

**Influences of backpack loading on recovery from anterior and posterior losses of balance:
An exploratory investigation**

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Abstract

Backpacks are common devices for carrying external posterior loads. However, relatively little is known about how these external loads affect the ability to recover from balance loss. In this exploratory investigation, 16 young adults (8 female, 8 male) performed forward and backward lean-and-release balance recovery trials, while wearing a backpack that was unloaded or loaded (at 15% of individual body weight). We quantified the effects of backpack loading on balance recovery in terms of maximum recoverable lean angles, center-of-mass kinematics, and temporal-spatial stepping characteristics. Mean values of maximum lean angles were 20° and 9° in response to forward and backward perturbations, respectively. These angles significantly decreased when wearing the additional load for only backward losses of balance. During backward losses of balance, the additional load decreased peak center-of-mass velocity and increased acceleration by ~ 10 and 18% respectively, which was accompanied by ~5% faster stepping responses and steps that were ~9% longer, 11% higher, and had an ~10% earlier onset. Thus, wearing a backpack decreases backward balance recovery ability and increases the challenge to recover balance in both the forward and backward directions.

Keywords: load carriage, reactive balance, postural control

1. Introduction

To prevent falling when a loss of balance occurs, humans rely on rapid, complex postural responses, such as so-called ‘ankle’ or ‘hip’ strategies, or reactive stepping (Komisar et al., 2019b). Typically, these responses help to regain control of the position and velocity of center of mass (COM) with respect to the base of support (BOS), usually consisting of the feet (Maki et al., 2003), and to maintain upright stance (Horak, 2006). The effectiveness of these postural responses, though, depends on a variety of individual (e.g., age, fatigue), task (e.g., holding an object), and environmental (e.g., stairs, lighting) factors (Komisar et al., 2019b).

An important but little-explored task factor is the effect of loads carried on the posterior trunk (e.g., backpacks) on postural responses to balance loss. Backpacks are among the most common forms of loads that humans carry (Li et al., 2019). Wearing a backpack affects both standing balance and gait. During standing balance, wearing an additional load can decrease postural stability that is greatest when the load is worn posteriorly (Martin et al., 2023). Specifically, wearing a backpack can increase movement and anterior excursion of the center of pressure (Martin et al., 2023). Wearing a backpack while walking leads to increased cadence, decreased stride length, increased trunk flexion angle, increased hip and ankle range of motion, and increased vertical and horizontal ground reaction forces (Liew et al., 2016).

Wearing a backpack may also adversely affect the ability to develop effective postural responses for regaining COM control after balance loss (Chow et al., 2006; Roberts et al., 2018). These effects likely occur because additional loads change the position of the COM and alter its mechanical relationship with the feet. Simpkins et al. (2022) recently demonstrated that when young adults experienced balance losses (treadmill movements to simulate slips) while carrying an anterior load, their likelihood of ‘falling’ into a safety harness increased, especially as the mass

1 of the load increased. Wearing a backpack may increase fall risk more than other methods of load
2 carriage because the posterior placement of a backpack shifts the COM backward, causing many
3 to compensate by leaning forward during standing and walking (Al-Khabbaz et al., 2008; Attwells
4 et al., 2006). Compared to other distributed load carriage designs (e.g., waist jackets, packs on
5 both sides), the posterior positioning of a backpack increases COM displacement and velocity
6 while walking (Li et al., 2019; Rugelj and Sevsek, 2011) and leads to more conservative walking
7 strategies, which include slower gait, and increased double support time and stride length
8 (Majumdar et al., 2010; Singh and Koh, 2009).

9 These changes in COM kinematics when wearing a loaded backpack likely also increase
10 the challenge of recovering from balance losses, due to the greater accelerations associated with
11 step-inducing perturbations (Carbonneau and Smeesters, 2014; Lakhani et al., 2011). Stepping
12 responses require the rapid coordination of movements to regain control of the COM to avoid falls
13 (Maki and McIlroy 1997). On the one hand, individuals may experience difficulty in recovering
14 from large destabilizations that affect the maximum recoverable perturbation magnitude,
15 especially in the backward direction given the posterior placement of the load and the reduced
16 posterior edge of the BOS when an individual is leaning backward (Carbonneau and Smeesters,
17 2014). On the other hand, the central nervous system may compensate for kinematic changes in
18 COM through more conservative balance responses, such as greater reactive step length to increase
19 the size of the BOS (Hsiao-Weckslar, 2008). Given the potential increase in COM kinematics (Li
20 et al., 2019; Rugelj and Sevsek, 2011), stepping onset may also occur more quickly with shorter
21 stepping times. However, research specifically examining reactive stepping responses with loaded
22 backpacks is needed to test these ideas.

