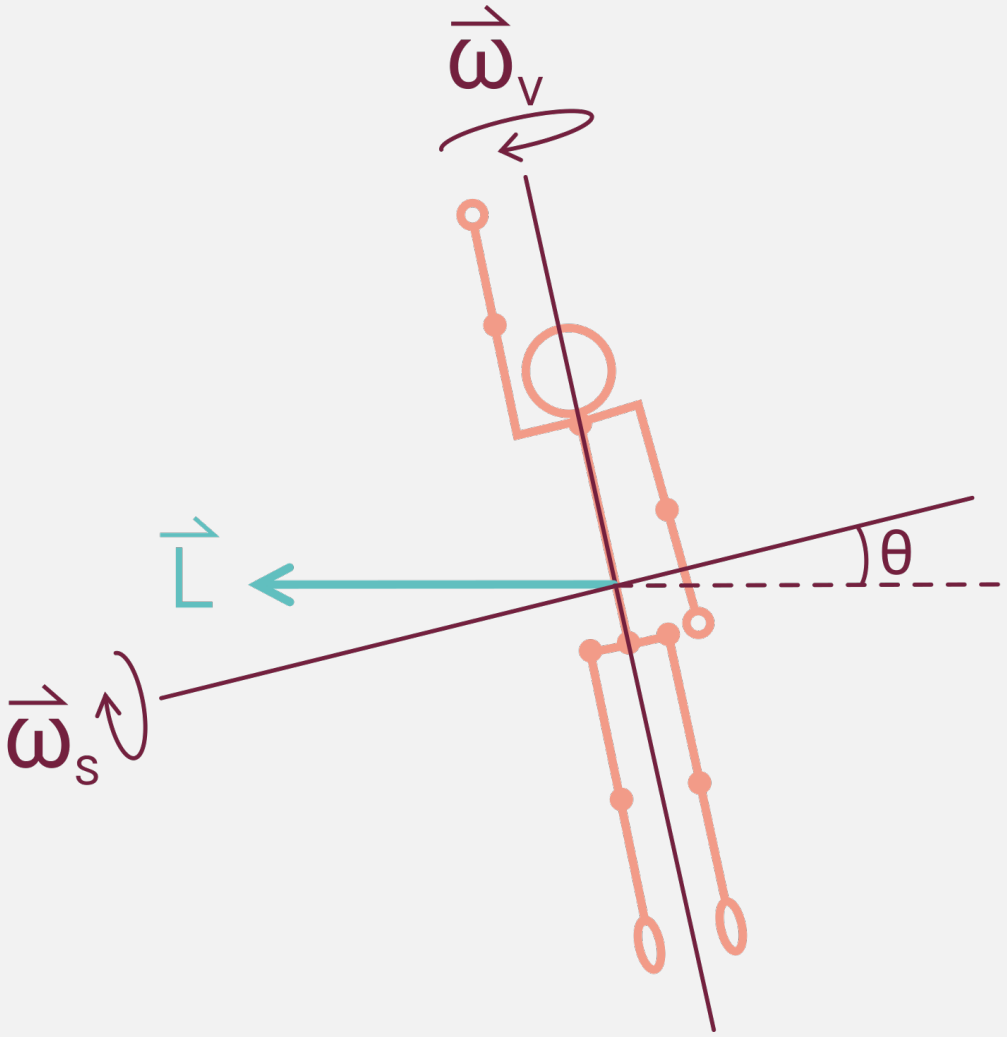

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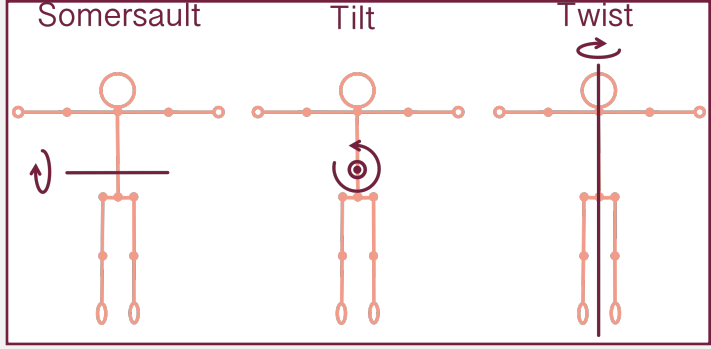
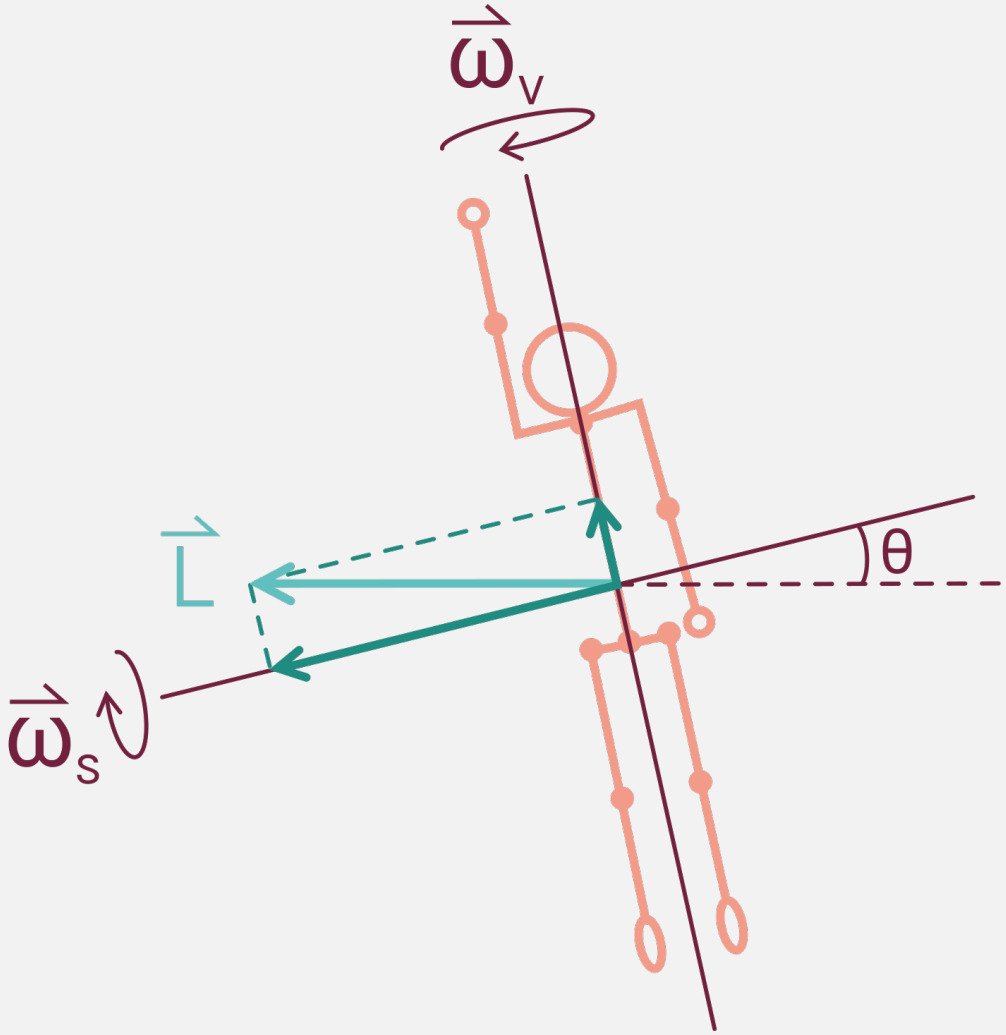
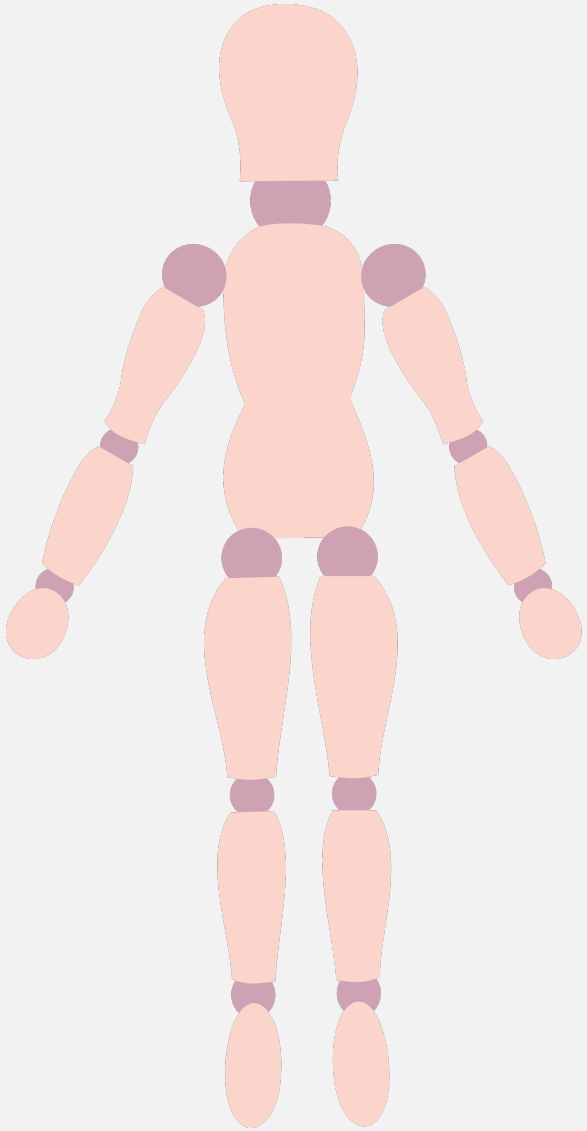
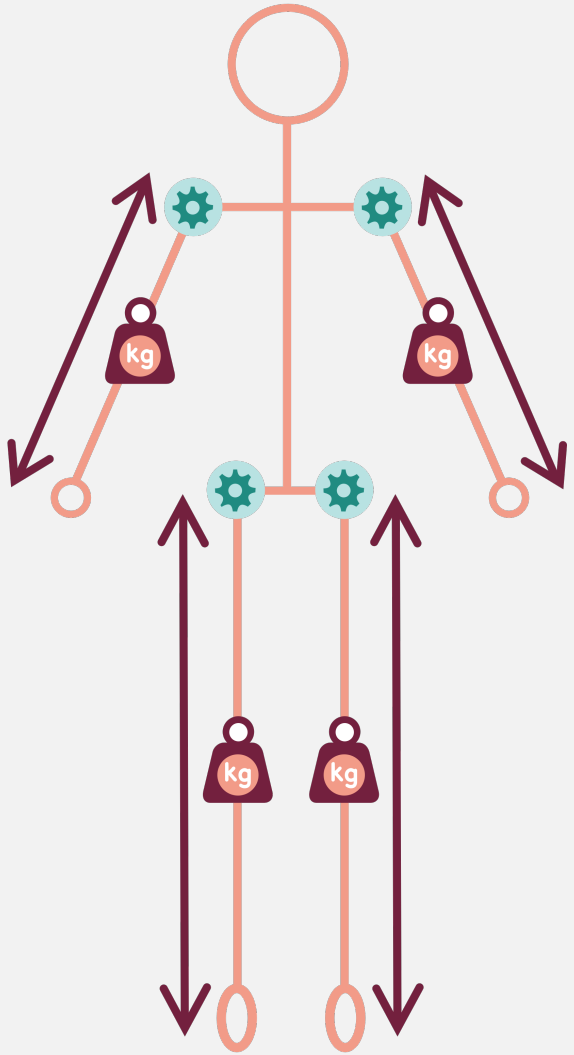




