Step by Step: A Comprehensive Approach to Stair Climbing Assistance

Margo Amatuzio, Grace Kreissler, Delani Wille, Riley Toth, Cameron Owens
Client: Mr. Dan Kutschera, PT   Advisor: Prof. Walter Block

Fall 2023

Background

- In 2009, 120,000 patients visited the ER for lower extremity injuries [1].
- Below-the-knee injuries often require extended recovery of up to 14 weeks [2].
- Mobility-impaired patients in wheelchairs cannot navigate the stairs in their homes given existing solutions, such as a garden bench, the iWalk device, and crutches.

Problem Definition

- **Challenges in Neuro-Rehabilitation for Mobility-Impaired Patients with Limited Weight-Bearing Capacity:** Supporting patients with weight-bearing restrictions during the transition to home environments, particularly when navigating steps, poses significant difficulties for physical therapists.
- **Limitations of Current Solutions:** Non-adjustable height, absence of a handle for ease of use, instability, discomfort, and lack of user-friendliness.
- **Need for Improved Equipment:** There is an urgent need for a medically designed, safer bench for older, weaker patients who cannot use existing solutions to navigate stairs.

Design Criteria & Specifications

Design a device that aids individuals with a below the knee weight bearing restriction in ascending and descending stairs.

The bench must meet the following quantitative specifications:

- Withstand a maximum load of 300 lbs.
- Low center of pressure displacement and path length under anterior-posterior and medio-lateral movement.
- Device weight under 5 lbs.
- Adjustable bench height.
- Accommodate OSHA standard stair tread of 9 inches and riser height of 9 inches [3].
- Adhere to target production cost of less than $100.

Figure 1. Current rehabilitation bench in use [4]: A patient with a non-weight bearing limb navigating the stairs. The limitations include lack of adjustability and medical design.

