Lodz University of Technology
Department of Automation, Biomechanics and Mechatronics

OPEN SCIENTIFIC LECTURES IN K11

Examining the Impact of Visual Perturbation Caused by Virtual Reality on Postural Stability

Presenter: Sayedmohsen Mortazavi Najafabadi

Discipline: Mechanical Engineering

Co-authors: Dr hab. inż. Dariusz Grzelczyk, Dr. Bartłomiej Zagrodny, Dr. Mohammed Najafi Ashtiani

29. April 2025

Introduction

What is Postural control?

1. Visual System

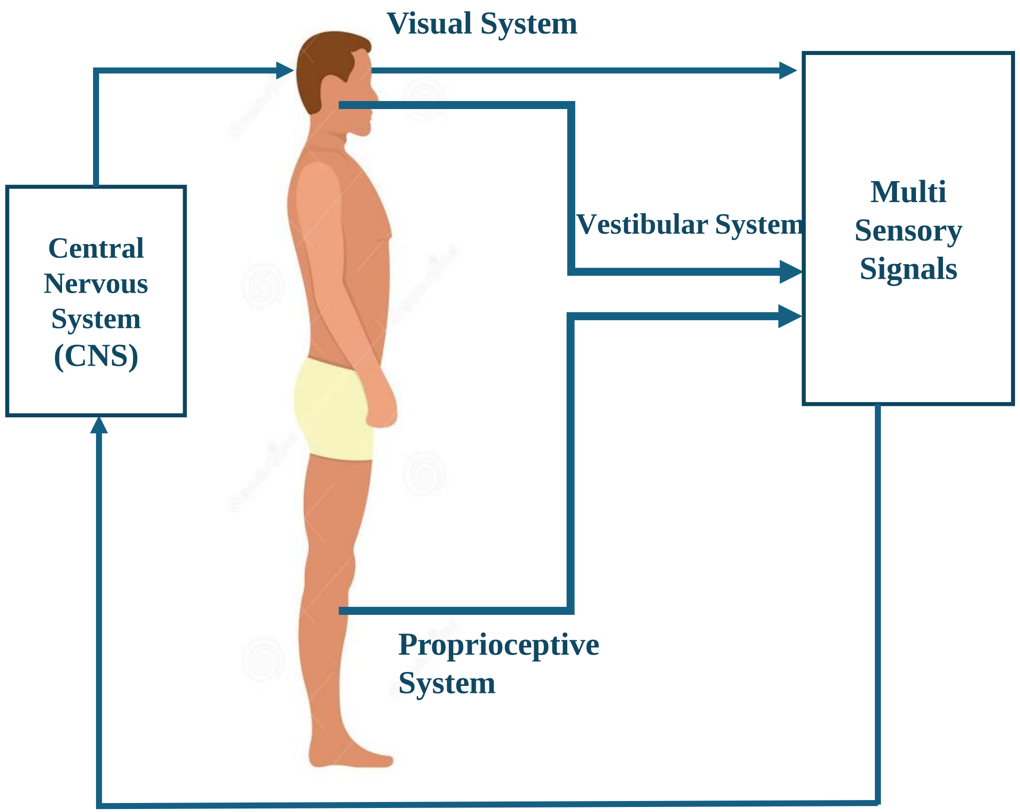
Role: Provides information about the position and movement of the body relative to the surrounding environment.

2. Vestibular System

Role: Detects changes in head position and motion (linear and angular) through the inner ear's semicircular canals.

3. Proprioceptive System

Role: Delivers feedback about joint angles, muscle tension, and limb position through sensory receptors in muscles, tendons, and joints.

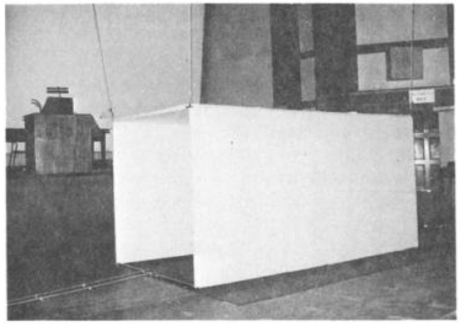


Postural control depends on sensory integration from the vestibular, proprioceptive, and visual systems. Among these, the visual system plays a particularly crucial role in maintaining balance. It helps regulate posture through a continuous feedback loop.

