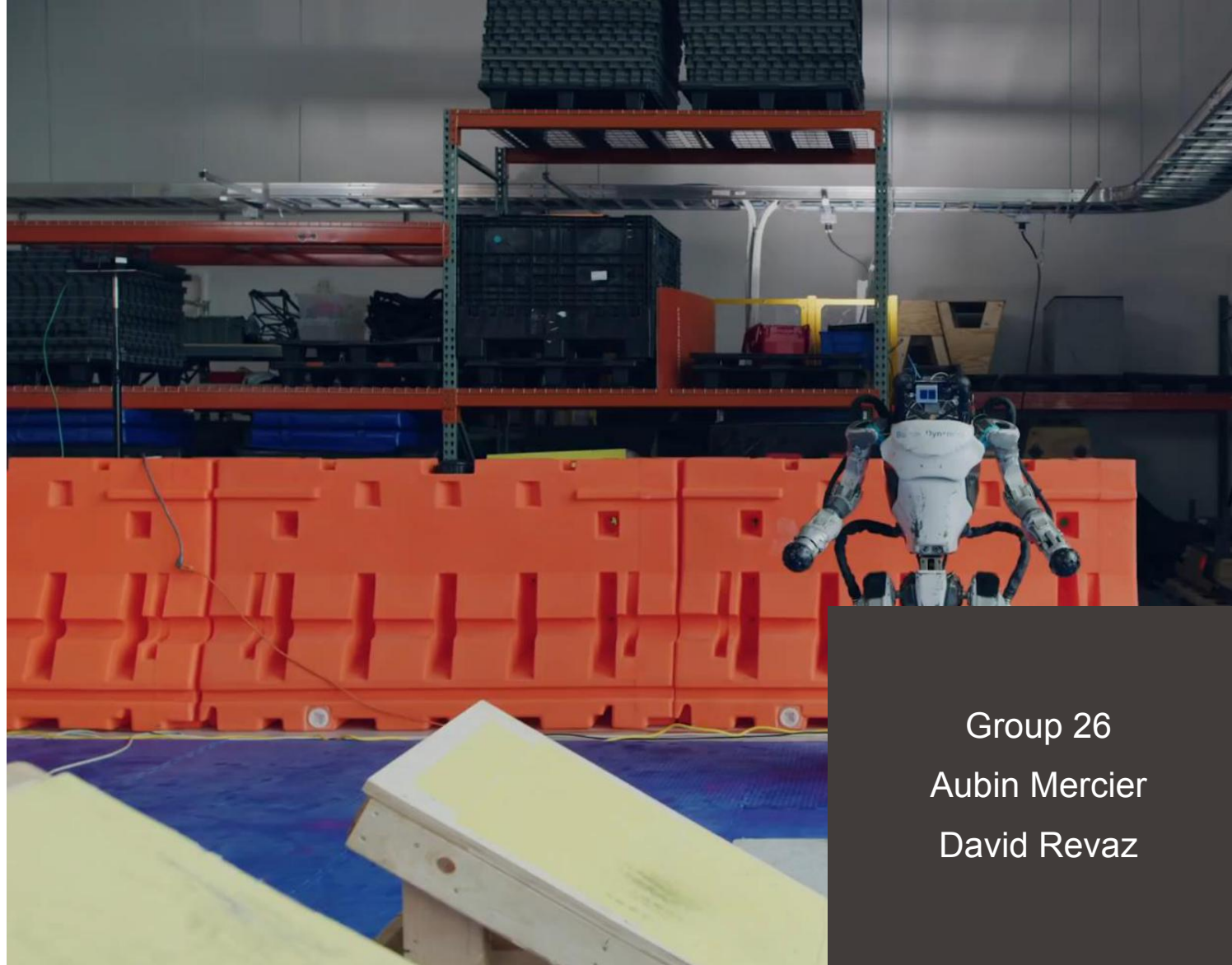




The condition for dynamic stability

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Summary

Theory about the stability in dynamic situations based on the inverted pendulum model

New spatial variable, the extrapolated center of mass which enables to formulate stability condition which is valid for both static and dynamic situations

Experimentation on standing human stability

Key concepts

Center of mass (CoM)

Center of pressure (CoP)