Final Design

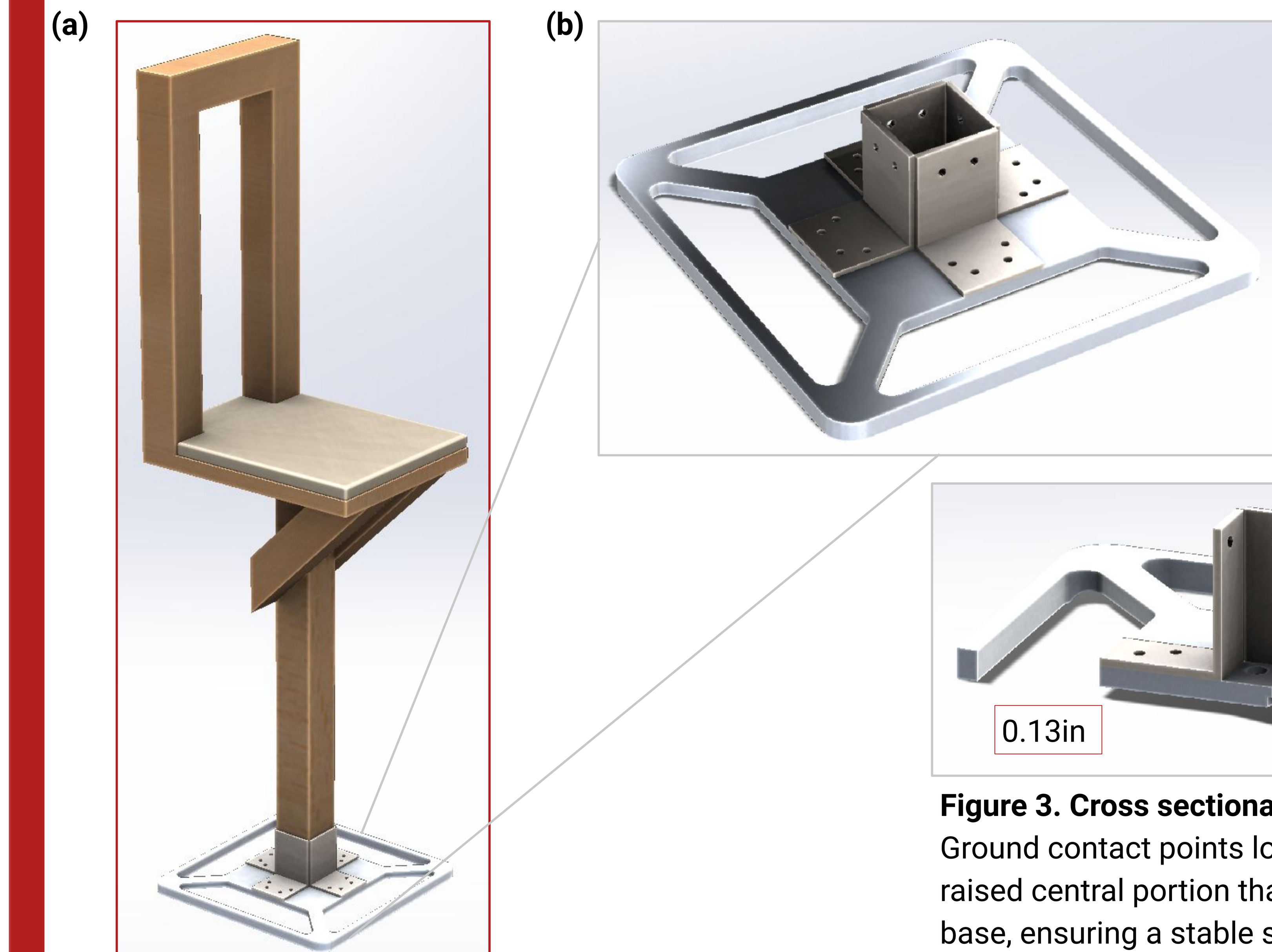

Figure 2. Prototype of the bench and aluminum base: **(a).** CAD rendering of the final design, constructed from wood with an aluminum base. **(b).** Wide aluminum base to expand the distribution of mass, raising the moment of inertia to enhance stability.

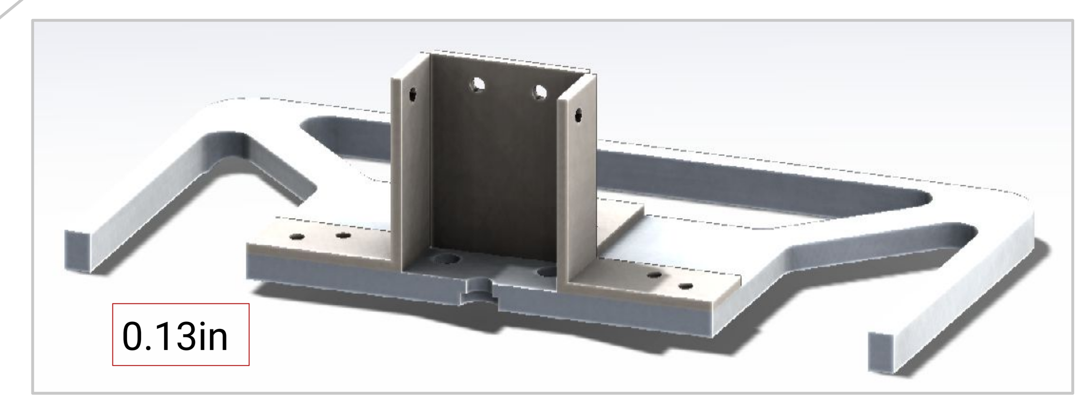

Figure 3. Cross sectional view of the aluminum base: Ground contact points located on the outer edge, with a raised central portion that centralizes the mass above the base, ensuring a stable structure on irregular surfaces.