To better understand the effects of posterior, external loads (i.e., backpacks) on balance recovery, we completed an exploratory investigation to examine the effectiveness and kinematics of stepping responses when recovering from large balance perturbations that were induced using a lean-and-release system. The primary objective of the study was to examine the influence of a backpack load on the maximum recoverable angle during forward and backward losses of balance. We hypothesized that a backpack load would decrease maximum recoverable lean angles during both forward and backward perturbations. Our secondary objective was to examine the effect of wearing a backpack on COM kinematics and temporal-spatial stepping characteristics following loss of balance. For this secondary objective, we had several hypotheses. First, we hypothesized that at equivalent lean angles, a backpack load would increase COM movement in both balance loss directions. Second, we hypothesized that a backpack load would increase step length, width, height, and step velocity, whereas stepping onset time would decrease, assuming that individuals would attempt to quickly increase the size of the BOS to accommodate the increased movement of the COM with the additional load. Given the posterior placement of the load, we further hypothesized that maximum lean angle, COM parameters, and temporal-spatial stepping parameters would also depend on the direction of balance loss.

2. Methods

2.1. Participants

Sixteen young adults (8 female, 8 male) between the ages of 21 and 30 years completed this study. This sample size was considered sufficient based on an *a priori* power analysis (using G-Power); assuming an alpha error probability of 0.05, a power of 0.8, and a sample size of 16 with equal numbers of males and females, the study was powered to detect effects of Cohen's $f = 0.13$, corresponding to small-to-medium effect sizes. Note that, due to errors in data collection (see

below), we obtained complete data from only 13 participants, though the study was still powered to detect effects of $f = 0.15$. All participants were free of self-reported diagnoses of osteoporosis or osteopenia, head, neck, lower body, or sacroiliac injuries, vertebral body compression fractures, traumatic brain injuries, or vestibular or other neurological disorders that affected balance. The study protocol was approved by the institutional review board at Michigan Technological University (1508271-4), and all participants provided written informed consent prior to any data collection. Respective means (SD) for age, stature, and body mass for the females were 23 (2) yr., 166 (11) cm, and 71 (10) kg. Corresponding values for the males were 25(3) yr., 174 (9) cm, and 78 (13) kg.

2.2. Procedures

To examine reactive balance ability, balance perturbations were induced using a lean-and-release (also referred to as tether-release) system (Do et al., 1982). At the start of each perturbation trial, participants stood with their feet in a standardized position for balance testing with the heels 17 cm apart and a 14° angle between the feet (McIlroy and Maki, 1997). While tethered to a wall behind them, the participant was asked to lean forward or backward by only rotating about the ankles in a plank-like position until the tether was taught (Figure 1). Tether length was adjusted to alter the shank lean angle, which was measured using a goniometer with the pivot at the lateral malleolus. Lean angle was calculated using a handheld goniometer, specifically the angle of the shank relative to vertical. The orientation of the shank was determined using the lateral malleolus and lateral epicondyle of the femur and was measured by a member of the research team who was trained specifically in landmarking and measurement techniques. The pillar of a free-standing gantry, which was directly posterior edge of the feet of the participant, served as vertical reference.

Lean angle measurements were evaluated using motion capture data, by calculating the included angle between the shank and the vertical prior to release (see Appendix: Tables A1 and A2).

An electromagnet was located in series with the tether, which was released by the researcher causing the participant to lose their balance. Participants were instructed to regain their balance in whatever way felt natural upon release, but while trying to minimize the number of steps taken to recover their balance. During all trials, participants wore a fall arrest harness connected to an overhead gantry. A load cell (Transducer Techniques, Temecula, CA) placed in series between the harness and the gantry was used to determine when the participants weighted the harness.

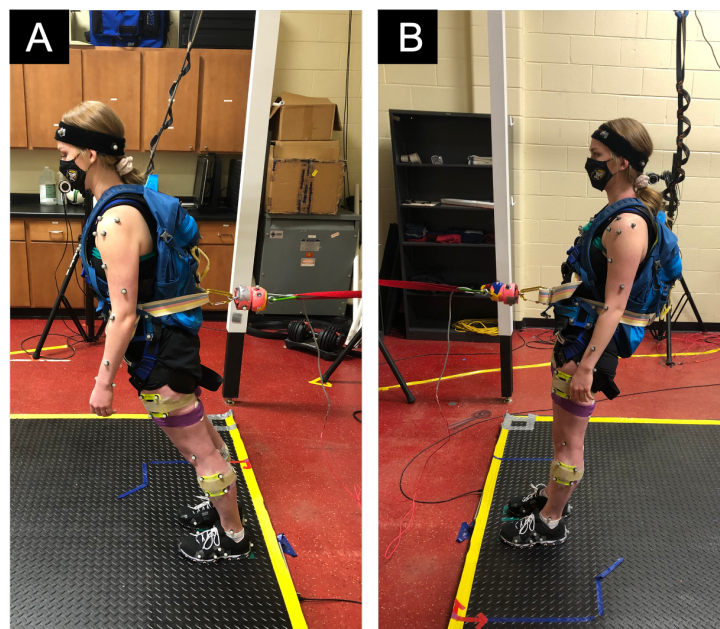


Figure 1. Forward (A) and backward (B) leans in the lean-and-release system.