Base of support (BoS)

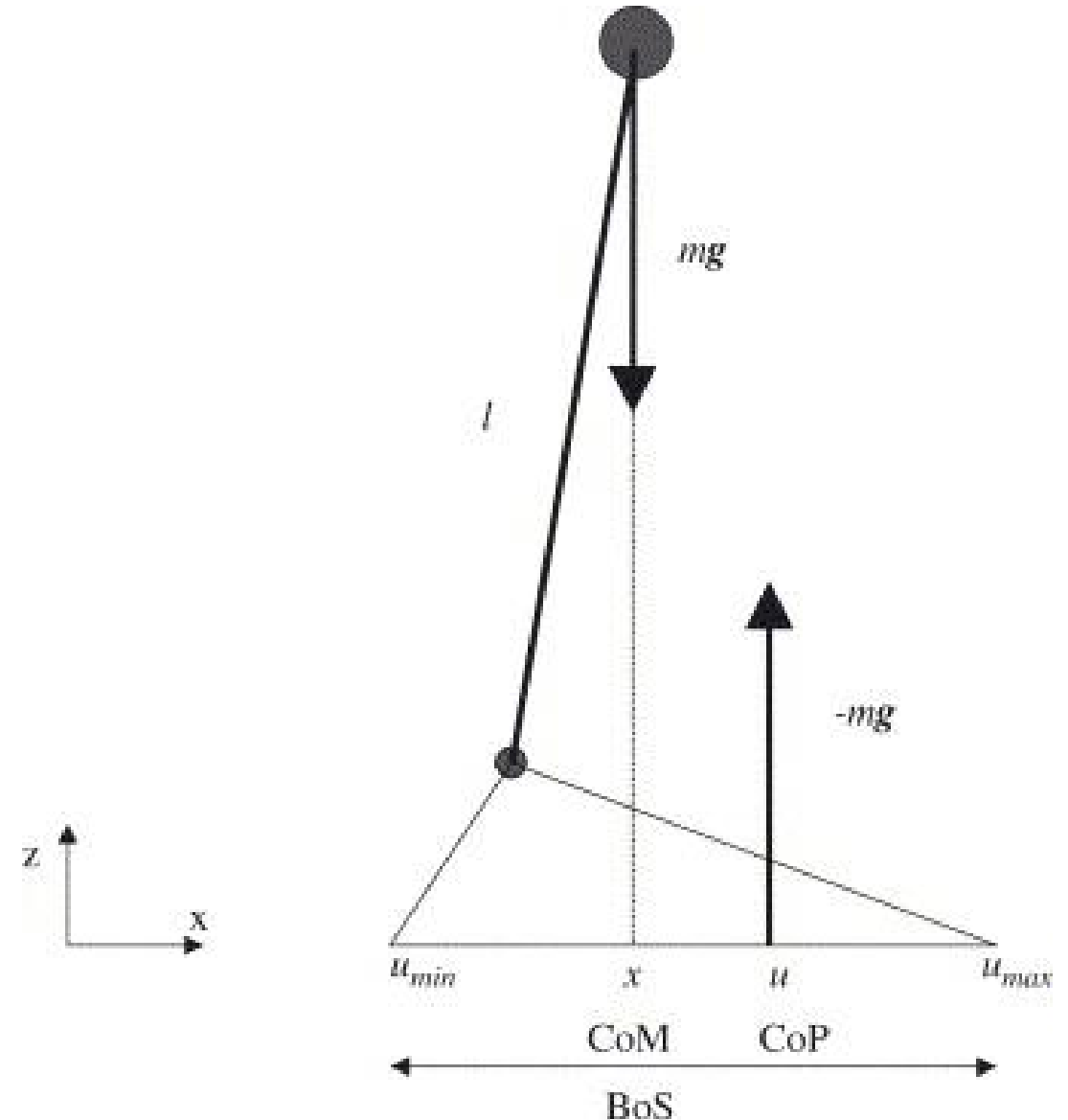
Extrapolated center of mass (XcoM)

$$\mathbf{r} + \frac{\mathbf{v}}{\omega_0}$$

$$\omega_0 = \sqrt{g/l}$$

Spatial stability (b)

Temporal stability (τ)



Stability situations when $v > 0$

Case a: $\text{CoM} < X_{\text{CoM}} < \text{CoP} < \text{BoS}_{\text{max}}$

No problem, No action

Case b: $\text{CoM} < \text{CoP} < X_{\text{CoM}} < \text{BoS}_{\text{max}}$

Action needed, move CoP in front of X_{CoM} .