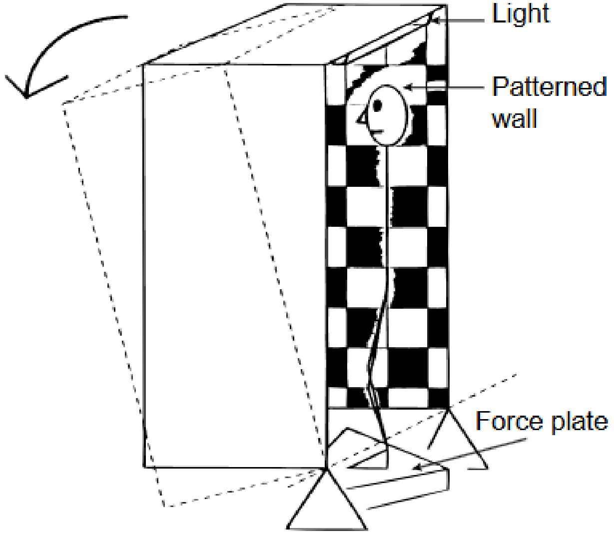
Lodz University of Technology
Department of Automation, Biomechanics and Mechatronics

Literature, Hypothesis and Aims

Lee and Aronson (1974) used a moving room to show that visual input strongly affects balance. When visual cues conflicted with body position, the body relied more on proprioceptive and vestibular information.



Hoshikawa (1999)**,** Found that tilting room environments cause increased body sway, highlighting the strong influence of visual surroundings.



Limitations:

1-Requires large physical space and complex construction

2-High cost due to use of computer-controlled motors

3- Limited Direction (A/P, M/L, tilting), and Pattern and speed of optical flow

Literature, Hypothesis and Aims

VR with head-mounted displays (HMDs) is portable, flexible, and allows precise control over visual stimulation.
Easy to manipulate parameters like direction, speed, pattern, distance, and texture of optical flow.

Limitations of Previous Research

Most studies focus on translational movements, neglecting rotational and tilting perturbations
Insufficient exploration of optical-flow components (direction, velocity, pattern, distance)

Aims and Hypothesis

Developed a full VR moving-room simulation with constant, accelerating, and tilting motions.
Measured postural responses (CoP and sway) under these different visual perturbations.
Compare the effects of constant-velocity, accelerating, and tilting visual disturbances on postural control.
Sudden VR-based visual perturbations will significantly impair balance metrics during quiet standing.

Material and Methods

Participants

Based on G*Power statistical software and an effect size of 0.4, a minimum of 25 young volunteers was required.

Inclusion and Exclusion criteria → Participants aged 18–40 were included. Exclusion criteria: smoking/alcohol use, recent injuries or surgeries, and neurological, metabolic, musculoskeletal disorders, or joint replacement.

The study was approved by the Lodz University of Technology Research Ethics Committee (protocol code: 2/2023; approval date: 30 March 2023)

Participants' basic anthropometric data (mean ± SD).

Participants	Sex	Age (years)	Body mass (kg)	Body height (cm)	BMI (kg/m²)
(N = 25)	Male = 11 Female = 14	22.4 ± 4.5	70.2 ± 15.6	171.1±7.1	23.8 ± 3.7