Participants initially completed 12 practice trials (six leaning forward, six leaning backward) in the lean-and-release system. These trials were used to mitigate the rapid learning that occurs at the beginning of reactive balance trials (Barrett et al., 2012; McIlroy and Maki, 1995). Practice trials were completed at lean angles of 10° forward and 2° backward, and these angles

were selected to consistently elicit a stepping response (Carbonneau and Smeesters, 2014; Lakhani et al., 2011). Participants then completed four blocks of ramp-up balance trials: 1) Forward Lean, Unloaded; 2) Forward Lean, Loaded; 3) Backward Lean, Unloaded; 4) Backward Lean, Loaded. In the forward lean conditions, participants were leaning forward when the tether was released, whereas during the backward lean conditions they faced in the opposite direction and were leaning backward when the tether was released. The order of presentation of the four conditions was counterbalanced using 4x4 Latin Squares to minimize potential confounding effects of learning and fatigue.

In all conditions, participants wore a backpack with the shoulder and hip straps fastened and tightened appropriately so that the backpack would not shift during the experimental trials (Sharpe et al., 2008). The backpack used was a one-size-fits-all Osprey Flare 22 school bag/daypack (45 (l) x 27 (w) x 25 (d) cm) purchased in 2019. The pack had adjustable padded straps and a small unpadded waist belt, which were adjusted to each person's torso so that there were minimal gaps between the backpack and the spine or shoulders. All chest straps were worn as per the manufacturer's recommendations. In the Unloaded conditions, the backpack was completely empty. In the Loaded conditions, weights were placed in the backpack to equal 15% of each participant's body weight. This specific load corresponds to the maximum recommended weight of a backpack (Brackley and Stevenson, 2004). We used steel weightlifting plates for ease of adjusting the loads, and this approach also kept the load close to the spine. The backpack had one compartment that was large enough to hold the weights. All weights were placed vertically in this compartment, with the largest weights being closest to the spine. The plates ranged in size from 0.25-2.25 cm in width and 10-25 cm in diameter. The remaining space in the bag was filled with bubble wrap to prevent the plates from shifting during testing.

Participants began at a lean angle of 10° for forward balance loss and 2° for backward balance loss. The lean angle was then increased by 2° in each condition, until the participant reached an angle at which they could no longer recover balance by taking a single step. A “failed” recovery was defined as taking or initiating multiple steps or losing balance that weighted the harness by more than 20% of body weight (Cyr and Smeesters, 2007). When a participant failed to recover balance, the same lean angle was repeated. If a participant failed three out of five attempts at a given lean angle, that angle was recorded as their maximum lean angle. Otherwise, the lean angle was increased by 2° until the maximum lean angle was reached (Mackey and Robinovitch, 2005). The experimental protocol took approximately 2.5 hours to complete, and participants were given as much resting time as needed between trials.

2.3. Data Acquisition

Full-body kinematics were collected at 100 Hz using a 12-camera optical motion capture system (Qualisys Inc., Sweden) with 74 surface markers. Individual markers were placed on the head (4), shoulders (4 on each side), forearm and upper arm (6 - 8 on each side), knees (2 on each side), ankles (2 on each side), and feet (6 on each side). Rigid clusters of markers (3 - 4 markers per cluster) were placed on the thorax, pelvis, thighs, and shanks. Load cell data were sampled at 100 Hz. All marker placements for calculating joint angles were based upon those recommended by Visual 3D for use with their software (see below), which are consistent with International Society of Biomechanics recommendations for biomechanical modelling (Wu et al., 2002; Wu et al., 2005).

2.4. Data Analysis

Data Processing. Individual markers were identified and gap-filled using Qualisys software. Marker position data were low-pass filtered (fourth-order, zero-lag, Butterworth, 6 Hz cutoff frequency (Schinkel-Ivy et al., 2020) and used to create a 13-segment biomechanical model (Dempster, 1955; Hanavan Jr, 1964) in Visual3D software (v.6, C-motion Inc., USA). The COM location was estimated as a weighted average of each body segment's approximate COM location (Schinkel-Ivy et al., 2020). During loaded trials, the trunk segment mass was adjusted to include the additional backpack load on the torso. This biomechanical model was used to calculate COM kinematics (peak displacement, velocity, and acceleration in the direction of balance loss) and temporal-spatial measures related to stepping (step length, height, width, onset time, and velocity).