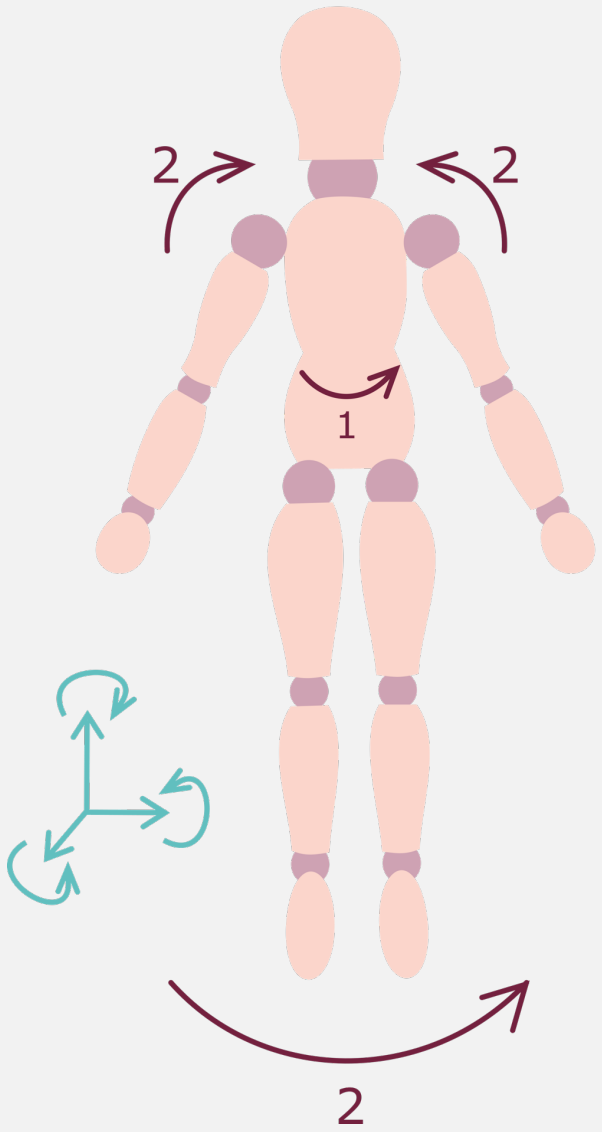
Modeling



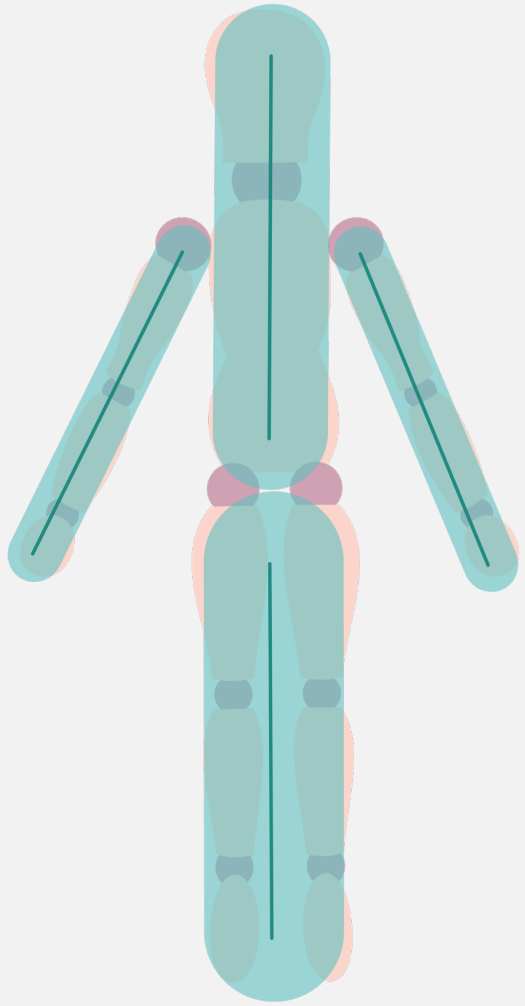


Skeletal model
Torque actuated

Our model



Degrees of freedom



Non-collision constraint

Predictive simulation method

Optimal control variables

- Duration (parameter)
- Joint position (states)
- Joint volocities (states)
- **Joint torques (controls)**

Objectives

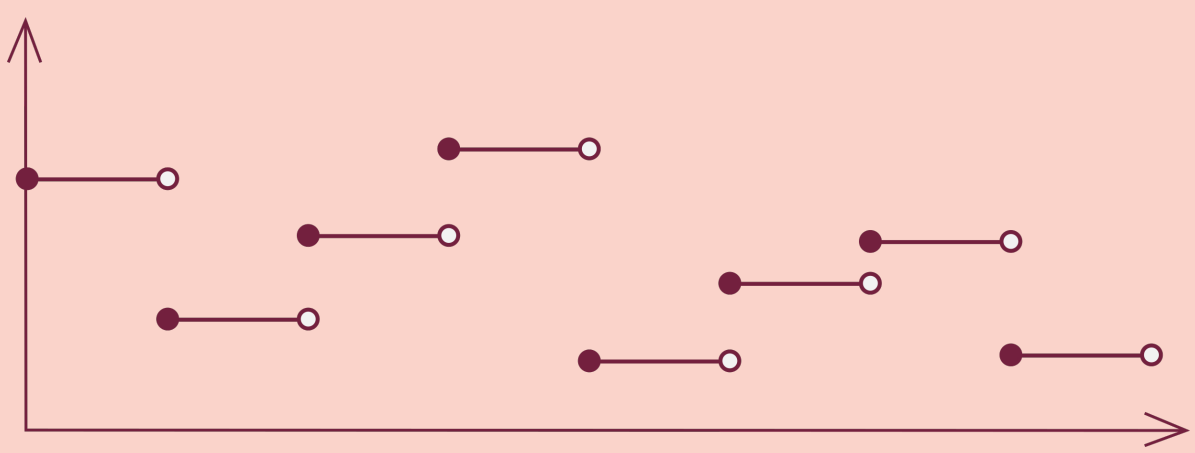
- Maximize twist rotation
- Minimize joint torques
- Minimize hand path

Constraints

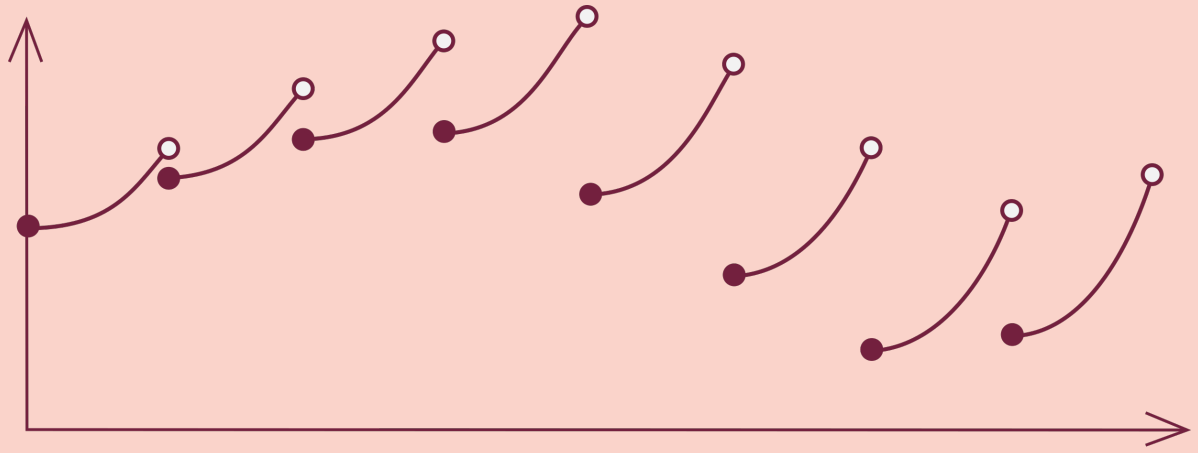
- Non-collision
- Positions bounds enforcing the acrobatic
- Positions bounds enforcing physiological movements