Material and Methods

Equipment

•**Pedobarographic force plate**

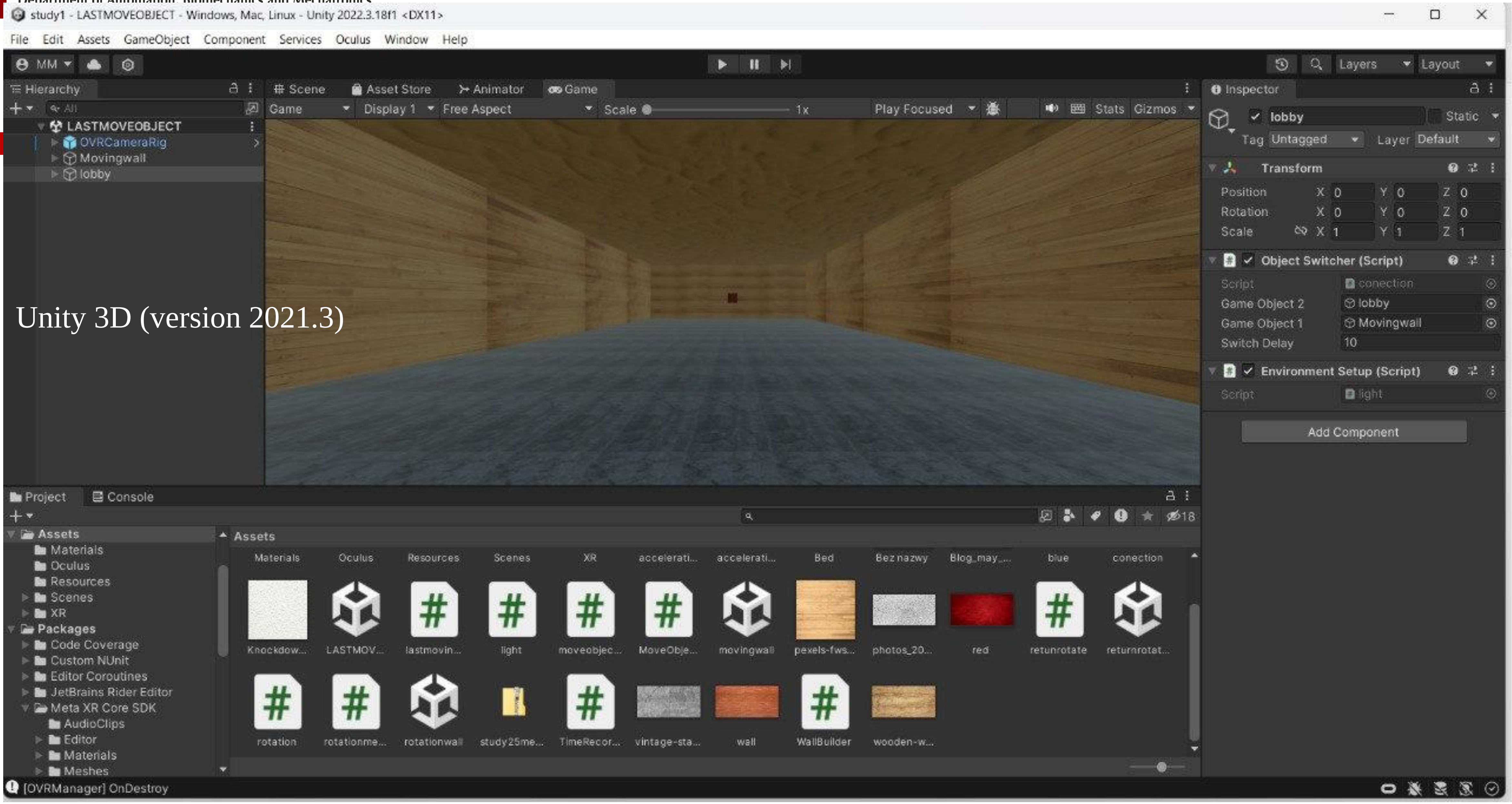
(Footscan® system**)**

•**Virtual Environment Software**

Unity 3D (version 2021.3)