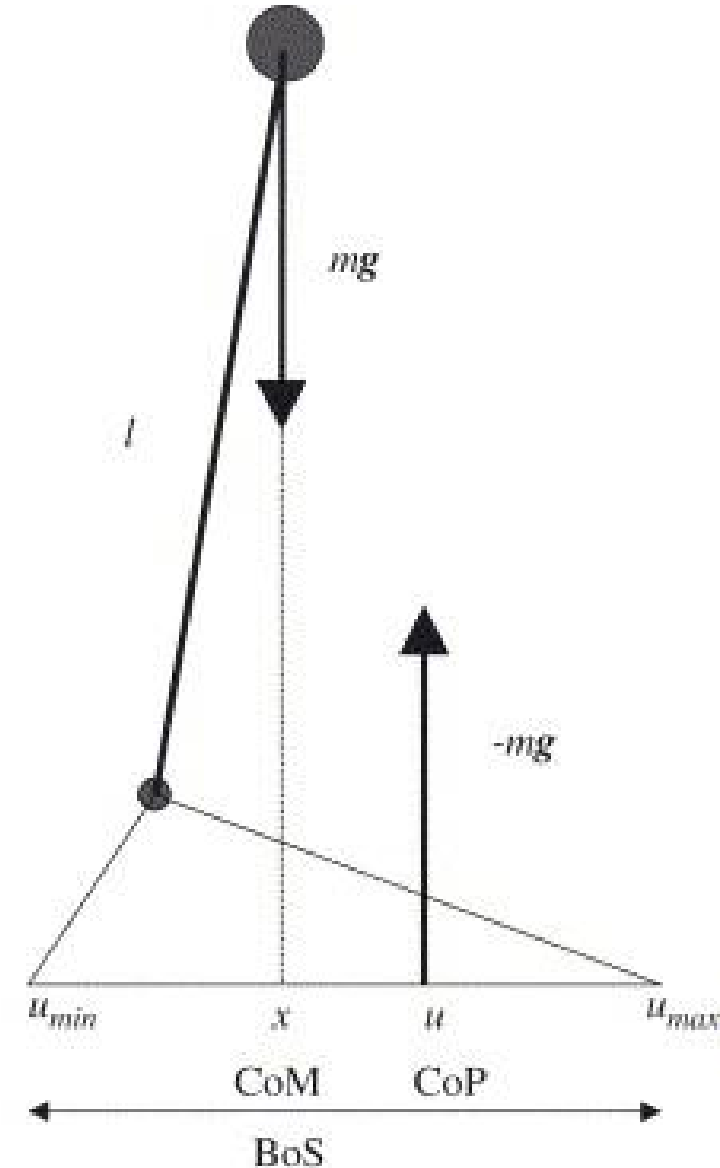
Time to action limited: X_{CoM} will reach BoS in a 'time to contact'

Case c: $X_{\text{CoM}} > \text{BoS}_{\text{max}}$

Unstable case, no movement of CoP prevent

CoM pass outward of the BoS

Only solution change the BoS



Experiment

10 subjects (5 male, 5 female)