Three event times were identified to extract the temporal-spatial outcome measures: 1) tether release (perturbation initiation); 2) step initiation (toe-off of the initial step, determined by peak positive velocity of the stepping foot in the transverse plane after tether release); and 3) step completion (heel-strike of the initial step, determined by peak negative velocity of the foot in the vertical plane or the second peak negative velocity if two peaks were present). All time codes were manually verified.

Step length was calculated as the anterior-posterior (A-P) distance between the heel marker prior to tether release and at step completion (Matson and Schinkel-Ivy, 2020; O'Connor et al., 2007). Step length was then normalized to participant stature (Wang et al., 2012). Step height was obtained from the peak height of the heel marker in the vertical direction between step initiation and completion. Step width was determined from the medial-lateral (M-L) distance between the stepping heel marker while standing and at step completion. Step time was calculated as the time between step initiation and step completion. Stepping onset time was calculated as the time between tether release and step initiation. Step velocity was identified as the peak A-P velocity of

the foot center between tether release and step completion (Matson and Schinkel-Ivy, 2020; O'Connor et al., 2007). COM position was estimated in Visual3D by weighting the mass and position of individual body segments. The first and second derivatives of COM position were used to determine peak COM velocity and acceleration, with peak values determined between step initiation and step completion.

2.5. Statistical Analysis

Our primary outcome measure was maximum recoverable lean angle, reflecting overall balance recovery ability, whereas the secondary outcomes were COM displacement, velocity, and acceleration, and the temporal-spatial measures related to stepping. All secondary outcomes were analyzed at each participant's maximum successful lean angle achieved in both loaded and unloaded condition in each direction of balance loss (Forward, Backward). Due to problems in motion capture, development of the full body kinematic model was not possible for any of the trials of three participants. Therefore, the CoM and temporal spatial stepping kinematics could not be calculated for these three participants. Other data were complete for these three, and complete data sets were utilized for the other 13 participants.'

We used separate repeated-measures analyses of variance (ANOVAs) to test the effects of loading (unloaded, loaded) and balance loss direction (forward, backward). Sex was included as a blocking factor, given evidence of differences in lower limb strength (Jacobs et al., 2007) and in maximum lean angles in similar balance recovery work (Carbonneau and Smeesters, 2014). Order of exposure to the four conditions was also included as a blocking factor. Simple-effects testing was used to explore significant interaction effects. We performed all statistical analyses in JMP 16 using the restricted maximum likelihood (REML) method. We concluded statistical significance

when $p < 0.05$. Note that some outcome measures were transformed prior to ANOVA (see Appendix Table B1) to achieve consistency with parametric model assumptions; summary results, however, are presented in the original units for clarity.

3. Results

A summary of the results of the ANOVA analyses is provided in Appendix Tables B1 and B2 in the Appendix. Results for different outcome measures are presented in subsequent sections.

3.1. Maximum Lean Angle

There was a significant main effect of balance loss direction and loading condition on maximum lean angle (Figure 2). Maximum lean angle was significantly smaller during backward vs. forward leans in both the unloaded and loaded conditions ($p < 0.001$). During backward leans, maximum lean angles were significantly smaller in the loaded vs. unloaded conditions ($p = 0.0213$), whereas there was not a significant effect of loading condition during forward leans ($p = 0.608$).

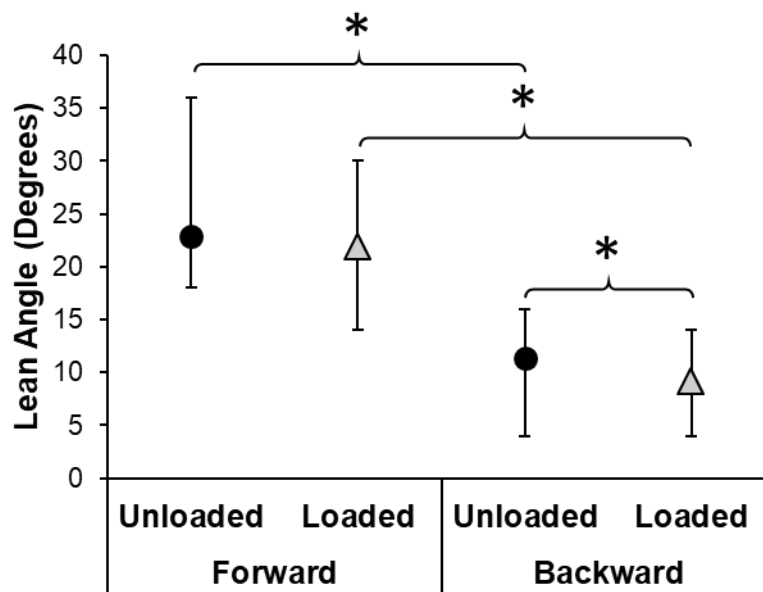


Figure 2: Effects of direction of balance loss and loading condition on maximum lean angle. Here and in subsequent figures, the symbol * indicates a significant ($p < 0.05$) paired difference, and error bars indicate 95%ile distributions of the data.