•**Head-Mounted Display (HMD)**

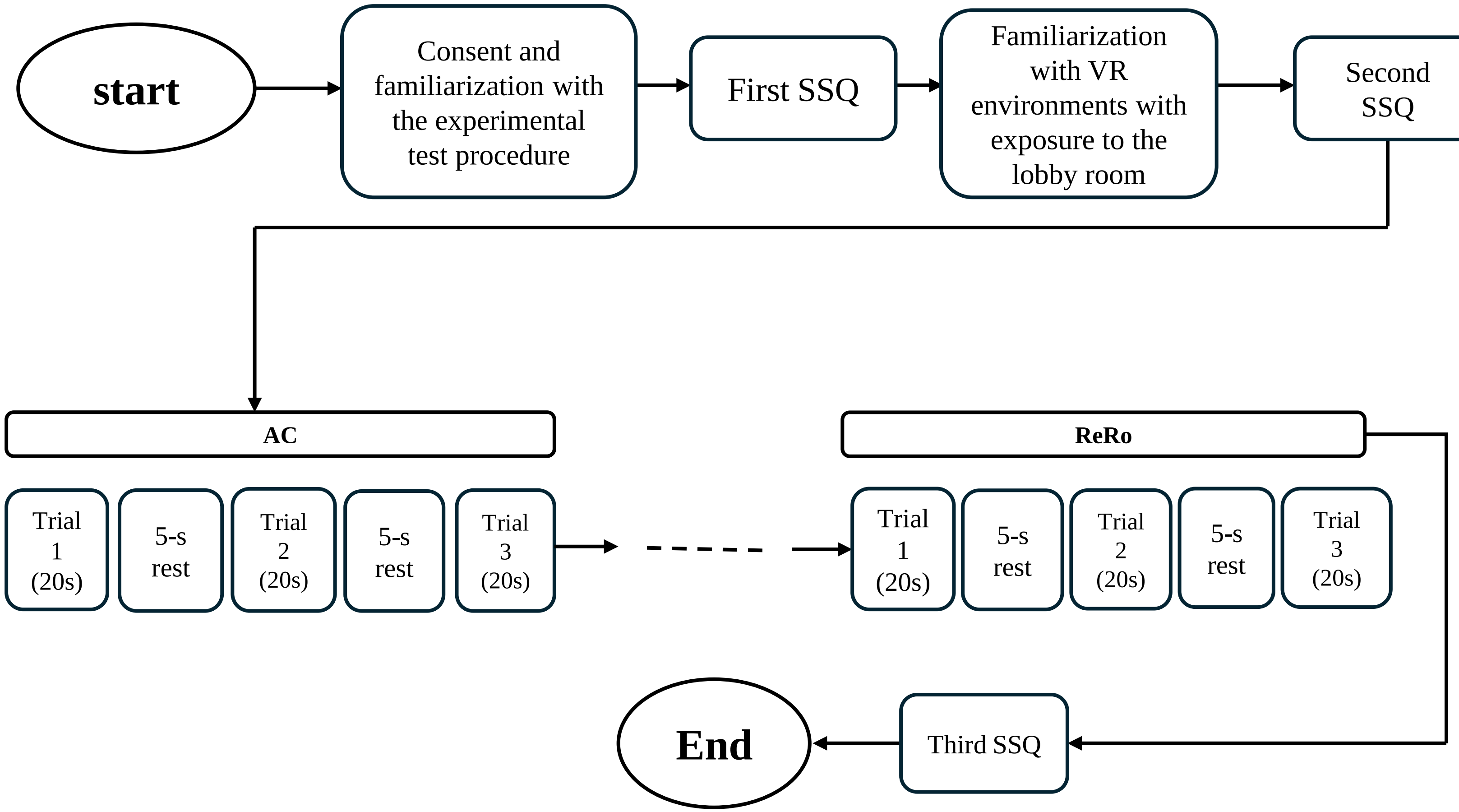
Oculus Rift-S (version 6)



Unity 3D (version 2021.3)

Material and Methods

A simulation sickness questionnaire (SSQ), which comprises a total of sixteen questions centered on simulator sickness, to which response scores range from 0 (none) to 3 (severe), The SSQ was used to determine further eligibility for the study, and participants with an SSQ score greater than five and any associated risk factors were excluded.



Flow chart of the study experimental procedure.