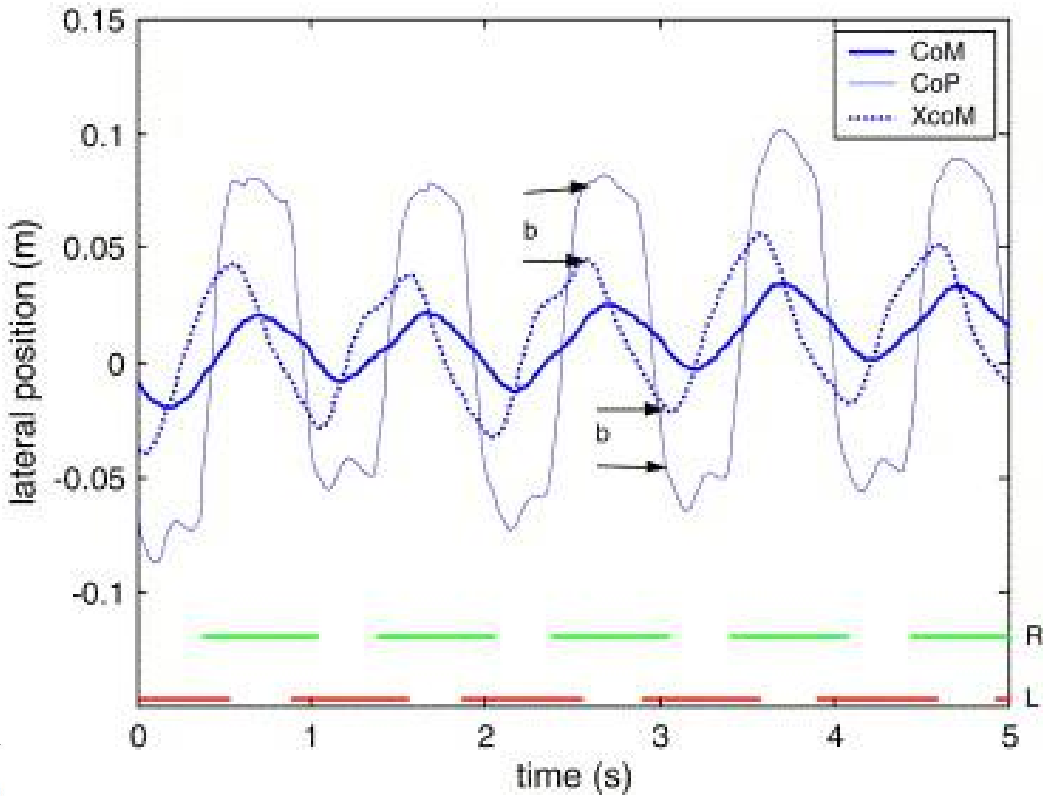
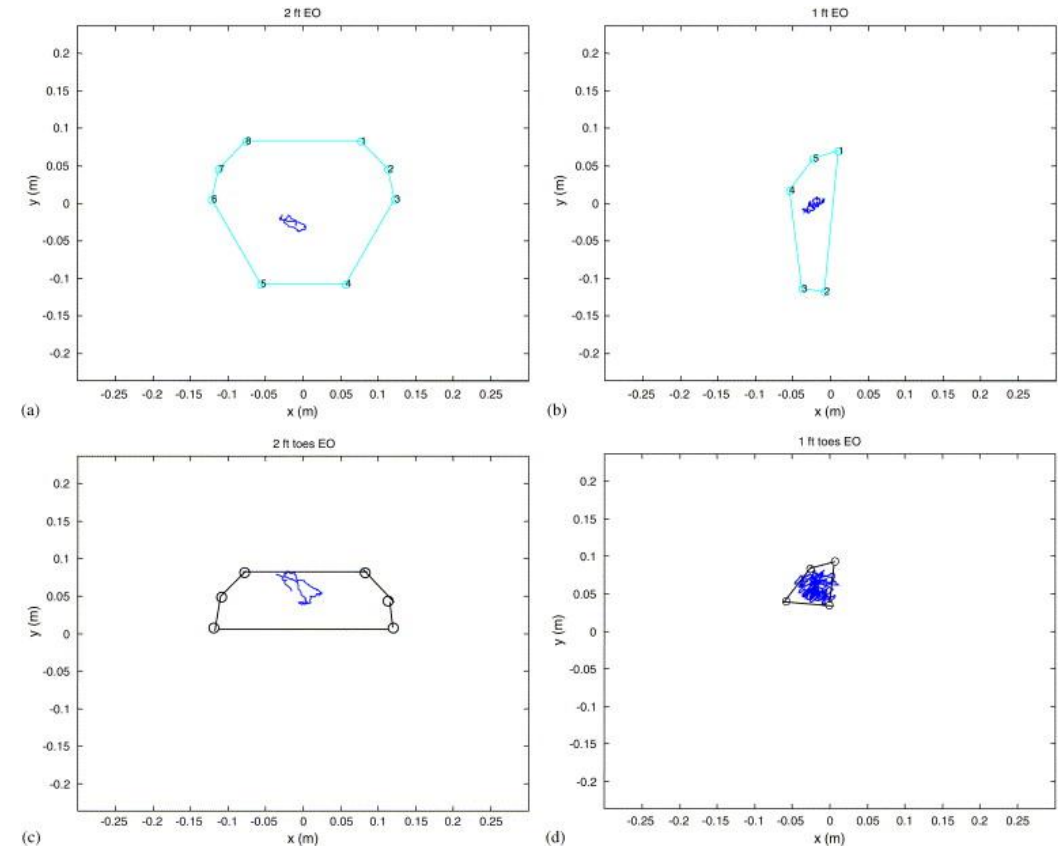
- age 23.3 (std:1.3) years
- body mass 74.1 (std:12.4) kg
- leg length 0.936 (std:0.06)m