Testing Stability

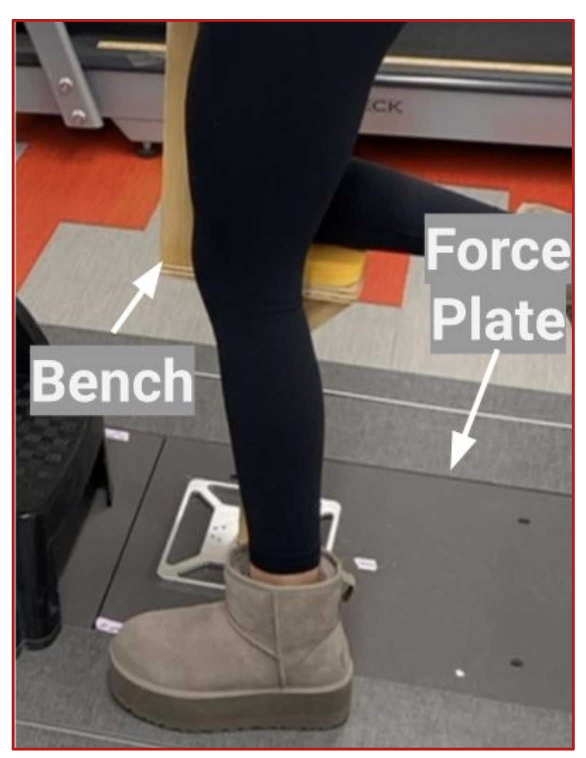

Figure 4. Force plate testing with aluminum base:

- Center of pressure (COP) is used to assess postural stability to reveal how an individual shifts their weight to maintain balance.
- COP trajectory collected over 10 second duration while subject held rigid posture.
- Three stability trials each for aluminum and wood bases.