Lodz University of Technology
Department of Automation, Biomechanics and Mechatronics

Material and Methods

Study Protocol

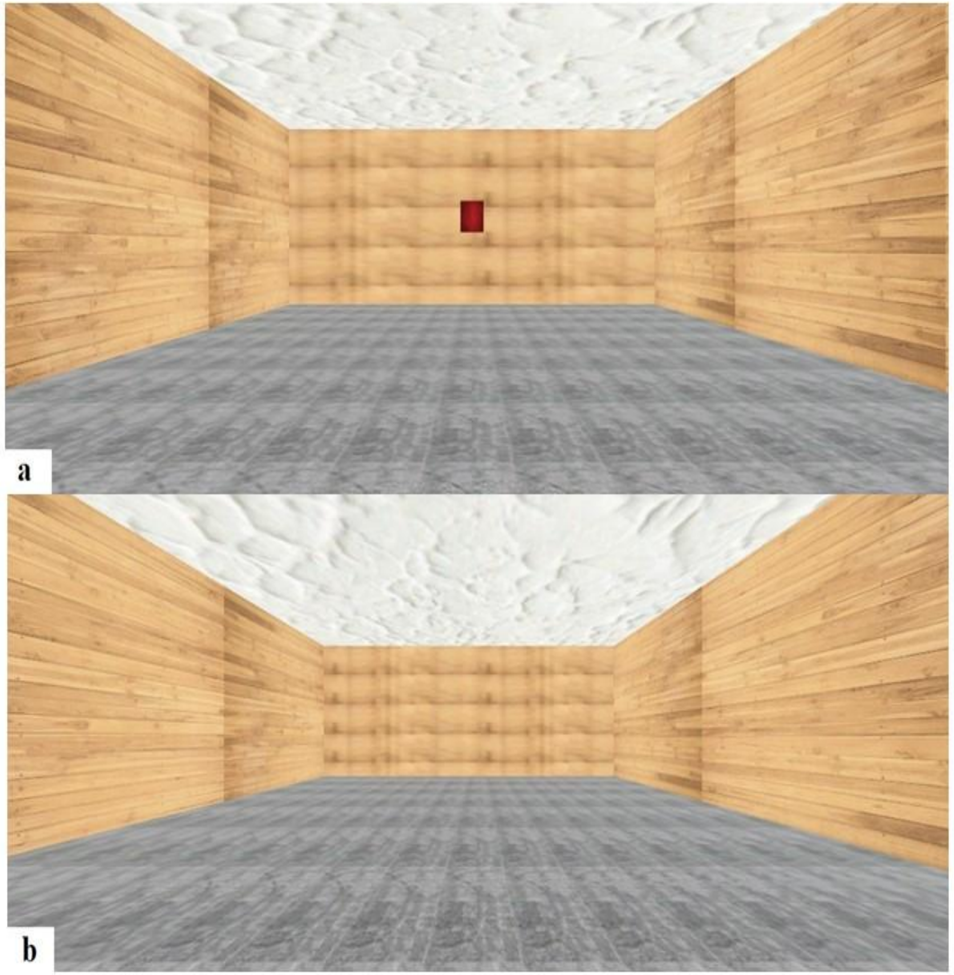
1. Moving Wall (MW): The front wall moved toward the participant at a constant speed of 9 m/s.

2. Accelerating Wall (AC): The wall moved toward the participant with increasing speed, starting with an acceleration of 1.8 m/s^2 for 0.5 second, followed by 8 m/s^2 for 1 second

3. Tilting Room (Ro): The entire virtual room rotated forward or backward at a speed of 20°/s, reaching a maximum tilt angle of 45°.

4. Returning Rotating Room (ReRo): The room rotated forward to 45° at a speed of 20°/s and then reversed back to its initial position

5. Quiet standing with no VR (NV): 10 s barefoot on the force plate



Virtual Environments: (a) lobby and transition area with a red box that, when viewed, moved into the testing environment; (b) closed room testing environment.

