Assessing the Impact of Loading on Mobility and Physical Exertion of Manual Wheelchair Users Using Wearable Sensors

Grace McClatchey, Maja Goršič, Erika V. Zabre, Jacob R. Rammer

Department of Biomedical Engineering, University of Wisconsin-Milwaukee, Milwaukee, WI, USA
Department of Biomedical Engineering, Marquette University, Milwaukee, WI, USA
gofasipe@uwm.edu, gorsic@uwm.edu, ezabre@uwm.edu, jrrammer@uwm.edu



INTRODUCTION

- Manual wheelchair users (MWU) face high physical demands during community mobility and participation.[1]
- Navigating outdoor environments with varying terrain and loads increases exertion and limits participation.
- Shoulder strain from propulsion and load carrying contributes to pain and long-term injuries.[2]
- Load carrying (e.g., groceries, bags) significantly impacts propulsion effort and maneuverability.[3]
- Research on how external loads affect mobility and exertion in real-world outdoor settings is limited.
- Inertial measurement units (IMUs) effectively capture biomechanics and real-world movement data.[4]
- Mobility is essential for MWU to engage socially and participate in community life.
- **Study Goal:** Evaluate how carrying an external load impacts MWU mobility and exertion using IMUs and heart rate monitoring in an outdoor setting.

METHODS

- Participants: 10 manual wheelchair users (7 male, 3 female); mean age 34 ± 9 years, regular wheelchair use
- Sensors & Devices:
  - Two IMUs: on right wrist & on wheelchair frame
  - Garmin wristwatch recorded heart rate and time
- Course Setup:
  - Outdoor course (~22 meters) with cones, ADA-compliant ramp (8.33% slope), gravel, flat areas, and turns

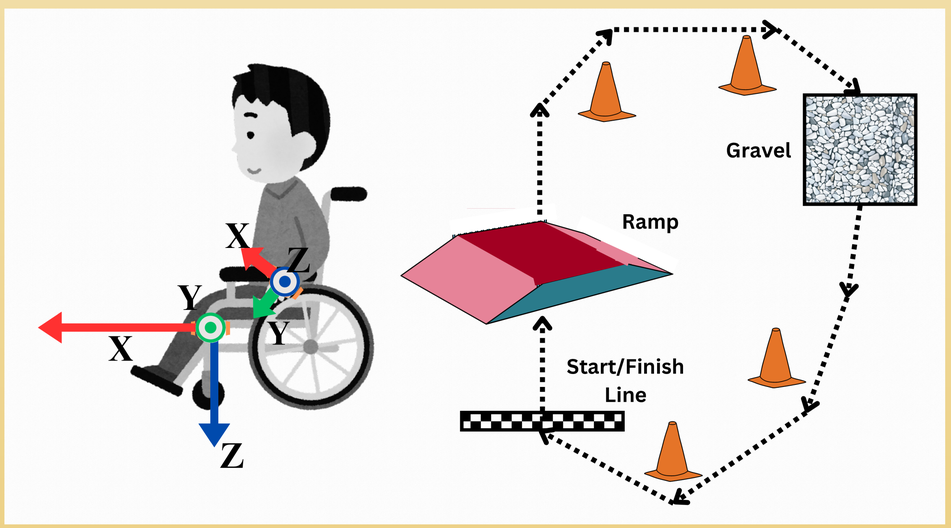


Figure 1: LEFT: Wheelchair user with two inertial sensors. Vector orientation of the IMU axes on the wrist and wheelchair is shown. RIGHT: Sketch of the course and all its elements.

- Participants completed an outdoor course under two conditions: with and without a weighted backpack with ~10% of body weight
- Data Collection:
  - Wrist IMU data used to identify push/recovery phases and calculate cadence
  - Wheelchair IMU used to detect pitch changes during ramp/gravel traversal
  - Wristwatch heartrate averaged across each trial
- Wilcoxon signed-rank tests used to compare completion time, cadence, and HR between conditions

This work was supported in part by the US Department of Health and Human Services, Grant No. 90ARHF0006.

RESULTS

- ***Completion time significantly increased*** in the loaded condition ($p = 0.042$): from 14.6s (unloaded) to 18.3s (loaded).
- ***Mean heart rate also significantly increased*** when carrying a load ($p = 0.038$): from 97.5 bpm (unloaded) to 104.1 bpm (loaded).
- Cadence showed no significant difference between loaded and unloaded conditions ($p = 0.760$).
- Participant responses varied: some increased, decreased, or maintained cadence under load.
- Wheelchair IMU data showed consistent tilt patterns over course obstacles (e.g., ramp, gravel).
- Despite cadence variability, load carrying consistently elevated cardiovascular and physical demand.

