CHANGES IN BALANCE AND JOINT POSITION SENSE DURING A 12-DAY HIGH ALTITUDE TREK

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The purpose of this study was to investigate changes in postural control and knee joint position sense (KJPS) during a trek to high altitude. Postural control during standing balance and KJPS were measured in 12 participants at sea-level, 3619m, 4600m and 5140m. Total ($p = 0.003$, $d=1.9$) and anterior-posterior sway velocity ($p= 0.001$, $d=1.9$) during standing balance with eyes open velocity was significantly greater at altitudes of 3619m and 5140m when compared with sea level. Despite a gradual ascent profile, exposure to 3619 m was associated with impairments in postural control. Importantly, these impairments did not worsen at higher altitudes. The present findings should be considered during future trekking expeditions when considering specific strategies to manage impairments in postural control that occur with increasing altitude.

KEY WORDS: postural control, force platform, mountain sickness.

INTRODUCTION: Decrements in balance have been well documented during short exposures of 24 hours (Cymerman, Muza, Beidleman and Fulco, 2001) or less (<60 mins (Wagner et al. 1997; Nordhal, Aasen, Owe & Molvaer 1998) to simulated hypobaric and normobaric hypoxia. Decrements occur at both high (1500 m to 3500m) and very high altitudes (3500m to 5500m) (Cymerman et al. 2001; Wagner et al. 1997; Nordhal et al.1998), and are also reported during prolonged exposure over two days at terrestrial altitudes of 1630 m and 2590 m (Stadelmann et al. 2015). Although balance is shown to be impaired at high (Baumgartner, Eichenberger & Bartsch 2002) and very high (Cymerman et al. 2001) altitudes, and decrements at terrestrial altitude have been shown to persist for three days at altitudes of 4559 m (Baumgartner et al. 2002). It remains unclear whether such decrements persist or are magnified during more prolonged gradual ascents at these altitudes.

The control of static and dynamic posture involves inputs from three sensory inputs to the central nervous system. Although the visual and vestibular inputs have been accounted for in previous assessments of balance at high altitude, somatosensory inputs have received limited attention. An assessment of balance using a moving platform has provided some insight into the impairment in somatosensory input at simulated hypoxia (Wagner et al. 1997). Performance in this task was impaired at 1524 m but the exact sensory mechanisms responsible remain unclear. Since a measurement of joint position sense will act as an isolated investigation of the somatosensory system, measurement at high altitudes will provide a clearer picture regarding the mechanisms by which decrements in balance occur at high altitude.

Therefore, the purpose of the current study was to investigate balance and knee joint position sense in healthy participants at sea-level, 3619 m, 4600 m and 5140 m during a 12-day trek in the Dhaulagiri region of Nepal.

METHODS: In April 2016 12 British military service personnel (9 males and 3 females), mean age ± SD: 28 ± 4 years (range: 25-41) volunteered for the current study and travelled from England to Nepal and completed a 14-day trek around the Dhaulagiri circuit in the Himalayas. Measurements were performed, in the period, during one day at Sea level [SL: 113 m] and at Italian Base Camp (IBC: 3619 m), Dhaulagiri Base Camp (DBC: 4600 m) and Hidden Valley (HV: 5140 m). This study protocol was approved by the Ministry of Defence Research Ethics Committee, and all participants provided written informed consent.

Balance was measured at sea level and at the three research camps with a portable force platform (9286B, Kistler, Winterthur, Switzerland). Balance was quantified via measures of centre of pressure velocity during standing on both legs (n=6, [eyes open=3, eyes closed=3]). Measurements lasted 30 s with breaks of at least 20 s between tests (Stadelmann et al. 2015). Standing balance was performed with feet positioned parallel 7 cm apart and arms in the fundamental standing position during all measurements (Nordhal et al.1998; 13]. A specialised software (MARS, Kistler, Winterthur, Switzerland) was used to assess the movements of the centre of pressure (CoP), calculating the following balance parameters during 30 s of stance: average total CoP velocity (CoPV), average CoP movement velocity in anterior posterior direction (CoPVa-p), average CoP movement velocity in medial lateral direction (CoPVm-l).