Material and Methods

Data and Statistical Analysis

Get raw data from pedobarographic force platform

Using Matlab software

Parameter	Definition	Formula
Maximum sway velocity	Highest time derivative of CoP displacement (cm/s).	MV=max(d COP/d t)
Max Excursion	Greatest absolute CoP displacement in AP and ML directions (cm).	$ME=max(max(COP\ ),\lvert min(COP:,j)\rvert)$
Sway area	Area of an ellipse that encompassed at least 95% of the sway data points (cm^2).	--------
Sway variability	Standard deviation of the CoP sway in AP and ML direction (cm)	$Var = Std(cop_j)$

All statistical analyses were performed using **IBM SPSS**

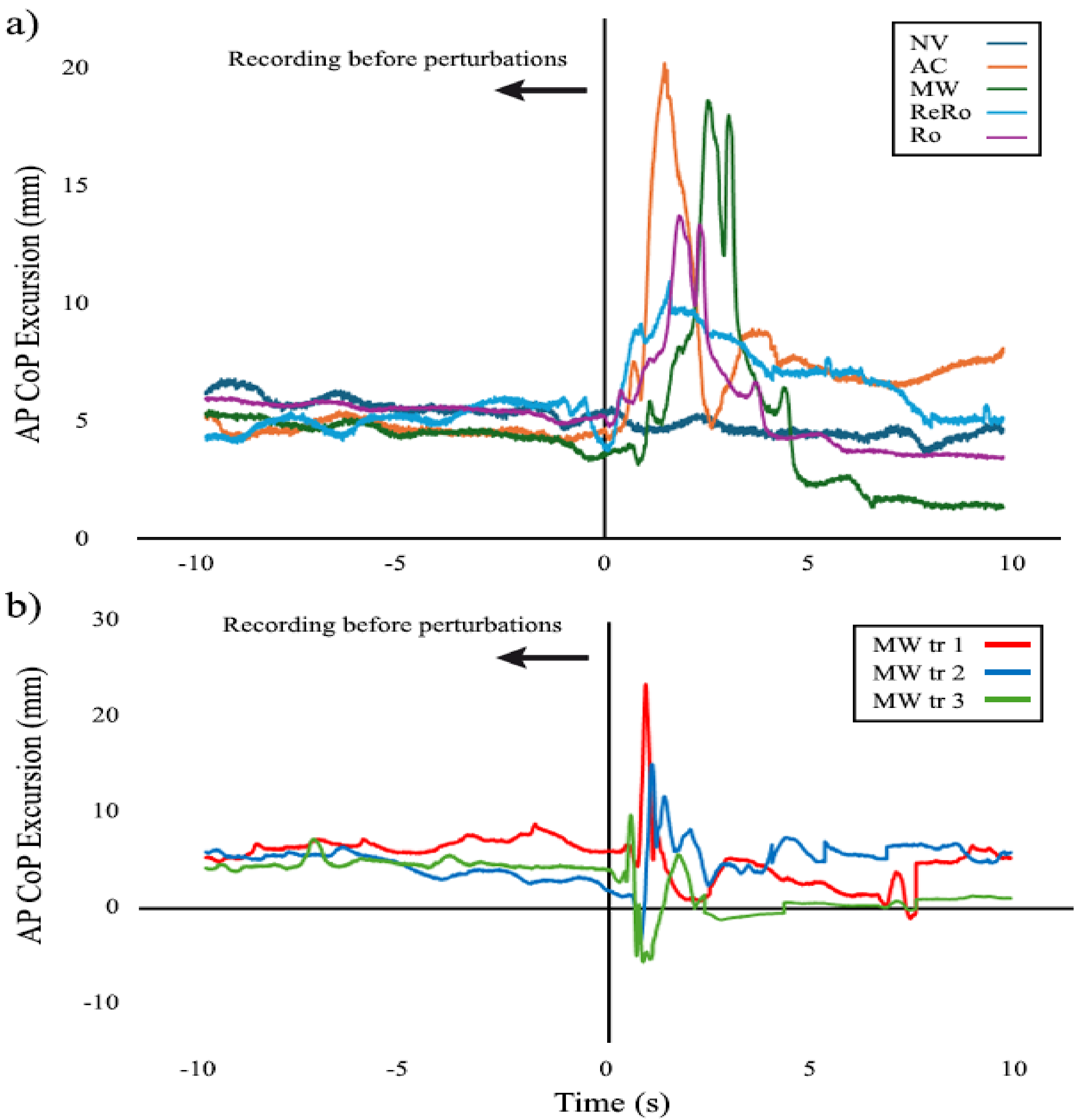
A **one-way repeated measures ANOVA** was conducted