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

Predictive simulation method



Piecewise constant controls

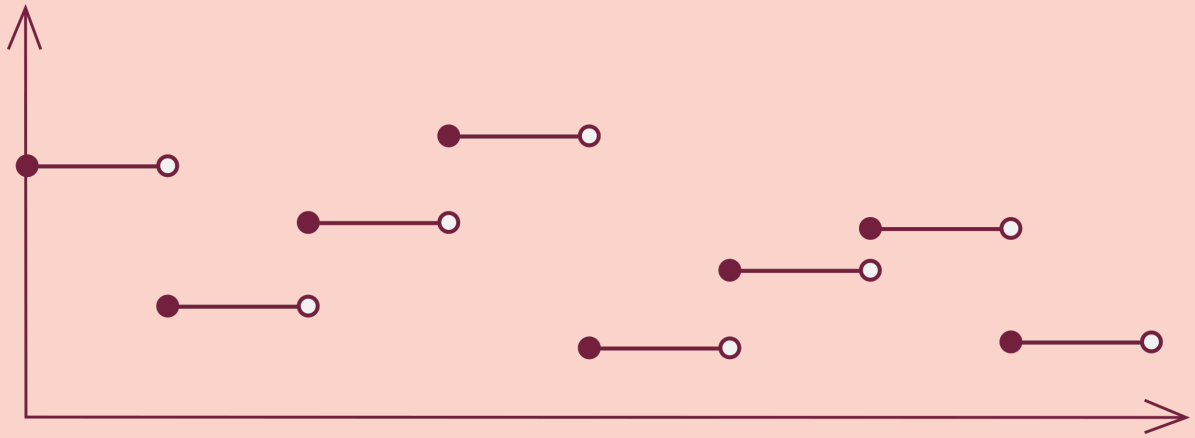


Direct multiple shooting

Bioptim

Biomechanical optimal control

Predictive simulation method



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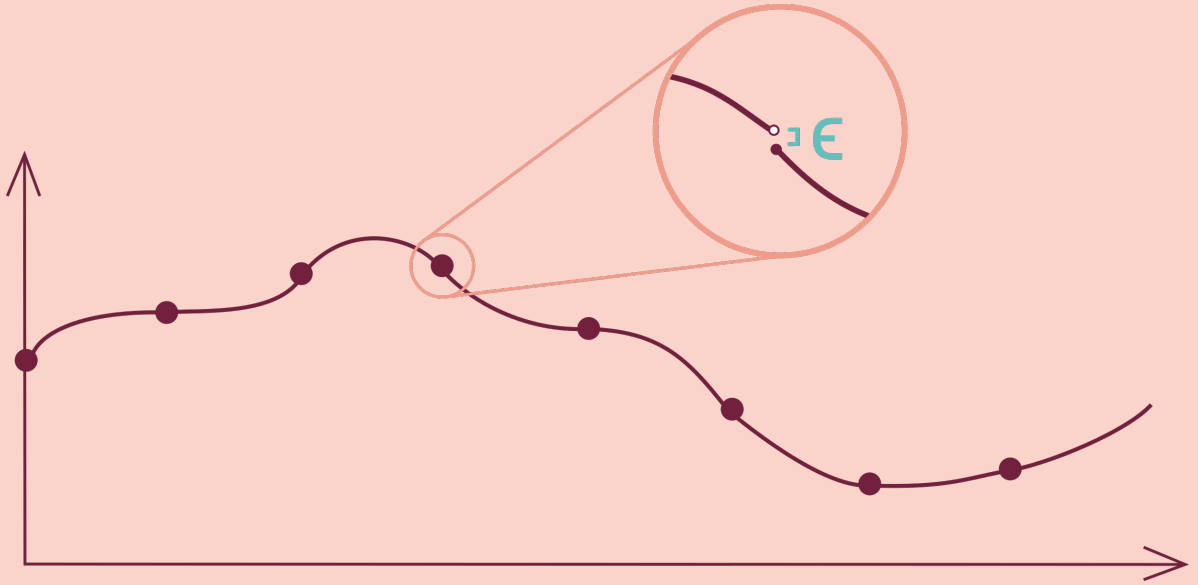


Direct multiple shooting

Bioptim

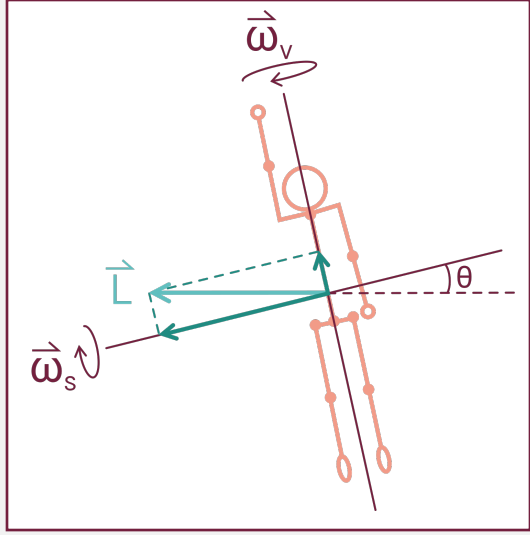
Biomechanical optimal control

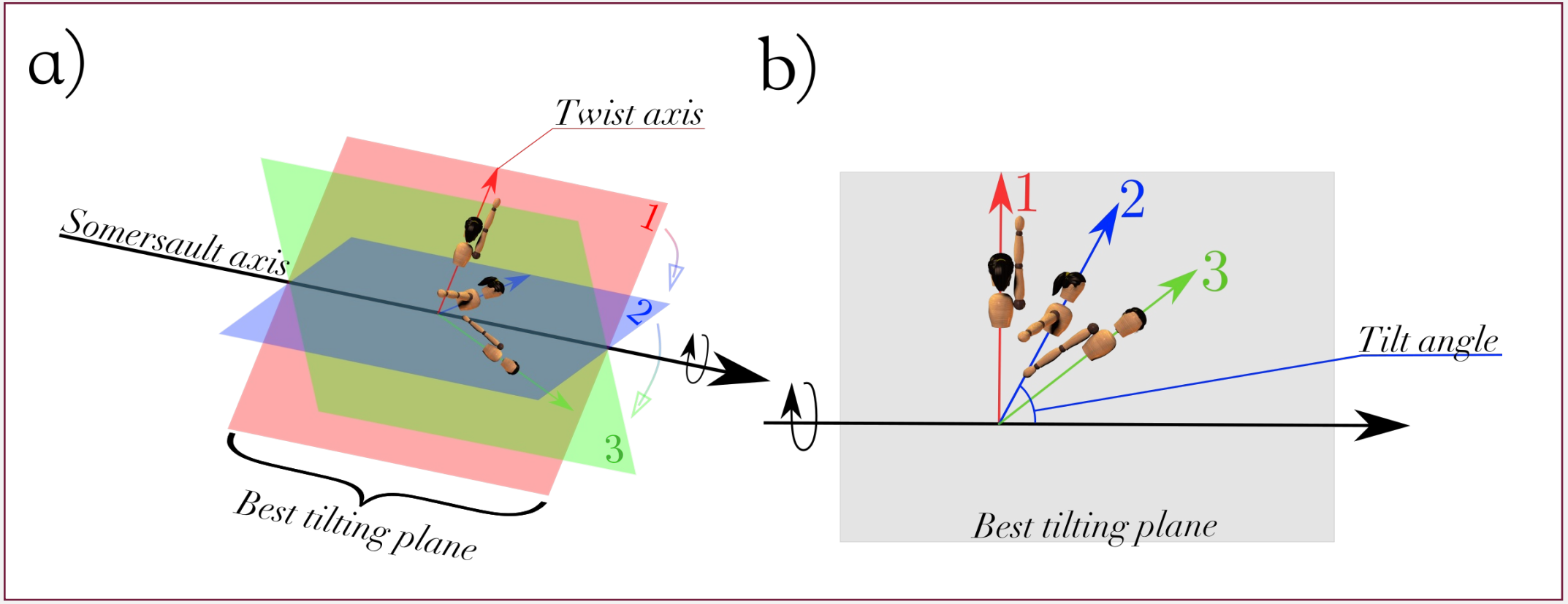
Optimal techniques

Optimal techniques showed us that ...

1. Moving segments in the best tilting plane allows to twist faster
2. Moving segments in phase with the nutation period allows to twist faster
3. Adjustments might be needed to transfer from twisting to wobbling mode