Knee joint position sense was measured using two-dimensional videography (Casio Exilim, EX-FC100, Casio Electronics Co., Ltd. London, UK; 30 Hz) of the right leg. The participants wore tight fitting clothing and white tape was placed on the right greater trochanter, lateral epicondyle and lateral malleolus. Participants wore a blind-fold and sat in a position where the knee was flexed at approximately 90° (Costello, Algar & Donnelly 2012). The limb was then extended by the examiner at a slow steady speed (~10°/s) to one of three index knee flexion index angles; 10°to 30°, 30° to 60° or 60° to 90°. The participants were asked to hold this position for ~ 5 seconds (Costello et al. 2012), the examiner then returned the leg to its starting position. Participants were then asked to actively reproduce the predetermined index angle three times. Knee angles were measured using Kinovea software (v 0.8.15, Kinovea, www.kinovea.com). For each KJPS trial, the actual error was calculated by subtracting the reproduced angle from the index angle. Positive and negative angles represented an overestimation or underestimation respectively. Absolute mean error (the average error in the three trials ignoring the direction of the error), relative error (the average of the errors in the three trials taking into account the direction of the error) and variable error (the standard deviation of the three relative error measurements) were calculated (Costello et al. 2012).

Data were analysed using IBM SPSS® Statistics (v 24, IBM, New York, USA). The Kolmogorov-Smirnov test and inspection of the data was undertaken to assess normality of balance and KJPS data. Changes between altitudes for balance, and KJPS, were assessed using a One-Way Repeated Measures ANOVA with Bonferroni-adjusted post-hoc t-tests (and effect size, Cohen's d). The scale for classification of effect size was based on Cohen (1998) with 0.2, 0.5, and 0.8 representing small, moderate and large differences respectively.

RESULTS: The COPV and COPVa-p during standing balance was significantly greater at altitudes of 3619m and 5140 m compared to sea level with eyes open (Table 1). There were no significant differences for COPV or COPVa-p with eyes closed but effect sizes were large demonstrating greater COPV during standing balance at most of the three altitudes compared with sea level (Table 1). In contrast, COPVm-l and KJPS demonstrated no significant differences between sea level and any of the three research altitudes. There were some *large* effect sizes for some of the KJPS measures however, the differences were small and less than the smallest detectable difference for this technique (Relph & Herrington 2015).

Table 1. Centre of pressure velocity at different altitudes

Measurement	Eyes	Sea Level	IBC 3619 m	DBC 4600 m	HV 5140 m	P ANOVA Overall
COPV	Open	8.54 ± 1.45	11.42 ± 2.61*¶	11.84 ± 3.54	11.78 ± 2.62*¶	**0.033**
COPV	Closed	11.32 ± 3.01	13.17 ± 3.30¶	15.22 ± 5.29¶	13.22 ± 3.28¶	**0.020**
COPVa-p	Open	5.90 ± 1.28	8.87 ± 1.92*¶	9.41 ± 2.98	9.42 ± 2.37*¶	**0.001**
COPVa-p	Closed	8.20 ± 2.75	10.53 ± 2.92¶	12.96 ± 4.97¶	10.55 ± 3.01¶	0.471

Data are presented as mean COPV in cm/s ± standard deviation

P ANOVA overall: Repeated Measures ANOVA within subject effects (SL, IBC, DBC, HV). (Bold < 0.05)
*** p<0.05 compared with sea level | ¶ Cohen's d > 0.8 compared with sea level**

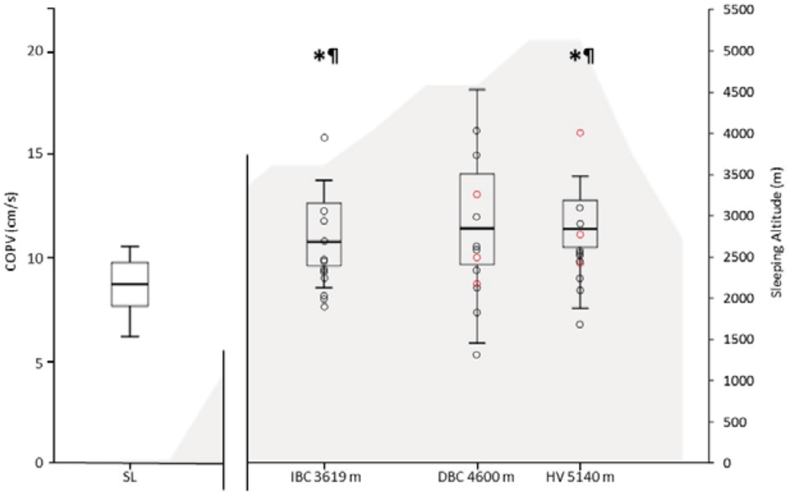

Figure 1: Centre of pressure total sway velocity (cm/s) for standing balance with eyes open along with altitude profile. Box plots show medians, quartiles, whiskers representing the max and min values, and dots representing individual participant values (O = positive LLS in 24 hrs before test). *p<0.05 vs. SL, ¶Cohen's d > 0.8 compared with sea level.