5 situations

- 2 feet
- 1 feet
- 2 feet toes
- 1 feet toes
- walking on a treadmill

EPFL

Results



Stance	Condition	Diam BoS (mm)	$b_{\min}$ (mm)	$\tau_{\min}$ (s)	CoP sway (mm r.m.s.)	XcoM sway (mm r.m.s.)	CoM sway (mm r.m.s.)	V CoM (mm.s ⁻¹ r.m.s.)
Two feet	Eyes open	76 (11)	64.2 (8)	14.1 (3)	5.0 (2)	5.0 (2)	4.9 (2)	2.6 (1)
	Eyes closed		64.7 (10)	12.9 (5)	5.2 (2)	4.4 (1)	4.4 (1)	2.8 (1)
One foot	Eyes open	22 (5)	15.5 (6)	2.3 (1)	8.1 (3)	5.3 (3)	5.0 (3)	5.1 (1)
	Eyes closed		7.3 (6)	0.4 (0.5)	15.9 (2)	10.2 (2)	9.0 (2)	14.3 (4)
2 ft. toes	Eyes open	16 (4)	5.6 (12)	1.3 (6)	7.7 (2)	8.6 (4)	8.5 (5)	4.4 (1)
	Eyes closed		12.2 (11)	0.7 (3)	16.5 (2)	11.8 (5)	11.4 (5)	10.1 (3)
1 ft. toes	Eyes open	15 (4)	-9.3 (14)	-1.8 (2)	10.6 (3)	8.3 (3)	6.1 (2)	17.7 (7)

Pros and Cons

Pros

- Enhanced Understanding of Stability
- Quantitative Measures

Cons

- Limitations of the Model
- Dynamic Situations Complexity

Lot of citations (1821 as of today!)

Robotics:

S. Wang et al. (2014), Design and Control of the MINDWALKER Exoskeleton,
<https://doi.org/10.1109/TNSRE.2014.2365697>

R. Gehlhar et al. (2023), A review of current state-of-the-art control methods for lower-limb powered prostheses, <https://doi.org/10.1016/j.arcontrol.2023.03.003>

J. Grizzle et al. (2014), Models, feedback control, and open problems of 3D bipedal robotic walking,
<https://doi.org/10.1016/j.automatica.2014.04.021>

Medicine:

L. Grevendonk et al. (2021), Impact of aging and exercise on skeletal muscle mitochondrial capacity, energy metabolism, and physical function, <https://doi.org/10.1038/s41467-021-24956-2>

F. Quijoux, et al. (2021), A review of center of pressure (COP) variables to quantify standing balance in elderly people: Algorithms and open-access code, <https://doi.org/10.14814/phy2.15067>

Exam questions

What's the XcoM and how it improves the old method ?

The XcoM is the extrapolated center of mass, XcoM is defined as the position of the center of mass (CoM) adjusted for its velocity. It's improves the old model by taking in account the velocity of the center of mass. It creates a new stability condition that is valid in static and dynamic situations

What's the difference between spatial and temporal stability ?

Spatial stability is the smallest distance between XcoM and BoS. It bears direct relation to the minimal impulse needed to bring the subject out of balance, and it can be applied not only for standing but for all postures in which the body is more or less erect.

Temporal stability is the spatial distance divided by the velocity. It refers to the time when you gonna fall if you do nothing.



Any questions ?