1 Moving segments in the best tilting plane allows to twist faster





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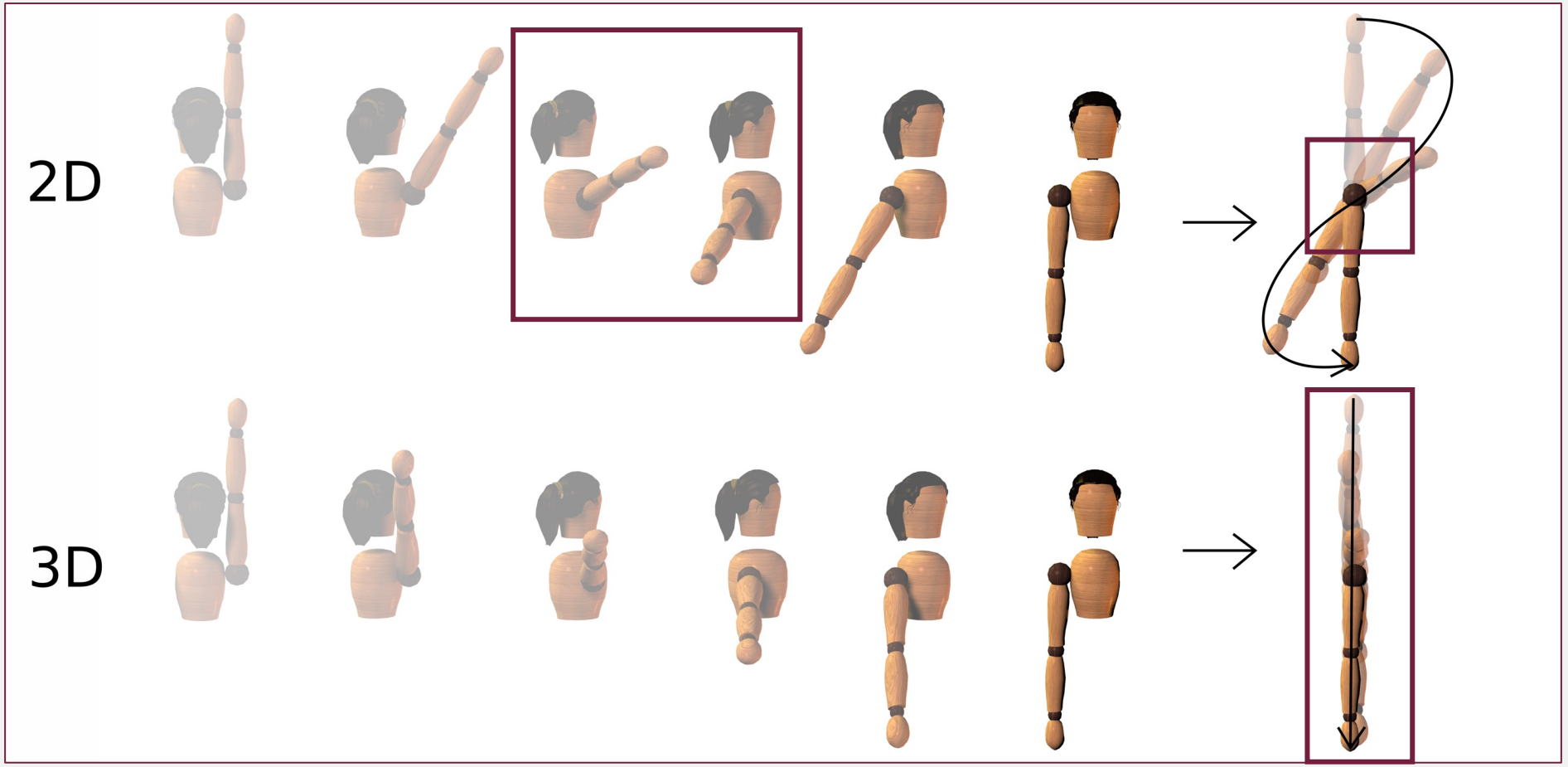

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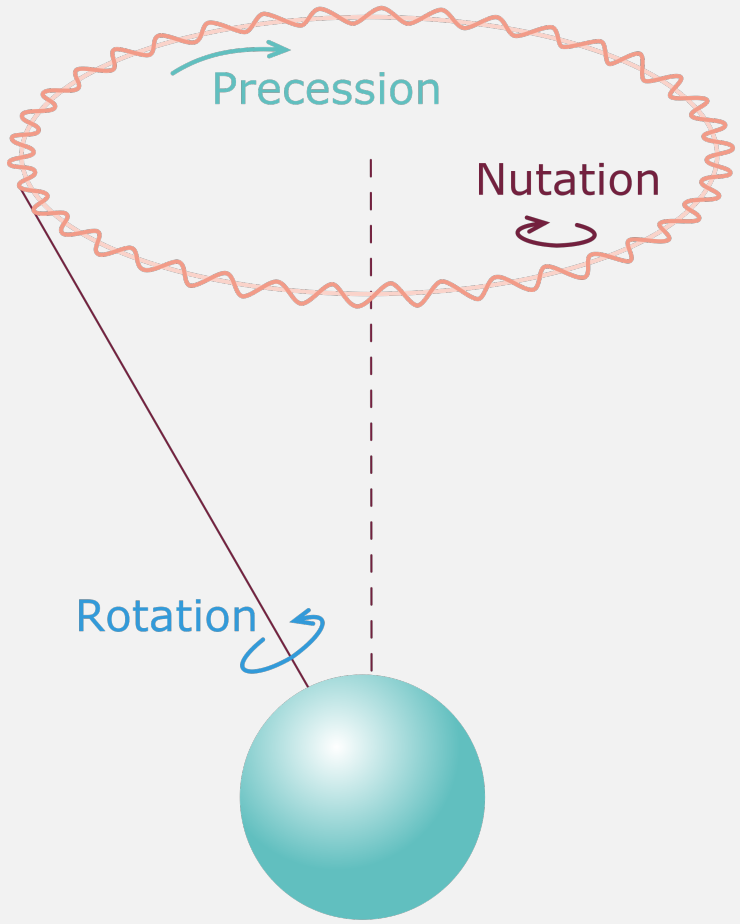
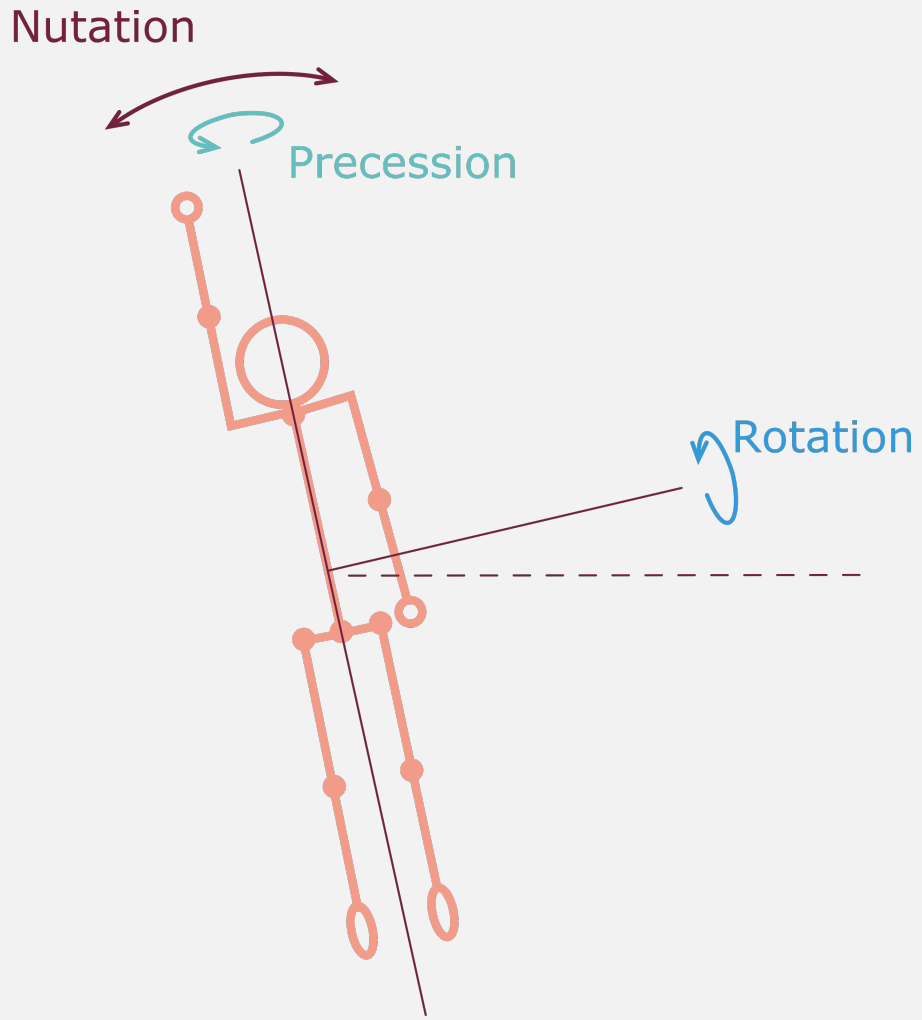
2 Moving segments in phase with the nutation period allows to twist faster





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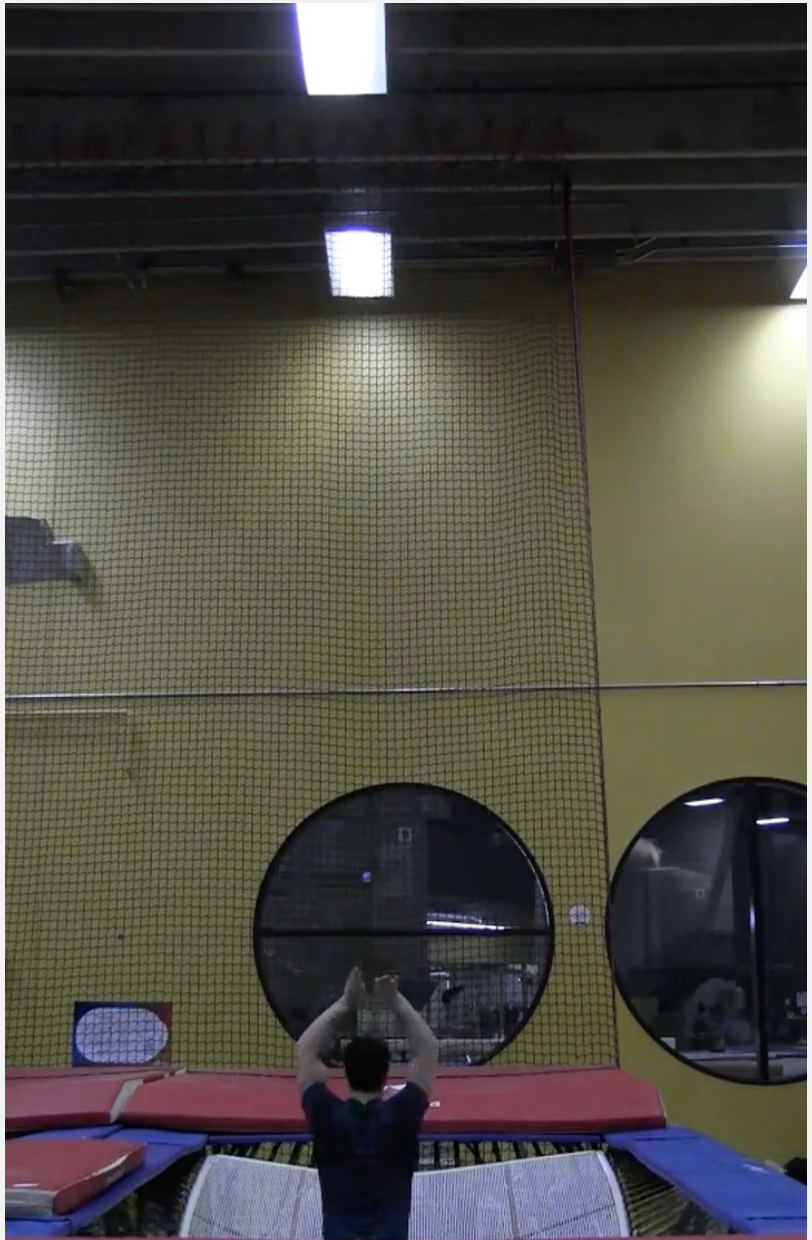