Bonferroni-corrected pairwise comparisons were used

Lodz University of Technology
Department of Automation, Biomechanics and Mechatronics

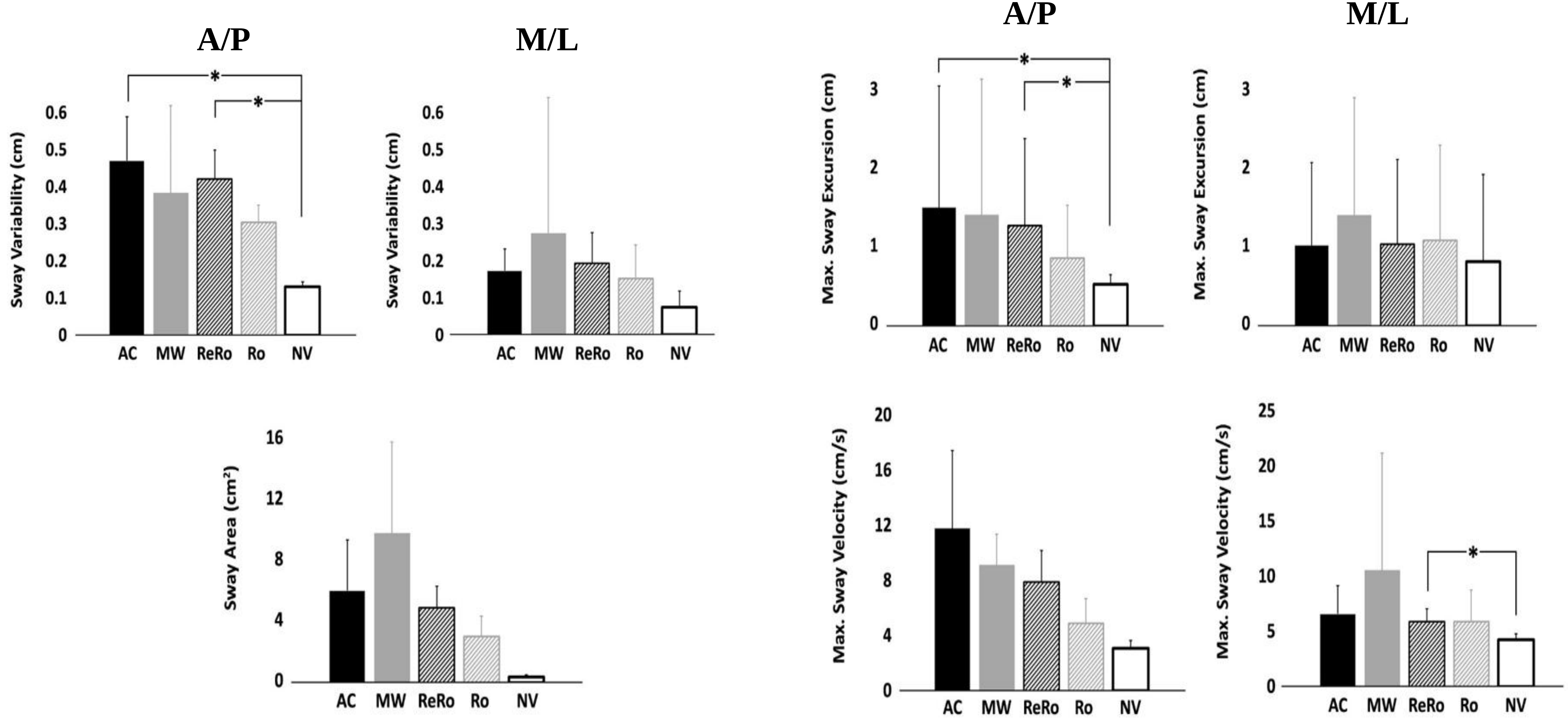
Results

Sample graphs of a) time-dependent variations of anterior-posterior (AP) CoP variations for five different visual environments including an accelerated moving wall (AC), a constant-velocity moving wall (MW), a returning rotation (ReRo), rotations (Ro), and no virtual reality change (NV) for subject #9, and b) three consecutive trials of MW for subject #2. Time at zero denotes the moment of perturbation application, because the perturbation was unexpected; it did not occur at a specific time, but for consistency, it is plotted in a synchronized manner.



