# CHANGES IN JUMP PERFORMANCE AND DYNAMIC BALANCE AT HIGH TERRESTRIAL ALTITUDE

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The purpose of this study was to examine the effects of altitude on dynamic balance and jump performance of a controlled landing during a 12-day high altitude trek. Following a two-legged jump, time to stabilization (5% of body mass for 0.5 s), maximum power, and jump height were measured in 11 participants using a portable force platform at sea level (BL), 3619 m (C1), and 5140 m (C3). Jump performance significantly decreased at C1 and C3 compared to BL ($P$=0.001). There were no significant differences found in time to stabilization and maximum power with increasing altitude. The present findings indicate that jump performance is significantly decreased with increasing altitude. However, dynamic balance and jump power remain unaffected.

**KEYWORDS:** time to stabilization, maximum power, trekking.

**INTRODUCTION:** Balance is essential to safely performing recreational and professional activities, as well as everyday tasks. Impairments in balance can lead to injury and has been used as a factor to classify elderly fallers and non-fallers (Melzer, Benjuya, & Kaplanski, 2004). During high altitude trekking activities, the severity of these balance impairments is increased and could potentially lead to death. Stumbling, tripping, and falling accounted for over 50% of alpine accidents (Kimura et al., 2012). Several studies have shown that exposure to altitude results in decrements in static balance (Clarke et al., 2018; Cymerman, Muza, Beidleman, Ditzler, & Fulco, 2001; Hoshikawa, Hashimoto, Kawahara, & Ide, 2010; Nordahl, Aasen, Owe, & Molvaer, 1998; Wagner et al., 2011), but the effects of altitude on dynamic balance have not yet been investigated.

Decrements in static balance have been investigated during short altitude exposure of 24 hours or less in simulated hypobaric and normobaric hypoxia at high (1500 m to 3500 m) and very high altitudes (3500 m to 5500 m) (Cymerman et al., 2001; Hoshikawa et al., 2010; Nordahl et al., 1998; Wagner et al., 2011). Decrements have also been investigated at terrestrial altitudes of 1630 m, 2590 m, and 4559 m during prolonged exposure, ranging from two to three days (Baumgartner, Eichenberger, & Bärtsch, 2002; Stadelmann et al., 2015). Recently, the changes in static balance at four different altitudes were investigated during a 10 day trek using the Zur Balance Scale (ZBS) (Zur, Fogelman, & Carmeli, 2016). It was found that ZBS scores decreased significantly at higher altitudes, leading the authors to conclude that change in balance may contribute to risk of falls at altitude (Zur et al., 2016).

While static balance has been shown to be impaired at high altitudes, the effect of altitude on dynamic balance has not been previously investigated. However, dynamic balance has been investigated in numerous investigations, specifically comparing athletes to non-athletes. In a study by Davlin (2004), it was found that gymnasts, soccer players, and swimmers performed better than non-athletes on dynamic balance tasks, indicating that unless regular training is taking place, dynamic balance skills may be lacking (Davlin, 2004). This is especially important for novice hikers who may be engaging in high altitude treks, as they may be more susceptible to tripping and falling compared to highly experienced trekkers.

In addition to decrements in balance at increasing altitude, previous research has also shown both consistency and reductions in power, as well as greater rates of fatigue with altitude (Clark et al., 2007; Garner, Sutton, Burse, McComas, Cymerman, & Houston, 1990). Garner et al. (1990) investigated neuromuscular performance during extreme hypobaric altitude and found that individuals were able to preserve muscle force generation capabilities. Furthermore, rate of fatigue during electrical stimulation was greater with increasing altitude. These findings are important, especially for individuals engaging in high altitude trekking activities, as fatigue may result in stumbling, tripping, or falling, and could potentially lead to injury or death.

It is essential to research dynamic balance, especially at altitude, as there may potentially be decrements in a hiker's ability to react to perturbations similar to those experienced on the trail, e.g., stubbing a toe on a rock or root or recovering balance after slipping/tripping. The purpose of this study was to examine dynamic balance, jump performance, and maximum power achieved during a jump at sea level, at 3619 m and at 5140 m during a 12-day trek in the Dhaulagiri region of Nepal.

**METHODS:** In April 2016, 11 British military personnel (Mean ± SD: age = 28 ± 4 yrs; 71.3 ± 10.3 kg) completed a 12-day trek around the Dhaulagiri region of Nepal. Participants of the study were sea level residents and had not been exposed to an altitude over 1000 m for at least 3 months. Balance was measured at sea level (BL: 113 m), Italian Base Camp (C1: 3619 m; trek day 7), and Hidden Valley (C3: 5140 m; trek day 12) using a portable force platform (9286B, Kistler, Winterthur, Switzerland). To assess dynamic balance, participants performed three jumps on the platform at each camp. Participants were asked to perform a countermovement jump as high as possible and to regain stability upon landing as quickly as possible.

Force plate data were analysed using BioWare (v. 5.3.0.7, Kistler, Winterthur, Switzerland) to determine maximum power, maximum jump height, and time to stabilization of participants' jumps at BL, C1, and C3. Maximum power was determined by calculating the peak power output produced by the participant prior to take-off. Jump height was determined by using flight time and the kinematic equation for displacement. Time to stabilization was calculated by measuring the time taken for the vertical force component to reach and remain within 5% of the participants' body mass for 0.5 seconds of duration (Ebben, VanderZanden, Wurm, & Petushek, 2010). Microsoft Excel (v. 2016, Redmond, WA) was used to determine maximum power, maximum jump height, and time to stabilization.

Changes in dynamic balance and jump performance were analysed through IBM© SPSS (v. 25, IBM, New York, USA) using a Repeated Measures ANOVA with post-hoc t-tests. Significance level was set at $P<0.05$.