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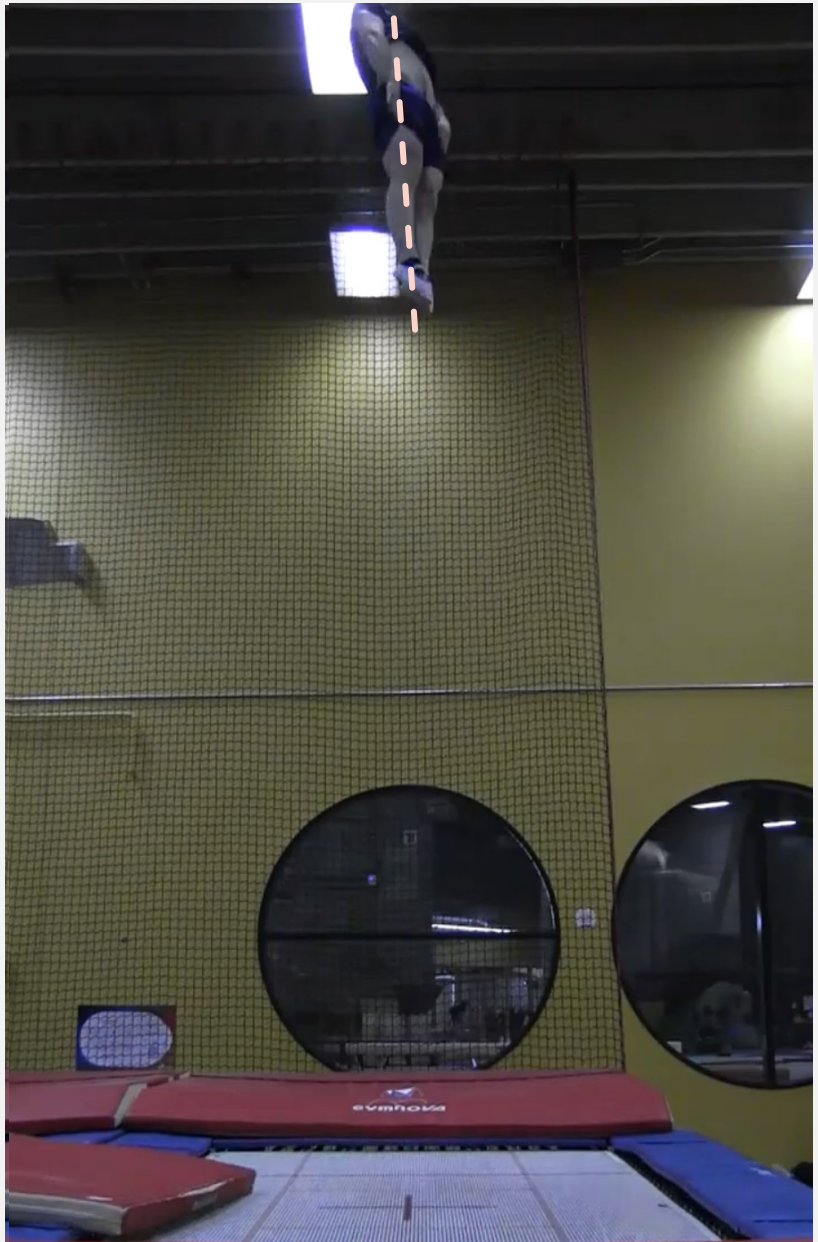
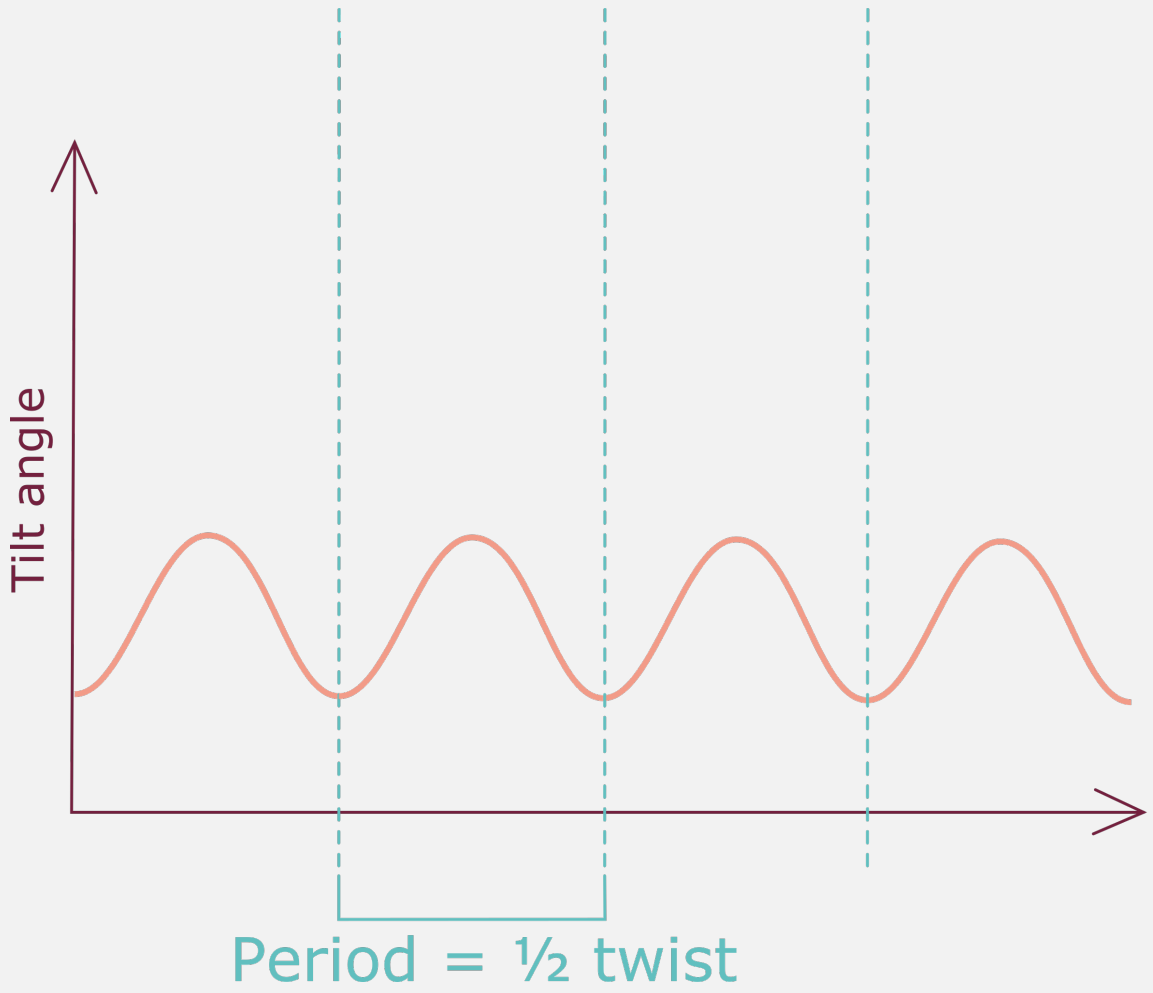


2 Moving segments in phase with the nutation period allows to twist faster

$$\left[1 - \frac{C}{A}\right] cos^2\alpha = \left[1 - \frac{C}{B}\right] cos^2\beta \quad [1]$$



[1]Yeadon, M. R. (1993). Utilising nutation in twisting somersaults. In *Proceedings of the Fourth International Symposium on Computer Simulation in Biomechanics (BMS3-16, 17). Paris: Ecole Nationale Superiere d'Arts et Metiers*.