Lodz University of Technology
Department of Automation, Biomechanics and Mechatronics

Results



CoP-related metrics of balance for five different visual environments including accelerated moving wall (AC), constant-velocity moving wall (MW), returning rotation (ReRo), Rotations (Ro), and no virtual reality change (NV) in a) anterior-posterior (AP) and b) medial-lateral (ML) directions with means and error bars as standard deviations. The asterisks * denote significant differences ($p < 0.05$).

Discussion

Our findings demonstrated that different virtual environments required distinct strategies for maintaining balance. The visual system processes constant velocity, whereas the vestibular organs detect linear acceleration and angular rotation

Compared to NV, sway variability and maximum sway excursions were considerably higher in the AC and ReRo environments. This result implies that a person's instability is more affected by rapid movement and the return movement of a rotating room than in other environments.

The sway area was unchanged in both AP and ML directions between VR and NV, contradicting our hypothesis. In the quiet VR condition, the organized, distraction-free scene helped participants keep a steady external focus on a central point, improving stability. A 10-second familiarization let them adapt to the headset’s weight, minimizing its effect on balance.

Conclusions

- VR-induced visual motion significantly perturbs postural control, especially under rapid and return-rotation scenarios.
- Traditional sway-area metrics may underestimate instability in VR tasks; kinematic-based measures (e.g., sway variability and excursion) are more sensitive.
- Environments that simulate acceleration or tilting with a return phase offer strong, yet tolerable, postural challenges without inducing simulator sickness.
- VR platforms can serve as scalable, cost-effective tools for balance assessment and training, paving the way for personalized rehabilitation.

References

Allison, L. K., Kiemel, T., & Jeka, J. J. (2006). The Dynamics of Sensory Re-Weighting in Healthy and Fall-Prone Older Adults. *Journal of Neurologic Physical Therapy*, *30*(4), 199. https://doi.org/10.1097/01.npt.0000281268.80572.a3

Beani, E., Filogna, S., Martini, G., Barzacchi, V., Ferrari, A., Guidi, E., ... & Sgandurra, G. (2022). Application of Virtual Reality Rehabilitation System for the assessment of postural control while standing in typical children and peers with neurodevelopmental disorders. Gait & Posture, 92, 364–370. https://doi.org/10.1016/j.gaitpost.2021.12.008

Chander, H., Kodithuwakku Arachchige, S. N., Hill, C. M., Turner, A. J., Deb, S., Shojaei, A., ... & Carruth, D. W. (2019). Virtual-reality-induced visual perturbations impact postural control system behavior. Behavioral Sciences, 9(11), 113. https://doi.org/10.3390/bs9110113

Phillips, D., dos Santos, F. V., & Santoso, M. (2022). Sudden visual perturbations induce postural responses in a virtual reality environment. Theoretical Issues in Ergonomics Science, 23(1), 25–37. https://doi.org/10.1080/1463922X.2020.1870052

Rosiak, O., Pietrzak, N., Szczęsna, A., Kulczak, I., Zwoliński, G., Kamińska, D., ... & Jozefowicz-Korczynska, M. (2024). The effect of Immersive Virtual Reality on balance: an exploratory study on the feasibility of head-mounted displays for balance evaluation. Scientific Reports, 14(1), 3481. https://doi.org/10.1038/s41598-024-54274-8

Lee, D. N., & Aronson, E. (1974). Visual proprioceptive control of standing in human infants. Perception & Psychophysics, 15(3), 529–532. https://doi.org/10.3758/BF03199297

Hoshikawa, T. (1999). Effects of room tilting on body sway: Adaptation and strategies for maintaining a standing posture. Japanese Psychological Research, 41(3), 186–192. https://doi.org/10.1111/1468-5884.00118

THANK YOU for your attention