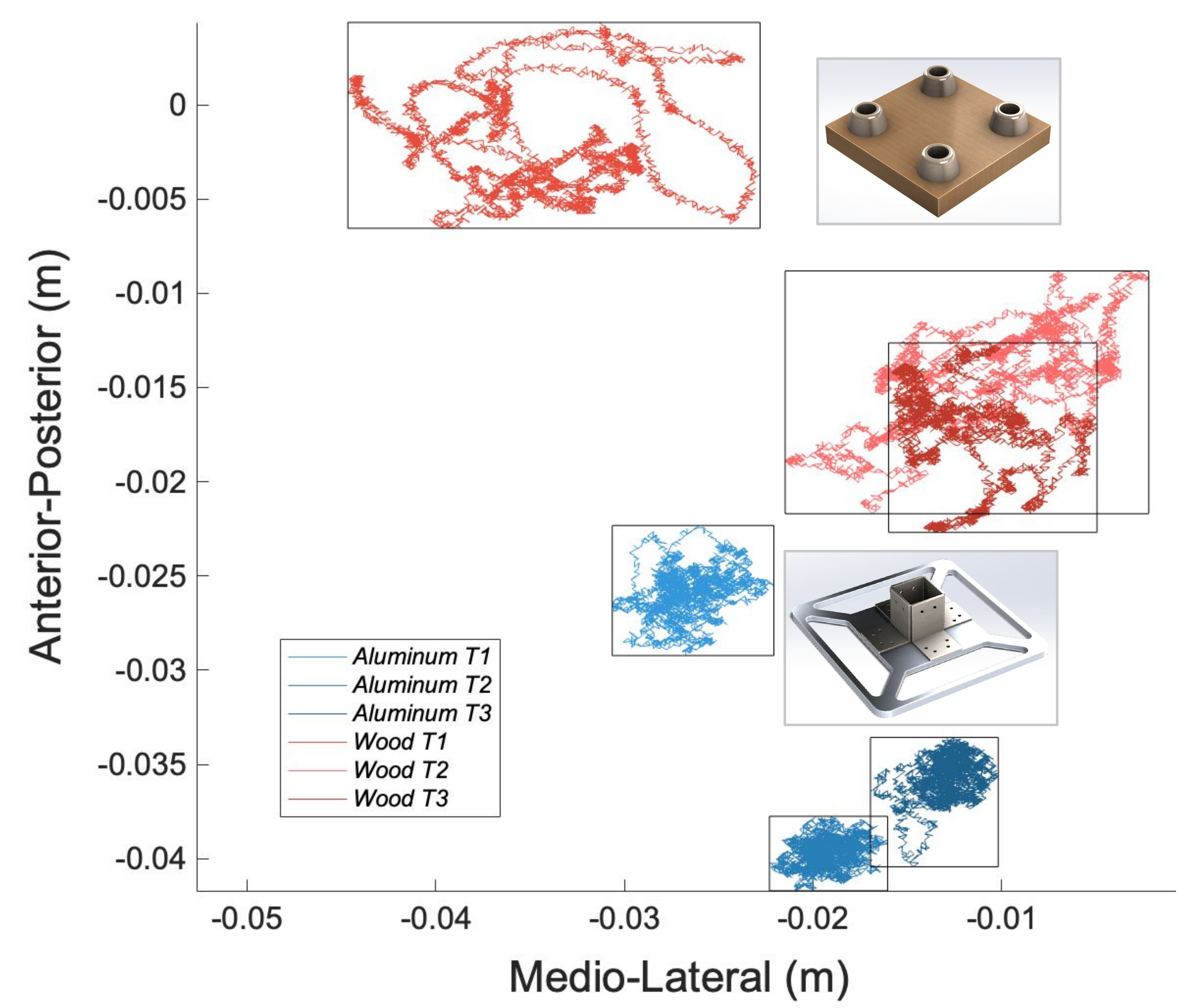

Figure 5. Comparative stability analysis: The variance in stability for aluminum (blue) and wood (red) bases, depicted by path clusters.

- Interpreting stability is not the proximity to the origin point (0,0), but the density of the cluster. Tighter clusters suggest greater stability, regardless of their position in the graph.

Results

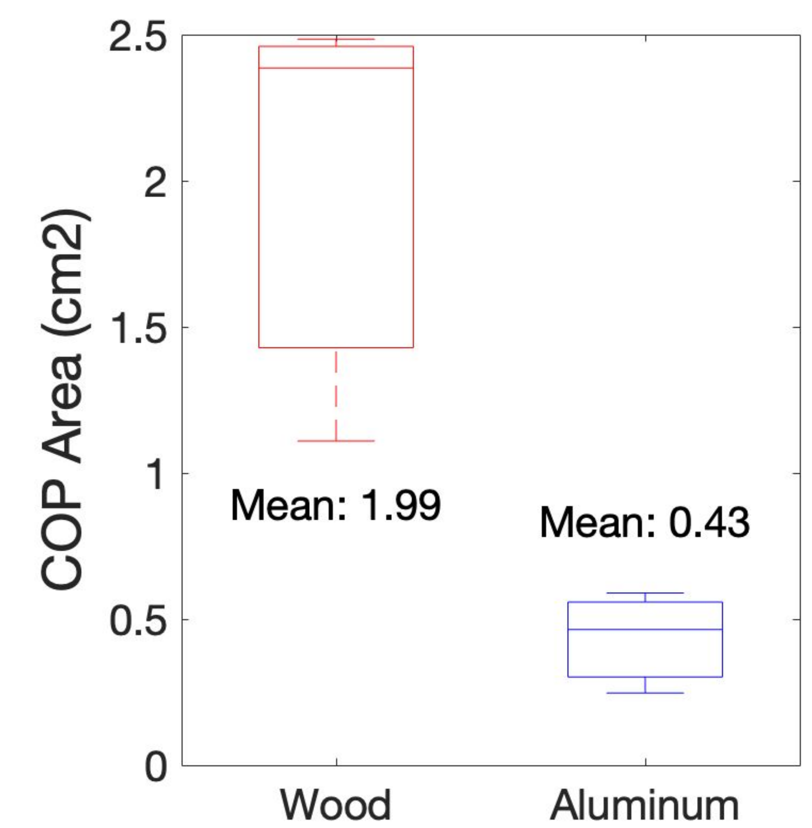

Figure 6. Magnitude of the COP displacement plot:

- A smaller mean area of the aluminum base suggests greater stability because the COP data points are clustered closely together, indicating minimal oscillation in the person's postural control.
- Independent samples t-test revealed a statistically significant difference between the two groups' means at ($p = 0.0264$, $\alpha = 0.05$).

