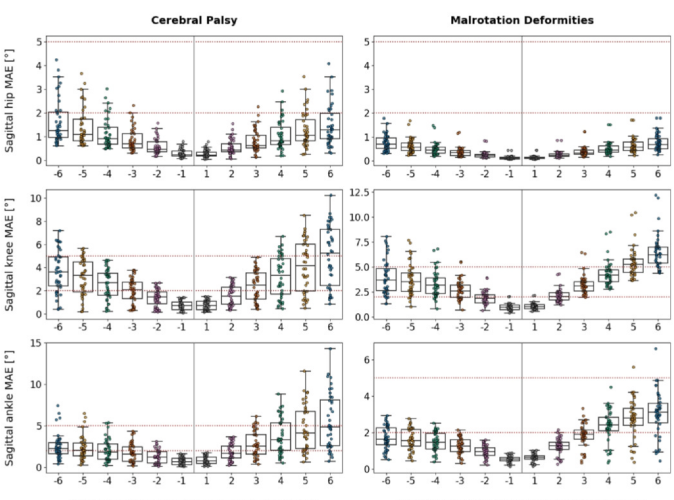
n = 20). For each participant, sagittal kinematics of the left and right hip, knee, and ankle were extracted, utilizing all available force plate hits (n ≥ 5) in each trial. Initially, data was extracted at the original IC using force plate hits at a 20 N threshold. Subsequently, augmented data was extracted by incrementally increasing the time shift by ± 1 frame, starting at the original IC, until a maximum offset of ± 6 frames was reached. This resulted in one original IC and 12 augmented IC values per force plate hit. The mean absolute error (MAE) between the original IC and each augmented IC was calculated on participant level.

Results

Both groups exhibit a median MAE exceeding 2° within an IC error of two to three frames for the knee and three to four frames for the ankle (Figure 1). With an error of five to six frames, a median MAE above 5° is reached for the knee. Delayed IC events show a more pronounced influence on kinematics than events set too early. No impact on hip kinematics was identified.

Figure 1. Sagittal hip, knee, and ankle mean absolute error angle differences at diverse IC offsets to the IC determined by force plates. Red dotted lines represent thresholds of 2° and 5°.



Discussion

This sensitivity analysis shows that even small errors in event detection can notably effect sagittal knee and ankle kinematics at IC, to the extent that the literature on CGA reliability advises caution in interpreting kinematic data [4], [6]. Error rates of event detection methods are reported in frames or milliseconds [7], [8], [9], but the effect of these errors on certain kinematics has been neglected. Our study recorded data at 150 Hz. Laboratories with lower sampling rates may experience even higher errors. Therefore, we highly recommend evaluating errors introduced by event detection because they could influence the quality and interpretation of CGA data.

References

[1] M. McGrath, J. Wood, J. Walsh, and P. Window, "The impact of Three-Dimensional Gait Analysis in adults with pathological gait on management recommendations," *Gait Posture*, vol. 105, pp. 75–80, Sep. 2023, doi: 10.1016/j.gaitpost.2023.06.014.

[2] A. Hebda-Boon, B. Zhang, A. Amankwah, A. P. Shortland, and D. Morrissey, "Clinicians' Experiences of Instrumented Gait Analysis in Management of Patients with Cerebral Palsy: A Qualitative Study," *Phys. Occup. Ther. Pediatr.*, vol. 42, no. 4, pp. 403–415, Jul. 2022, doi: 10.1080/01942638.2022.2037808.

[3] M. H. Schwartz, J. P. Trost, and R. A. Wervey, "Measurement and management of errors in quantitative gait data," *Gait Posture*, vol. 20, no. 2, pp. 196–203, Oct. 2004, doi: 10.1016/j.gaitpost.2003.09.011.

[4] J. L. McGinley, R. Baker, R. Wolfe, and M. E. Morris, "The reliability of three-dimensional kinematic gait measurements: A systematic review," *Gait Posture*, vol. 29, no. 3, pp. 360–369, Apr. 2009, doi: 10.1016/j.gaitpost.2008.09.003.

[5] K. Kaufman *et al.*, "Reliability of 3D gait data across multiple laboratories," *Gait Posture*, vol. 49, pp. 375–381, Sep. 2016, doi: 10.1016/j.gaitpost.2016.07.075.

[6] J. M. Wilken, K. M. Rodriguez, M. Brawner, and B. J. Darter, "Reliability and minimal detectible change values for gait kinematics and kinetics in healthy adults," *Gait Posture*, vol. 35, no. 2, pp. 301–307, Feb. 2012, doi: 10.1016/j.gaitpost.2011.09.105.

[7] B. Dumphart *et al.*, "Robust deep learning-based gait event detection across various pathologies," *PLOS ONE*, vol. 18, no. 8, p. e0288555, Aug. 2023, doi: 10.1371/journal.pone.0288555.

[8] R. M. S. Visscher *et al.*, "Towards validation and standardization of automatic gait event identification algorithms for use in paediatric pathological populations," *Gait Posture*, vol. 86, pp. 64–69, May 2021, doi: 10.1016/j.gaitpost.2021.02.031.

[9] M. Lempereur *et al.*, "A new deep learning-based method for the detection of gait events in children with gait disorders: Proof-of-concept and concurrent validity," *J. Biomech.*, vol. 98, p. 109490, Jan. 2020, doi: 10.1016/j.jbiomech.2019.109490.

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The effects of virtual reality on muscle synergies during walking and balancing in healthy adults

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Introduction

Muscle synergies refer to coordinated patterns of muscle activity that work together to produce voluntary movements [1]. These synergies simplify the control process by reducing the degrees of freedom involved in movement. The integration of immersive virtual reality (VR) in motor rehabilitation is based on the fundamental principles of neuroplasticity and sensorimotor learning [2]. However, there has been limited research into the effects of VR on muscle synergies, despite advances in understanding these concepts in healthy as well as various pathological conditions [3-5].