**RESULTS:** Table 1 reports time to stabilization, maximum power, and jump height at BL, C1, and C3. Jump performance was significantly decreased at C1 and C3 compared to BL ($P$ = 0.001). There were no significant differences found in time to stabilization and maximum jump power with increasing altitude.

**Table 1: Measured variables at different altitudes (n = 6).**

| Measured Variable | Sea Level 113 m | Camp 1 3619 m | Camp 3 5140 m | P-value |
|---|---|---|---|---|
| **Time to Stabilization (s)** | 0.75 ± 0.19 | 0.95 ± 0.36 | 0.69 ± 0.14 | 0.055 |
| **Maximum Power (W/kg)** | 188.17 ± 60.17 | 215.97 ± 73.43 | 245.72 ± 68.35 | 0.336 |
| **Jump Height (m)** | 0.29 ± 0.06 | 0.26 ± 0.06* | 0.25 ± 0.05* | 0.001 |

Data are presented as mean ± standard deviation
*Statistically significant reduction compared to sea level

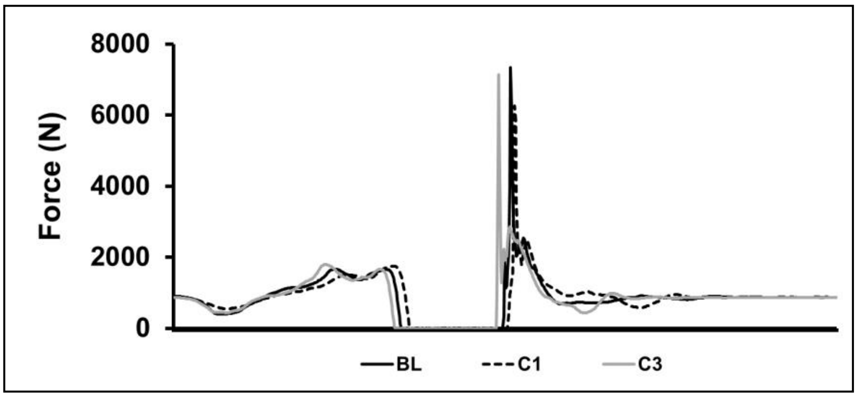


**Figure 1: Vertical force data of a participant at sea level (BL), C1, and C3. Flight time decreased (BL = 0.579 s; C1 = 0.552 s; C3 = 0.528 s).**

**DISCUSSION:** This study is the first study to investigate dynamic balance at altitude. The aim of the current study was to examine changes in dynamic balance and maximum power achieved during a jump at sea level, at 3619 m and at 5140 m during a 12-day trek. As hypothesized, jump performance decreased significantly as altitude increased ($P$=0.001; Table 1). However, time to stabilization and maximum power were unaffected with increasing altitude. Participants in the current study reported decrements in static balance without decrements in joint position sense with increasing altitude, up to 3619 m (Clarke et al., 2018). It could be proposed that the maintenance in proprioceptive ability in these participants allows them to maintain dynamic balance at high altitudes, even though static balance is impaired. No changes were seen in dynamic balance (time to stabilization) with increasing altitude. This is contrary to previous research that have shown decrements in static balance during short altitude exposure in simulated hypobaric and normobaric hypoxia and prolonged exposure at terrestrial altitude (Cymerman et al., 2001; Hoshikawa et al., 2010; Nordahl et al., 1998; Wagner et al., 2011). However, these results are similar to previous research measuring magnitude of sway using moving balance platforms at simulated altitude. Wagner et al. (2011) found that during two conditions (eyes open, sway-referenced visual, fixed platform and eyes open, fixed visual, sway-referenced platform), balance either did not change or significantly improved with increasing altitude. A similar study by Wagner et al. (2016) yielded comparable results and found that balance and motor control were unaffected at altitudes below 5000 m. As previously mentioned, regular training may assist in maintaining dynamic balance skills, which may be important for hikers engaging in high altitude treks for prevention of tripping and falling (Dalvin, 2004).

Maximum power did not change with increasing altitude. Similar to the current study, Garner et al. (1990) investigated neuromuscular performance at extreme altitude and observed that torque was well-preserved at three different altitudes (0 m, 6400 m, and 7620 m). Previous research has investigated the relationship between altitude and maximum power during countermovement jumps during acute altitude exposure (Garcia-Ramos et al., 2018). Garcia-Ramos et al. (2018) found that acute exposure to terrestrial altitude enhanced vertical jump performance and attributed these improvements to the theoretical maximal velocity at which lower limbs can extend (Garcia-Ramos et al., 2018). However, these improvements may not be seen during prolonged altitude exposure (> 24 hours), such as with the current study.

Previous research has shown effects of altitude training camps on jump performance (Garcia-Ramos et al., 2016). Both maximum power and jump height increased following a 3-week altitude intervention (Garcia-Ramos et al., 2016). However, jump performance was measured at sea level following the altitude training camp. Improvements in jump performance (i.e., maximum power and jump height) may have been seen in the current study if jump performance was tested at sea level following the 12-day trek.

This contextually relevant assessment provides novel insight in an individual's ability to react to perturbations similar to those experienced on the trail (e.g., stubbing a toe on a rock or root, recovering balance after slipping or tripping). A limitation of the current study is that participants may have been fatigued from the trek, which in turn may have affected results.

**CONCLUSION:** Jump height decreased significantly with increasing altitude. The lack of change in time to stabilization suggests that although study participants demonstrated decrements in static balance (Clarke et al., 2018), this does not translate to decrements in dynamic balance at terrestrial altitudes of below 5000 m. Attenuation in power may have been seen if jump performance was measured at sea level following the 12-day trek.

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