3.2. Center-of-Mass Parameters

Sample COM kinematics are illustrated in Figure 3. The direction of balance loss significantly affected peak COM displacement, velocity, and acceleration, which were each higher for forward leans (all p values < 0.001 ; Figure 4). COM velocity ($p = 0.019$) and acceleration ($p = 0.034$) were respectively 10% lower and 18% higher when wearing a loaded backpack during the backward condition.

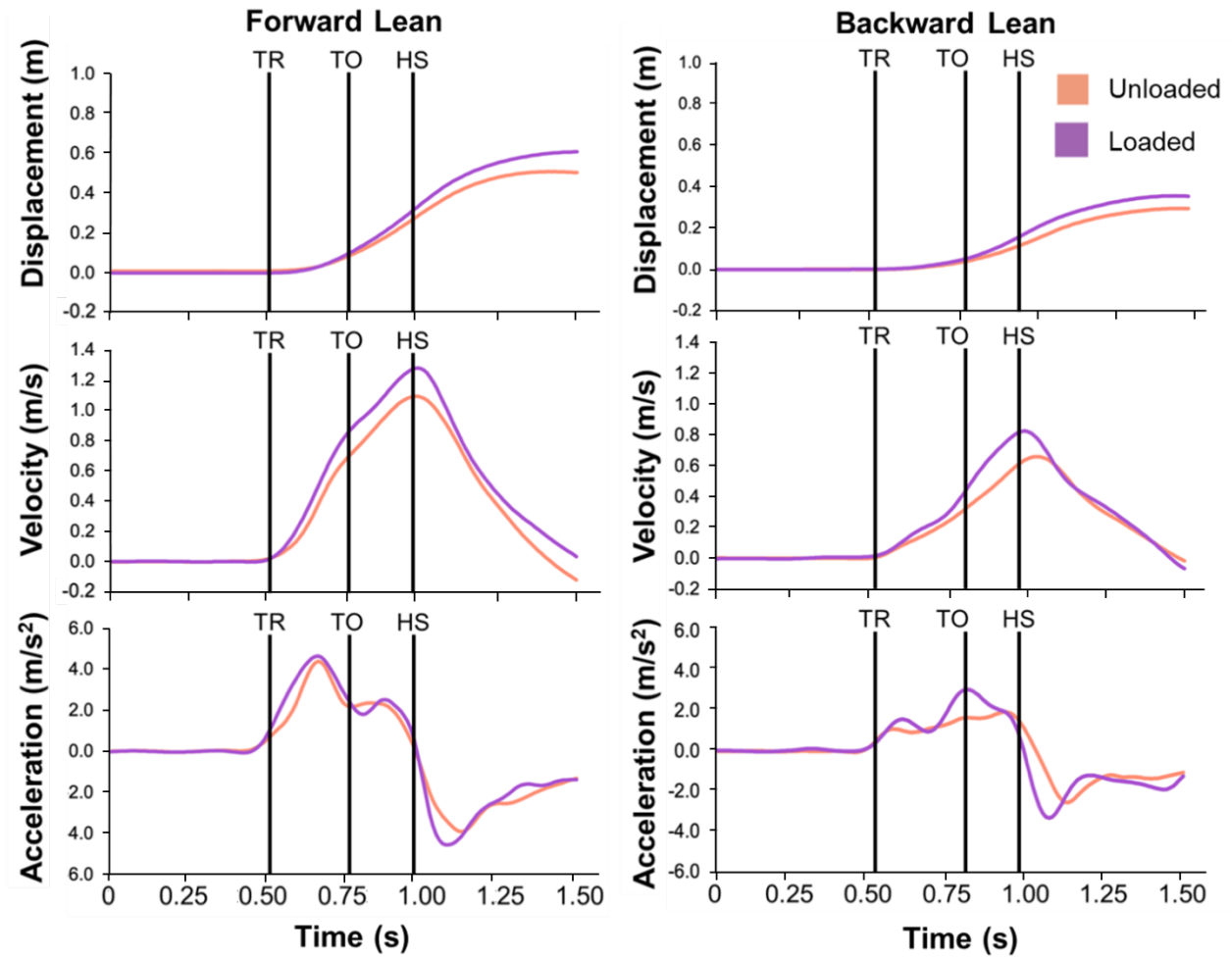


Figure 3: Sample time-series data for COM kinematics during forward and backward lean perturbations. TR = tether release, TO = toe-off (step initiation), and HS = heel-strike (step completion).