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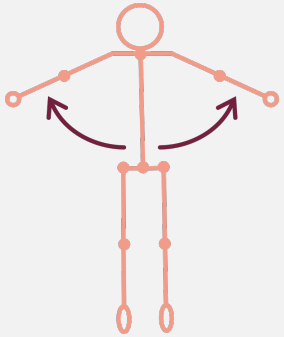
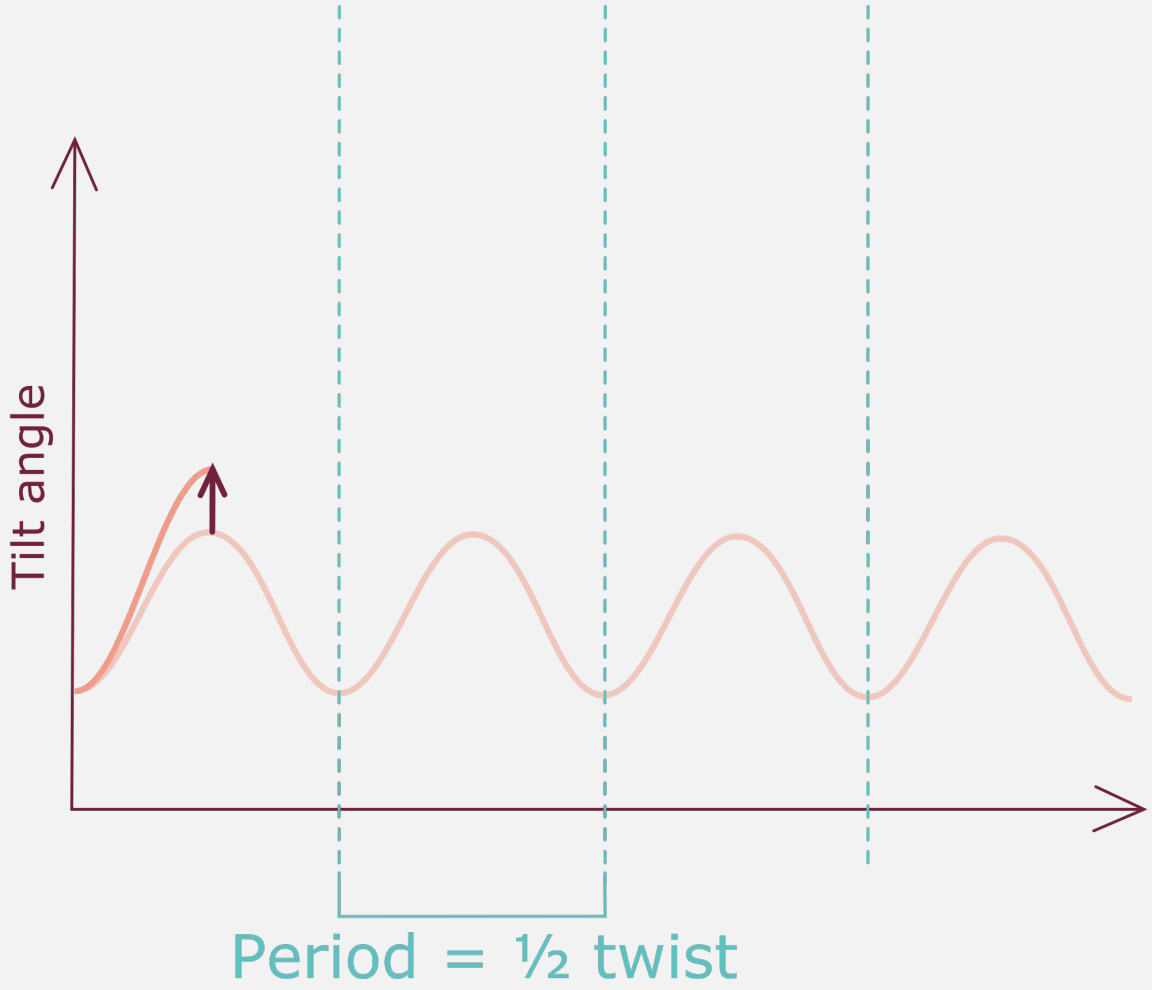
$$\left[1 - \frac{C}{A}\right] cos^2\alpha = \left[1 - \frac{C}{B}\right] cos^2\beta$$ [1]

Each ½ and full twist, the arms can be abducted





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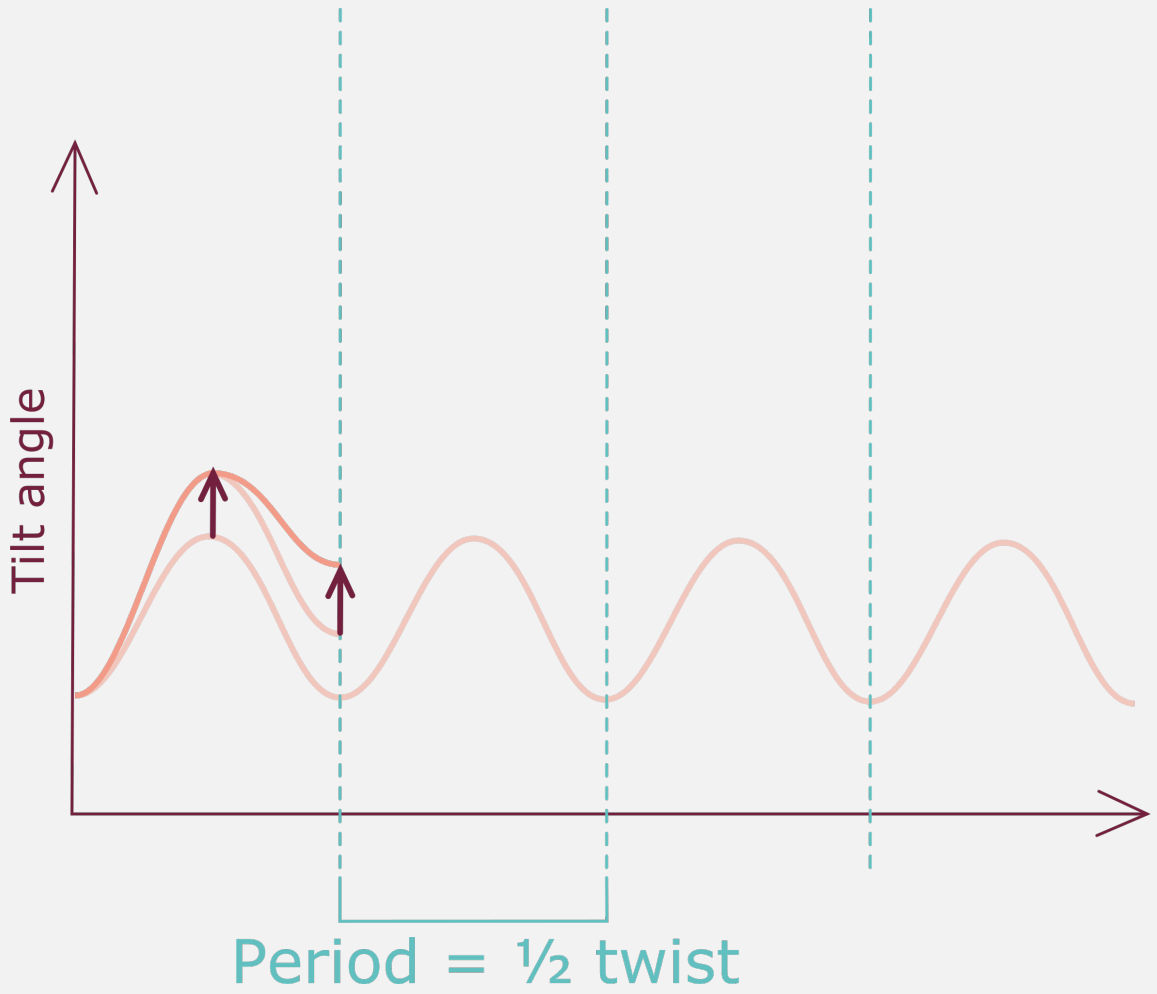

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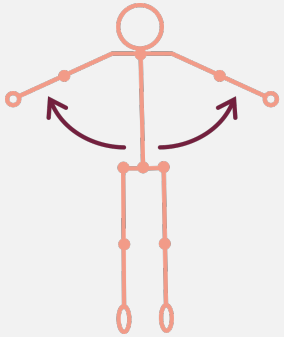
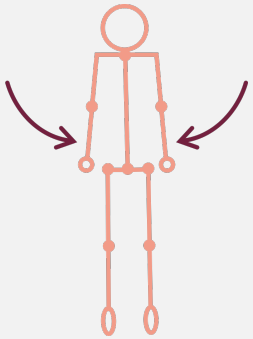


Each ¼ and ¾ twist, arms can be adducted



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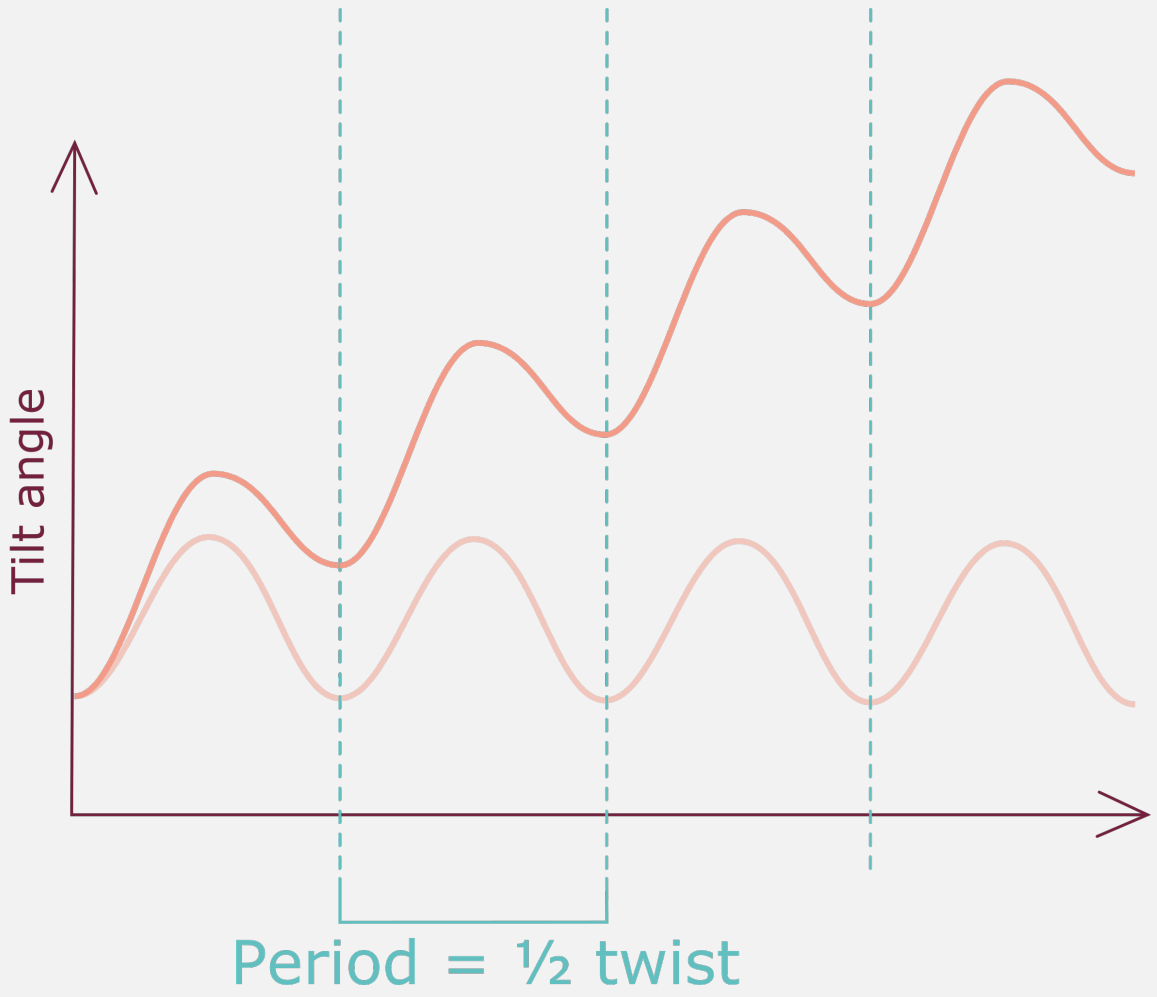