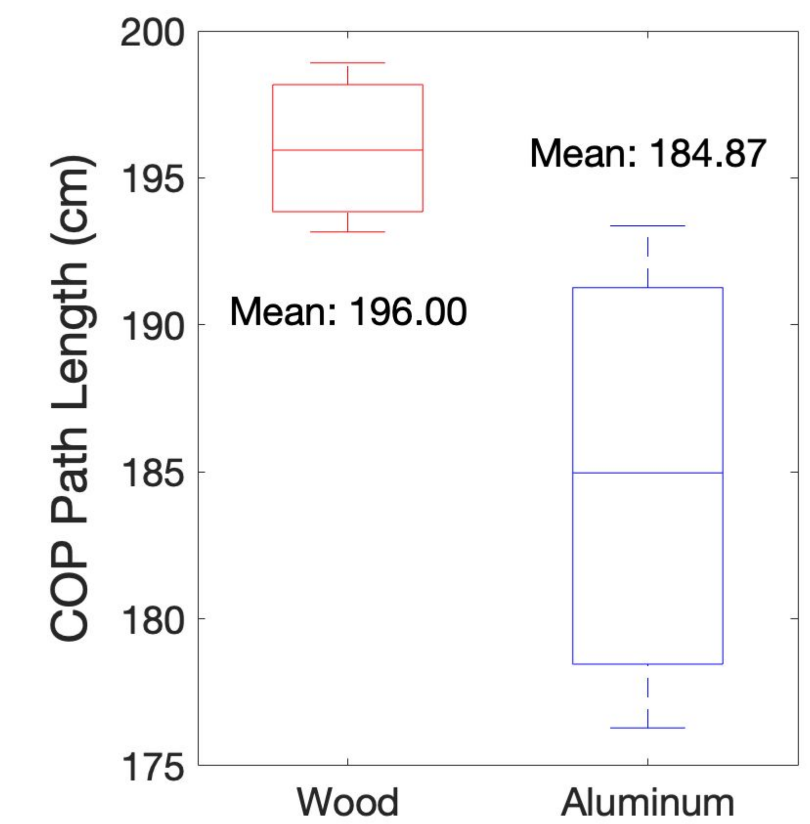

Figure 7. COP path lengths plot:

- The path length is the cumulative distance that the COP travels during a specific period of time.
- The value indicates the overall sway of the person maintaining their balance.
- The smaller mean COP path length of the aluminum base indicates less movement, thus greater stability relative to the wood base.

Future Work

Fabrication

- Design a main support and handle made from aluminum that can be quickly adjusted to fit the dimensions of the patient's anatomy.
- The remaining components will be fabricated from aluminum as well to maintain current configuration and center of gravity.
- Design a stair lip deflection mechanism to increase the devices usability.

Testing

- Testing will commence on the all aluminum prototype to yet again to verify the design meets specifications such as minimum weight, adjustability, and safety.

References & Acknowledgements

We would like to acknowledge our client Mr. Dan Kutchera, and our advisor Prof. Walter Block for their assistance and guidance.

[1] A. Lambers, Daan Ootes, and D. Ring, "Incidence of Patients with Lower Extremity Injuries Presenting to US Emergency Departments by Anatomic Region, Disease Category, and Age," *Clinical Orthopaedics and Related Research*, vol. 470, no. 1, pp. 284–290, Jan. 2012, doi: https://doi.org/10.1007/s11999-011-1982-z.
[2] S. Aloraibi et al., "Optimal care for the management of older people non-weight bearing after lower limb fracture: a consensus study," BMC Geriatr, vol. 21, p. 332, May 2021, doi: 10.1186/s12877-021-02265-z.
[3] "1910.25 - Stairways. | Occupational Safety and Health Administration." Accessed: Dec. 04, 2023. [Online]. Available: https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.25
[4] D. Kutschera, Sep. 12, 2023.