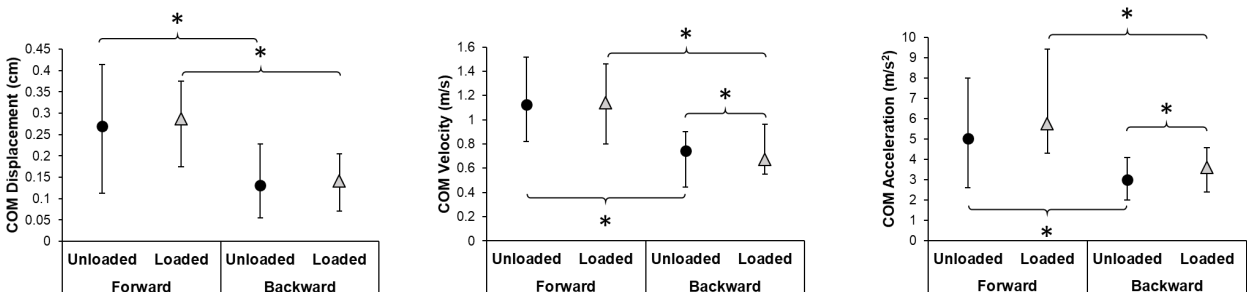


Figure 4: Center of Mass (COM) displacement (left), velocity (center), and acceleration (right) in unloaded and loaded conditions during forward and backward lean perturbations.

3.3. Temporal-Spatial Stepping Measures

Balance loss direction significantly affected step length, width, and peak velocity, which were all higher for forward vs. backward balance loss (all p values ≤ 0.001 ; Figure 5). We found no significant effects of balance loss direction on step height or onset time. Step time was affected by balance loss direction during the unloaded ($p = 0.002$) but not the loaded ($p = 0.356$) conditions. Backpack loading significantly increased step length, step width, step height, and step completion time ($p \leq 0.012$), and it caused an earlier step onset ($p \leq 0.049$). During the backward balance loss condition, backpack loading caused steps that were 9% longer, 11% higher, and 21% narrower, and 10% faster onset. Male participants demonstrated significantly shorter stepping onset times ($p = 0.026$) and larger peak velocities ($p = 0.031$).

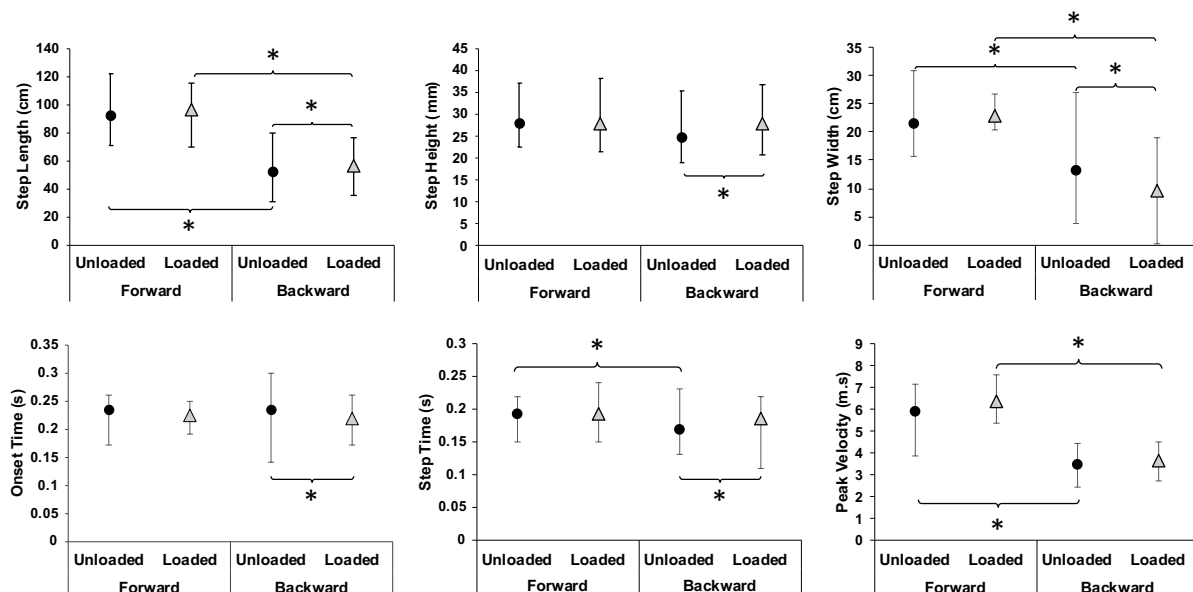


Figure 5: Temporal-spatial stepping parameters during forward and backward perturbations in both loaded and unloaded conditions: Step length (% of body height) (A), Step height (B), Step width (C), Step onset time (D), Step time (E), and Step velocity (F).