Research Question

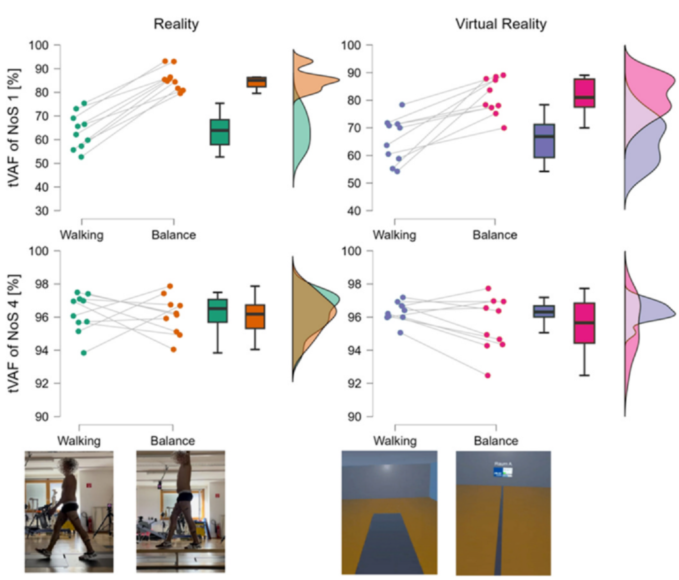
Are there differences in muscle synergies of walking and balancing in the real world compared to a fully immersive VR?

Methods

Three-dimensional motion capture data (Vicon Motion Systems, Oxford, UK) and electromyography data of 12 lower limb muscles (Cometa, Milan, Italy) were collected from ten participants performing walking and balancing tasks. Both tasks were performed in the real world and in VR. Participants wore a Meta Quest II (Meta, Dublin, Ireland) to be fully immersed in a first-person view and could freely navigate and interact in a room-scale VR environment. Muscle synergies were extracted via non-negative matrix factorization [6], and the number of synergies (NoS) was determined by the knee-point of the total variance accounted for (tVAF) cur ve across all conditions [7]. Repeated measure ANOVA was used to compare tVAF of one synergy (NS1) and tVAF of NoS (NoS) between environments (real world versus VR) and tasks (walking versus balancing). For each participant, shared synergies were determined by calculating the Pearson correlation coefficient (> 0.632) among all possible condition pairs [8].

Results

The tVAF of one synergy (NS1) and the determined NoS of 4 showed no significant differences between the real world and VR (Fig. 1). A high ratio (70 to 88%) of shared synergies was found across all comparisons. The difference in tVAF between walking and balancing was less pronounced in VR compared to the real world (N1 $p < 0.001$ and NoS $p = 0.354$).



Caption: Comparison of tVAF at NOS between tasks in real and virtual environments, showing individual data points and distributions via boxplots.

Discussion

Our results showed that VR does not alter muscle synergies during walking and balancing. In agreement with previous studies [9], both analyses showed a significant difference in muscle synergies between walking and balancing. However, the difference between the two tasks was less pronounced in VR than in the real world. This finding can be explained by the lack of proprioceptive demands during the balancing task in VR (participants walked on the floor) compared to the real world (participants walked on a beam) [3]. In conclusion, our data suggest that VR does not alter muscle synergies during walking but may alter motor control during more challenging tasks with higher proprioceptive demands.

References

[1] E. Bizzi and V. C. Cheung, "The neural origin of muscle synergies," Frontiers in Computational Neuroscience, vol. 7, p. 51, 2013.
[2] K. E. Laver et al., "Virtual reality for stroke rehabilitation," Cochrane Database of Systematic Reviews, no. 11, 2017.
[3] B. Horsak, M. Simonlehner, B. Dumphart, und T. Siragy, „Overground walking while using a virtual reality head mounted display increases variability in trunk kinematics and reduces dynamic balance in young adults“, Virtual Reality, Bd. 27, Nr. 4, S. 3021–3032, Dez. 2023, doi: 10.1007/s10055-023-00851-7.
[4] P. Kaufmann et al., "Trial-to-trial similarity and distinctness of muscle synergy activation coefficients increases during learning and with a higher level of movement proficiency," bioRxiv, p. 2023.09.19.558460, Jan. 2023, doi: 10.1101/2023.09.19.558460.
[5] L. Pitto et al., "SimCP: A Simulation Platform to Predict Gait Performance Following Orthopedic Intervention in Children With Cerebral Palsy," Front. Neurorobot., vol. 13, Jul. 2019, doi: 10.3389/fnbot.2019.00054.
[6] H. S. Seung and D. D. Lee, "Learning the parts of objects by non-negative matrix+ factorization," Nature, vol. 401, p. 791, 1999, doi: 10.1038/44565.
[7] M. C. Tresch, V. C. K. Cheung, and A. d'Avella, "Matrix Factorization Algorithms for the Identification of Muscle Synergies: Evaluation on Simulated and Experimental Data Sets," J Neurophysiol, vol. 95, p. 2212, 2006, doi: 10.1152/jn.00222.2005.
[8] M. M. Nazifi et al., "Shared and task-specific muscle synergies during normal walking and slipping," Front Hum Neurosci, vol. 11, p. 40, 2017, doi: 10.3389/fnhum.2017.00040.
[9] J. L. Allen, H. D. Carey, L. H. Ting, and A. Sawers, "Generalization of motor module recruitment across standing reactive balance and walking is associated with beam walking performance in young adults," Gait Posture, vol. 82, pp. 247, 2020.

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Sagittal malalignment in patients with adult spinal deformity seems to increase frontal instability during gait

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