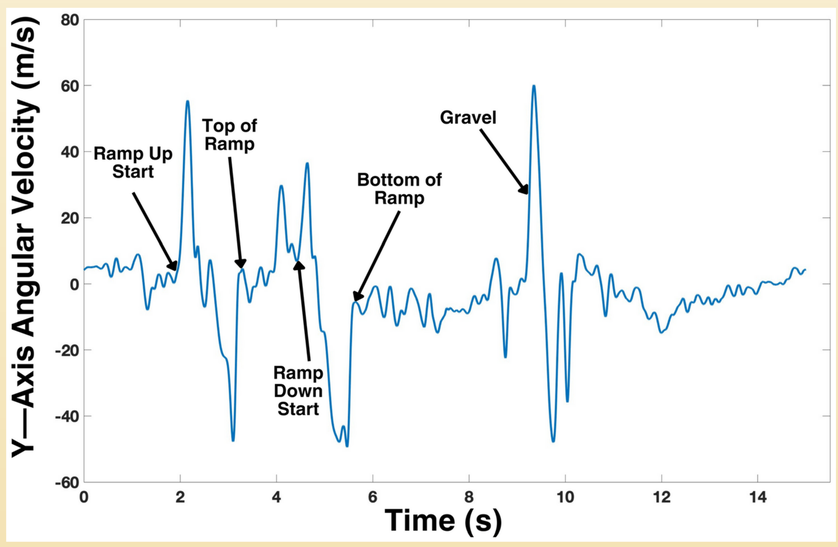


Figure 2: Wheelchair IMU y-axis angular velocity for Participant 1 for unloaded condition, with marked wheelchair pitching movements indicating different segments of the course.

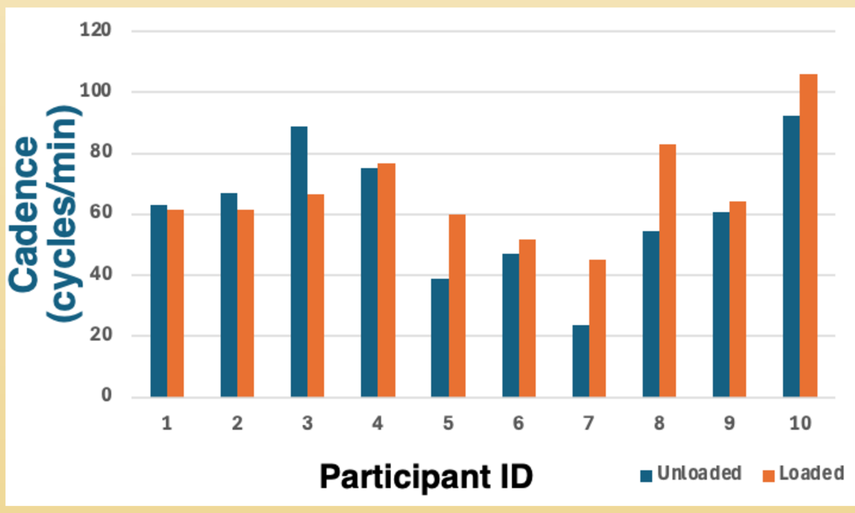


Figure 3: Unloaded and loaded cadence for each participant for the section going up and down the ramp.

DISCUSSION

- Loaded condition increased both heart rate and completion time, highlighting added cardiovascular and physical strain.
- Cadence responses varied across participants: some users increased cadence with lighter strokes; others decreased cadence with stronger pushes.
- ***Individual variability highlights the importance of personalized assessment and training for MWU.***
- Results support designing rehab programs that build strength, endurance, and load management strategies.
- Heart rate increase under load suggests even moderate weight can significantly impact cardiovascular effort.
- Supports the use of routine cardiovascular monitoring for MWU during daily activities.
- Limitations: small sample size, only one trial per condition, fixed testing order.
- Future research should include more participants, multiple trials, and long-term musculoskeletal monitoring.

REFERENCES

1. Rouvier, T. et al. (2022). PLOS ONE 17(6): e0269657.
2. Warner, M.B. et al. (2022). Disabil Health J 15(3): 101326.
3. Sprigle, S. & Huang, M. (2015). Assist Technol 27(4): 226–235.
4. de Vries, W.H.K. et al. (2023). Sensors 23(16): 7174.