4. Discussion

Recovering from balance disturbances during common activities, such as carrying a load, is fundamental to avoiding falls (Horak, 2006). The primary aim of this exploratory study was to examine the influences of external loads on balance recovery ability. Specifically, we examined the influence of loading a backpack, with 15% of bodyweight, on maximum recoverable lean angle, COM parameters, and temporal-spatial stepping measures during forward and backward losses of balance.

The backpack load significantly decreased maximum lean angle, supporting our primary hypothesis. Yet, this effect was only statistically significant for backward balance loss, supporting our secondary hypothesis of a directional dependence. Additional evidence on the effects of a backpack load was obtained from the temporal-spatial measures. COM kinematics (velocity and acceleration) increased during backward losses of balance. Along with these differences, backward losses of balance led to participants using longer, higher, and narrower steps that took longer to complete. These findings partially support the two hypotheses of our secondary objective, that COM kinematics and stepping temporal-spatial measures would increase with the additional load. Together, these results suggest that participants compensated for the backpack load, and the associated change in height of their “combined” COM, by increasing the size of their BOS (via longer steps), perhaps to minimize the overall impact of the backpack load on their ability to recover from balance loss. However, the additional load on the back did not affect the timing of the initiation of the stepping response.

Our results extend existing evidence on the effects of wearing loaded backpacks among civilian adults to show that individuals also modify their stepping behavior to regain control of their COM after balance loss (Liew et al., 2016; Martin et al., 2023). Specifically, previous

research has found that backpack loads worn while standing decrease overall postural stability, and that this effect is accompanied by increases in COP area anterior-posterior COP excursion (Martin et al., 2023). Furthermore, while walking, wearing a backpack with a larger load result in short strides and increased cadence (Liew et al., 2016).

Our results also complement previous work that assessed the influence of loads on reactive balance control, showing that steps during balance recovery significantly differ from voluntary movements in terms of speed, timing, and lack of anticipatory postural adjustments (Komisar et al., 2019b; Maki and McIlroy, 1997). Previous work examined balance recovery from treadmill-induced perturbations while carrying no load or anterior loads of 10% and 20% BW (Simpkins et al., 2022). This work found that load presence and mass increased the likelihood of falling into a safety harness and increased COM velocity. Research examining anterior load carriage during continuous platform perturbations found increased compensatory stepping (Duncan et al., 2018). While the absence of measures of stepping characteristics in Simpkins et al. (2022) makes direct comparisons difficult, we found differences in COM velocity between loaded and unloaded conditions, but only for the backward loss of balance condition.

A possible explanation for this divergence in findings is that Simpkins et al. (2022) had participants carry loads anteriorly and actively (via the upper limbs), whereas the load in our setup was carried posteriorly and passively (via the backpack straps). Thus, placement of the load may have resulted in lower mechanical demands, allowing participants to quickly modify their step length and height, and to minimize the overall impact of loading on whole-body balance recovery. Differences in positioning of the load and balance control have been previously observed during standing balance (Martin et al., 2023). A second explanation is that Yang et al. (2022) focused on first-trial responses to balance loss, wherein participants did not

1 have the opportunity to practice reactive stepping at lower perturbation levels. Further research is
2 needed to better understand the motor and cognitive demands of balance recovery while carrying
3 loads passively and actively, and to quantify the differences (if any) between reactive stepping
4 behaviors with repeated exposure to balance loss.

5 Consistent with earlier evidence (Carbonneau and Smeesters, 2014), participants here
6 recovered from substantially larger lean angles during forward versus backward balance losses,
7 irrespective of loading condition. In response to backward losses of balance, individuals had
8 decreased COM kinematics, step length, widths, times and velocities when compared to forward
9 losses of balance. These results do, however, highlight the overall challenge of recovery from
10 backward loss of balance, likely reflecting a combination of the reduced distance of the posterior
11 base of support to the axis of rotation (ankle joint), an inability for participants to stand on their
12 toes rather than stepping to recover balance, and the reduced visual information available when
13 stepping backward to guide foot placement.