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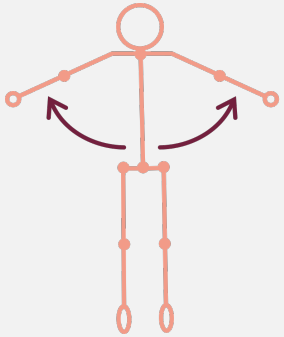

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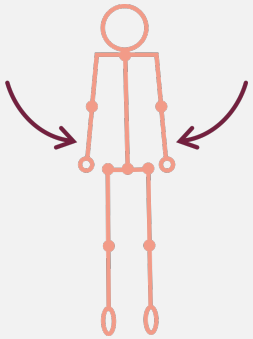

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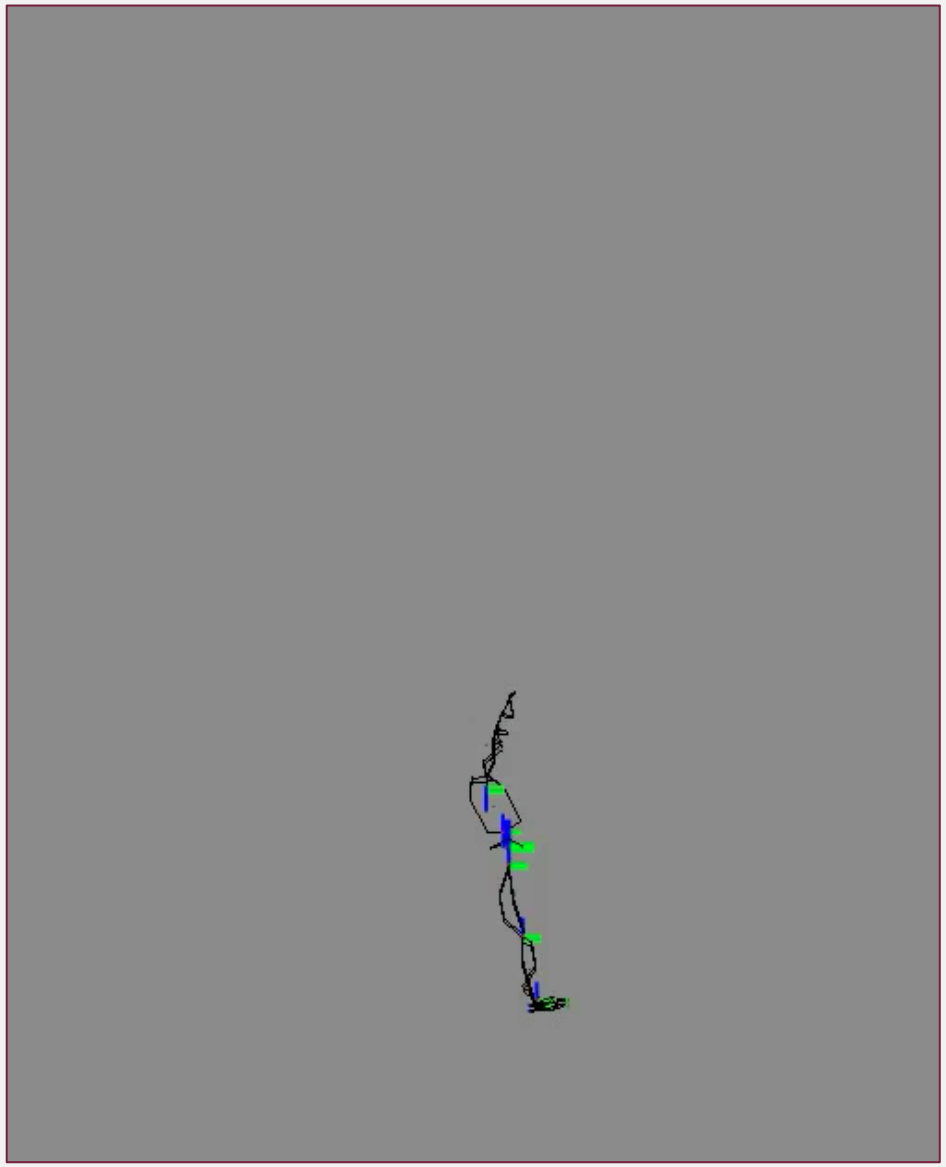
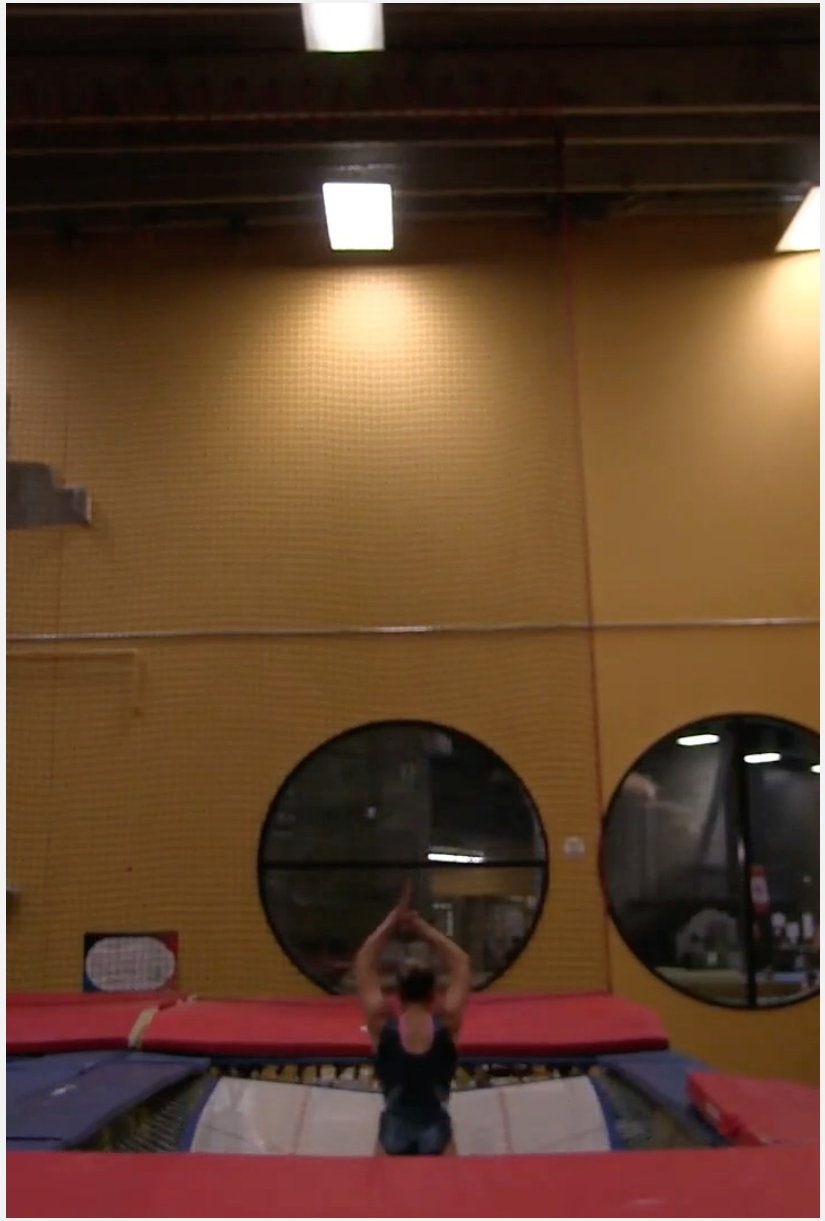


Conclusion:

Movements in the best tilting plane at the ¼ twists

3 Adjustments might be needed to transfer from twisting to wobbling mode



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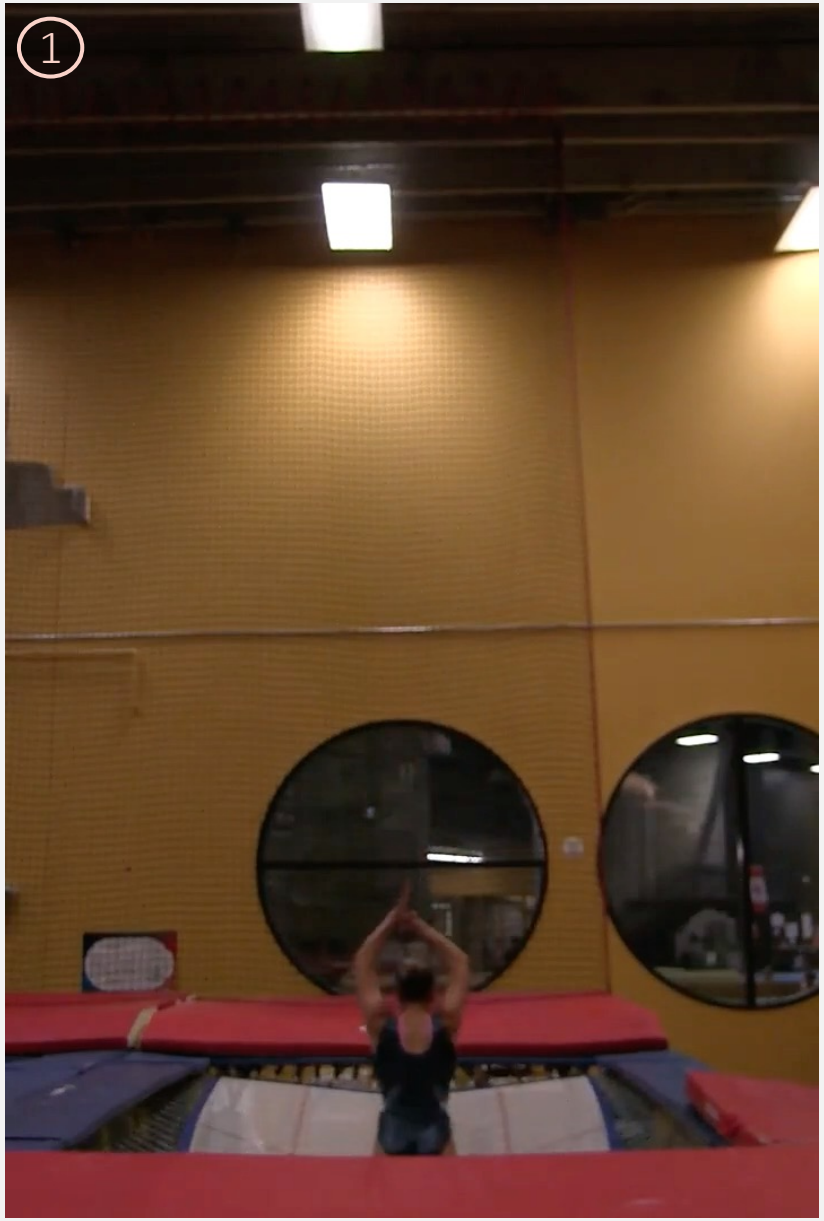

① Twisting phase

Rotation: somersault & twist

Oscillations: tilt

② Somersaulting phase

Rotation: somersault

Oscillations: tilt & twist

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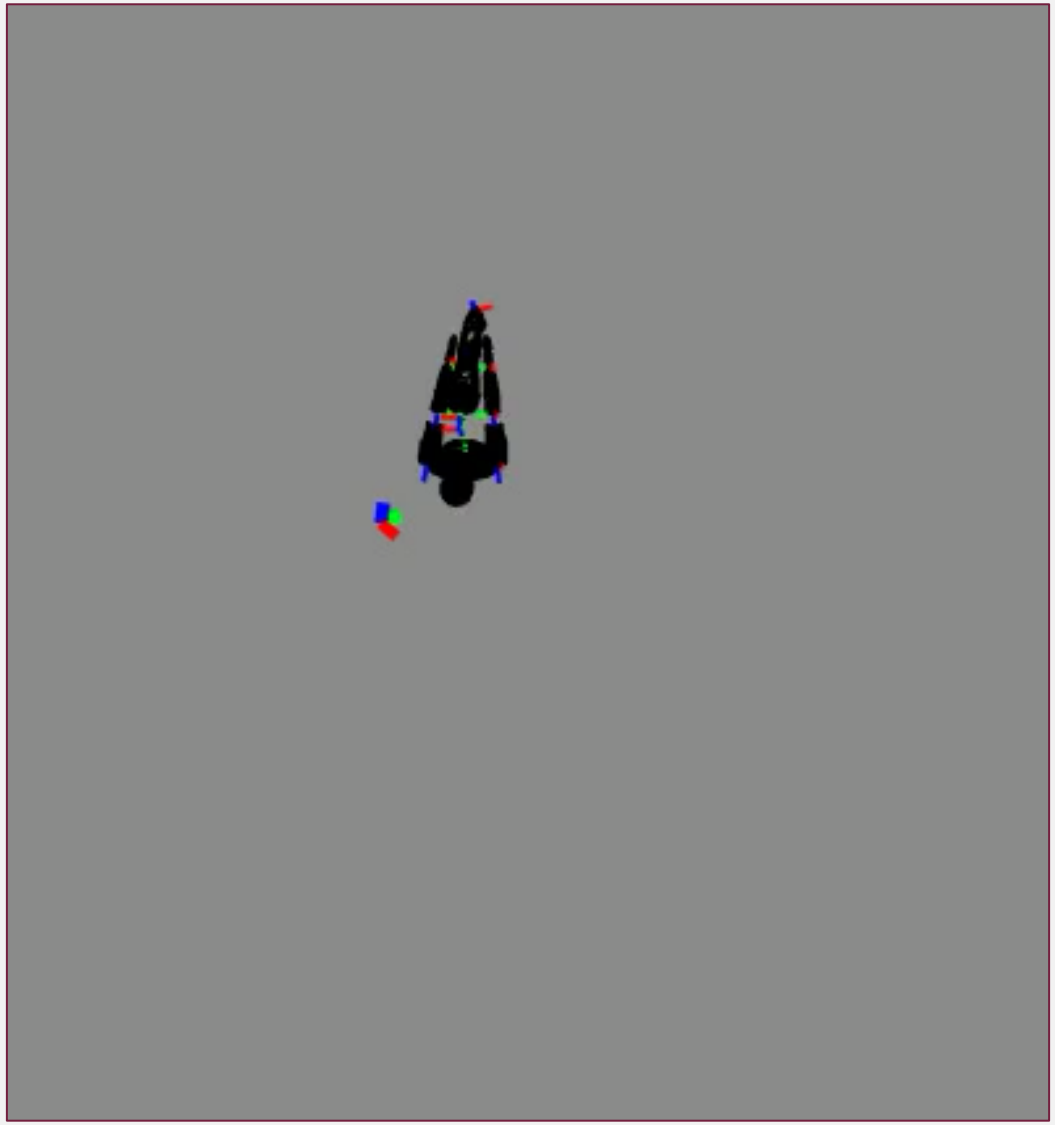

Why is that problematic ?

Not in line with sport requirements

Harder to keep track of their orientation

How to transfer from twisting to wobbling ?

Rotation velocities

Relative moment of inertia

$$cos^2\alpha_0 = A(B-C)/B(A-C)^2$$

[2]Yeadon, M. R. (1993). The biomechanics of twisting somersaults Part I: Rigid body motions. *Journal of Sports Sciences*, *11*(3), 187-198.

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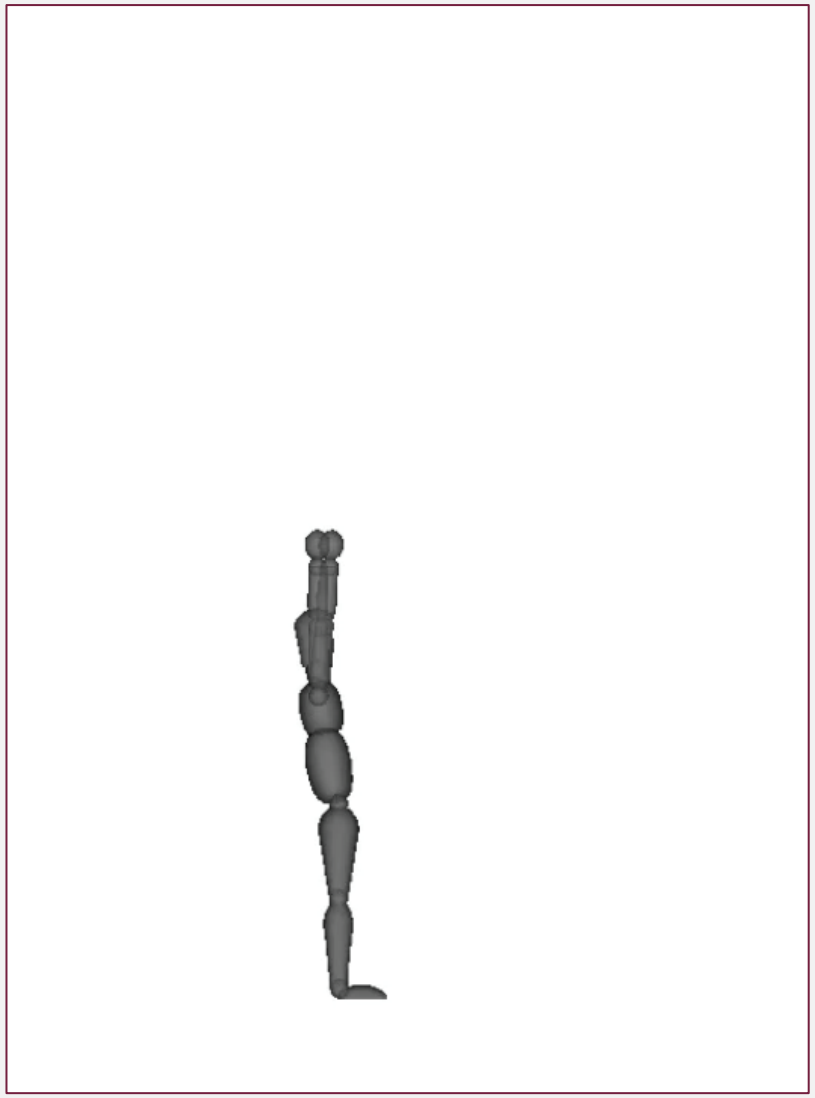

① Twisting phase

Straight position

Minimize time to reach 3 twists

② Piking phase

From straight position to pike position

Minimize time to join the hands and lower legs

③ Somersaulting phase

Pike position

Twist angle in [-90°, 90°]

3 Adjustments might be needed to transfer from twisting to wobbling mode

What did we learn from optimization ?

- Transfering from twisting to wobbling mode is not as easy as often thought
- The piking phase is not passive
- It is necessary for athletes to take time to adjust before and during the pike position
- Athletes should not be pushed to twist and pike as fast as possible

Optimal control allowed us to give practical advices to coaches