As illustrated in Figure 1. the balance scores of participants with a positive LLS AMS score were distributed along the spectrum of balance scores presented by the entire group.

DISCUSSION: This represents the first research study to investigate the effects of a prolonged gradual trekking ascent to high altitude on balance and knee joint position sense. The key findings were that total and anterior-posterior centre of pressure velocity were increased at 3619 m and above. Overall these impairments in postural control did not worsen at higher altitudes of 4600 m or 5140 m. In contrast knee joint position sense scores remained stable throughout the trek.

The fact that balance was impaired at 3619 m and 5140 m when compared with sea level but the magnitude of impairment did not increase with altitudes > 3619 m (Table 1) is noteworthy. This lack of further balance impairment above 3619 m corroborate and supplement data from previous investigations (Stadelmann et al. 2015; Baumgartner et al. 2002), where posturographic parameters remained impaired over the course of a 4-day sojourn between 1630 m and 2590 m (Stadelmann et al. 2015) and a 3-day stay at 4559 m (Baumgartner et al. 2002). Considering the results of current and previous work (Stadelmann et al. 2015; Baumgartner et al. 2002) postural sway is impaired when SpO2 falls below 95%, but is likely to remain stable in relation to sea level when above 75%. Although further research is required to fully establish the mechanisms involved, it is more likely that inputs to the CNS from the somatosensory system are unaffected by the increased hypoxic hypoxemia and instead act to stabilise the impairments in visual and vestibular systems.

The current study found larger sway velocities with eyes closed than with eyes open (Table 1), however sway velocities in the eyes open condition demonstrated larger impairments with altitude. This is in contrast to previous research undertaken where rapid simulated (Nordhal et al.1998; Stadelmann et al. 2015; Wagner et al. 2011) or terrestrial (Baumgartner et al. 2002) ascent demonstrated decrements in eyes closed balance. However, research utilising gradual and prolonged exposures (Stadelmann et al. 2015), have also reported balance decrements primarily and to a greater extent in the eyes open condition. This may indicate that the impairment in the visual inputs to the CNS acclimatise during gradual ascent profiles and that the decrements in postural control reported in the current study are primarily due to impairments in the vestibular system. Targeted strategies such as virtual reality systems may be implemented to offset the impairments to the vestibular system and act to teach the CNS to use or adjust the relative weight of other inputs such as vision and somatosensory system to substitute for the deficient vestibular system (Sparrer, Duong Dinh, Ilgner & Westhofen 2013).

Although participants in the current study demonstrated impairments in postural control there was no concomitant impairment in knee joint position sense. The current study is the first to indicate that the knee joint position sense is not affected by altitudes up to 5140 m and is not a contributory factor to the impairments in postural control. The control of joint position sense utilises specific afferent pathways conveying signals to the somatosensory cortex and on exposure to hypoxia this brain region has been shown to maintain higher levels of oxygen delivery than the superior temporal gyrus which receives input from the vestibulocochlear nerve (Binks, Cunningham, Adams & Banzett 2008). Therefore, oxygen deficit greater than the levels that elicit impairments in postural control may be required to elicit impairments in joint position sense.

CONCLUSION: In conclusion, postural control was impaired at 3619 m and remained impaired without worsening with increasing altitude throughout the trek (up to 5140 m). Travelling over dangerous mountainous terrain wearing sometimes-heavy equipment has its own inherent risks and compounding this with impaired postural control makes the trekker particularly vulnerable to trips or falls [2]. Importantly, the findings of the current study may highlight the increased fall risk for individuals exposed to terrestrial altitudes between 3619 m and 5140 m even when utilising a gradual ascent profile. The present findings suggest that trekking performance is mostly limited by impairments in postural control and not joint position sense which may be indicative of limitations within the vestibular system. Such findings should be considered during future trekking expeditions when considering specific strategies targeted at reducing or controlling such impairments.

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