14 The specific backpack load may have affected our findings. We selected this load to
15 avoid exacerbating injury risk during balance recovery, which involves faster movements and
16 higher joint loads than quiet stance or gait. Encouragingly, participants in our study did not
17 report adverse effects. However, previous studies of gait in healthy adults used backpacks with
18 loads ranging from 10-40% of BW and military personnel frequently report backpack loads
19 exceeding 40% BW (Beekley et al., 2007; Genitrini et al., 2022; Jaworski et al., 2015).
20 Comprehensive reviews of backpack use during both standing and walking suggest that load
21 magnitude may have a significant effect on standing balance and gait parameters, particularly for
22 civilian populations (Adamo et al., 2007; Liew et al., 2016). In our study, young adults
23 successfully adapted their postural control mechanisms for the additional 15% BW. However,

1 increased COM accelerations and corresponding neuromuscular demands with increased loads
2 may increase the challenge of balance recovery, and further research is needed to understand
3 how heavier backpacks affect balance recovery in a range of populations.

4 The type of backpack may have also affected our findings. During initial piloting we
5 found that traditional school backpacks designed with smaller shoulder straps and without a hip
6 belt caused discomfort in the shoulders, particularly at larger release angles. Therefore, in future
7 studies it will be important to ensure that backpacks used have adequate padding and ability to
8 secure the load firmly to the backpack to minimize the strain on the shoulders. Given that there is
9 evidence for an effect of load magnitude on postural stability (see above), we also suggest that
10 future research should investigate the effects of backpack design, load size, and load distribution
11 on balance recovery.

12 We acknowledge several study limitations. First, we note the exploratory nature of this
13 study, which was considered a necessary first step in understanding the effects of backpacks on
14 balance recovery. However, given the exploratory nature of this work, any significant effects
15 need to be treated with caution and confirmatory studies future studies are needed. Second, we
16 focused on young adults, and further research is needed to understand the effects of carrying a
17 loaded backpack on balance recovery among older individuals, and persons with musculoskeletal
18 or neurological impairments. Third, the balance perturbations were expected (i.e., participants
19 were told they would lose balance) and were repeated. Different results may occur from more
20 fully unexpected balance perturbations. Our approach may also have allowed participants to pre-
21 plan their responses to balance loss. Fourth, we used relatively simple perturbations in known
22 environments free of obstacles, and in only the forward and backward directions. While such a
23 design provides some information on how backpack loads affect balance recovery, further

research is needed to understand how individuals recover balance from diverse types of perturbations (including sideways balance loss) while carrying a loaded backpack, especially in more complex settings where stepping may be constrained or otherwise more challenging, such as in cluttered or slippery environments, or when walking on stairs or ramps (Gosine et al., 2021; Komisar et al., 2019a). Fifth, we acknowledge the limitations of the lean-and-release technique. This technique has been used commonly across diverse populations. While this approach provides some consistency in perturbation magnitude, real-time measures of lean angle and participant posture were not obtained, nor have these measures been obtained in prior work. As such, there is inevitably some variability in the magnitude of the perturbations, though we suggest that the ultimate effect is relatively small (see Tables A1 and A2) and unlikely to confound or bias the results we report here. Finally, we focused on balance recovery by stepping, and did not examine grasping reactions. Compensatory stepping mechanics differ when individuals simultaneously reach to grasp objects (Te et al., 2023), and further research is needed to understand the impact of wearing a backpack on whole-body responses to balance loss.

Despite these limitations, the current findings have potential practical implications regarding the effects of backpacks on reactive balance control. Given the association between reactive balance ability and falls, our findings highlight the importance of considering load carriage and specifically backpacks when performing environmental fall risk assessments. While the changes were observed were relatively small, and the backpack did not affect overall balance recovery ability, we believe the results still provide an indication of the potential adverse influence of additional load on balance recovery ability. Even with relatively conservative loading parameters in response to simple, known perturbations, there will still changes in COM acceleration and stepping responses. It is thus plausible that with larger loads and more complex

balance perturbations such changes will be even greater and to the extent that overall balance recovery ability is compromised. Furthermore, while no significant differences in sex our primary experimental factors (i.e., lean direction and loading condition). This suggests the plausibility of sex affecting balance recovery ability with larger loads or more complex perturbations, and warrants future investigation.

5. Conclusions

We demonstrated that, among young adults, an additional posteriorly-worn load of 15% of body weight decreases balance recovery ability but does not affect timing of the response initiation. To accommodate the external load and increased COM velocity and acceleration, participants took longer, higher steps that took longer to complete. Furthermore, our findings suggest that the effect of the backpack load depends upon the direction of balance loss, with backward losses of balance being more substantial with the posteriorly worn backpack load. Our findings provide initial evidence of the effects of load carriage on balance recovery and support the need for further research in this area. This study also provides proof-of-concept for a protocol and framework that can be used to address additional questions on balance recovery and load carriage, while further providing practitioners with new evidence related to backpack loads and potential adverse effects on balance.

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1 References

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