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Study II: Mechanoreceptive sensation is of increased importance for human postural control under alcohol intoxication

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ABSTRACT

Standing postural stability relies on input from visual, vestibular, proprioceptive and mechanoreceptive sensors. When the information from any of these sensors is unavailable or disrupted, the central nervous system maintains postural stability by relying more on the contribution from the reliable sensors, termed sensory re-weighting. Alcohol intoxication is known to affect the integrity of the vestibular and visual systems. The aim was to assess how mechanoreceptive sensory information contributed to postural stability at 0.00% (i.e. sober), 0.06% and 0.10% blood alcohol concentration (BAC) in 25 healthy subjects (mean age 25.1 years). The subjects were assessed with eyes closed and eyes open under quiet standing and while standing was perturbed by repeated, random-length, vibratory stimulation of the calf muscles. Plantar cutaneous mechanoreceptive sensation was assessed for both receptor types: slowly adapting (tactile sensitivity) and rapidly adapting (vibration perception). The correlation between recorded torque variance and the sensation from both mechanoreceptor types was calculated.

The recorded stability during alcohol intoxication was significantly influenced by both the tactile sensation and vibration perception of the subjects. Moreover, the study revealed a fluctuating association between the subjects' vibration perception and torque variance during balance perturbations, which was significantly influenced by the level of alcohol intoxication, vision and adaptation. Hence, one's ability to handle balance perturbations under the influence of alcohol is strongly dependent on accurate mechanoreceptive sensation and efficient sensory re-weighting.

1. Introduction

Human postural control in an upright position is a complex process involving sensory inputs from visual, vestibular, proprioceptors and mechanoreceptors. The central nervous system (CNS) gathers and processes this sensory information to estimate the position and motion of the body. Unavailable or disrupted signals from one or more sensors may result in a decrease in postural stability. However, by relying more heavily upon the correctly functioning sensory signals, the CNS can partly compensate, termed sensory re-weighting [1].

Acute alcohol intoxication is accompanied by otoneurological signs of spinocerebellar and vestibulocerebellar ataxia [2], positional alcohol nystagmus, oculomotor abnormalities [3], gaze-evoked nystagmus [4] and increased visual dependency when conflicting vestibular information is present [5]. These characteristics of alcohol intoxication are caused because alcohol interferes with the transmission of nerve impulses at the synapse. Alcohol reduces the amplitude of mono- and poly- synaptic reflexes [6], and therefore prolongs the latency and reduces the amplitude of long latency muscle responses [7]. In addition, alcohol intoxication also physically disrupts the information received by the vestibular end organs, because alcohol changes the specific gravity differential between the cupula and the endolymph (buoyancy mechanism) in the semi-circular canals [8].

In the first part of this publication series (Study I), we reported that alcohol intoxication caused a rapid decrease in postural stability, measured as torque variance, between 0.06% and 0.10% blood alcohol concentration (BAC) in unperturbed and perturbed standing. Alcohol intoxication also caused a progressively increased instability when exposed to sustained repeated balance perturbations and caused a clear deterioration in sensorimotor adaptation ability (Study I). Even with visual information available, the CNS was unable to completely compensate for the alcohol-related destabilization. In fact, the visual information produced while highly intoxicated was often counter-productive for postural control and sensorimotor adaptation (Study I).

Since alcohol intoxication causes disrupted visuo-vestibular functions, sensory information from visual and vestibular receptors might not be deemed accurate by the CNS. In addition to vestibular and visual sources for postural control, the feet serve the CNS with somatosensory information from cutaneous, low-threshold,

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mechanoreceptors on the plantar soles [9]. This information is particularly important when balance is perturbed [10]. The plantar mechanoreceptors give detailed temporal and spatial information about sole contact pressures [11], and are thus important for sensing changes to body orientation [12]. These mechanoreceptors can be rapidly adapting (Pacinian and Meissner's corpuscles) or slowly adapting (Ruffini corpuscles and Merkel disk receptors). Rapidly adapting mechanoreceptors signal the amplitude and the rate changes of the pressure exerted on the skin to the CNS [13] i.e. the changes of posture necessary for postural stability [14]. Slowly adapting mechanoreceptors signal continuously and precisely how the pressures are spatially and sequentially distributed on the skin to the CNS [13], i.e. the foot sole-surface interaction.

The aim of this second study in this publication series was to determine the contribution of low threshold mechanoreceptive information from the feet while intoxicated at 0.00%, 0.06% and 0.10% BAC for postural control and adaptation with eyes closed and eyes open.

2. Materials and methods

2.1. Participants

The same 25 participants (13 women and 12 men, mean age 25.1 years, range 19–41) that performed postural stability tests involving alcohol intoxication (Study I) also had their sensation measured, see Table 1. The experiments were all performed in accordance to the Helsinki declaration of 1975 and approved by the local ethical committee.

2.2. Procedure

The sensitivity of the low threshold mechanoreceptors of both feet was measured in an un-intoxicated state in all participants. Postural stability was measured at 0.0% BAC, 0.06% BAC and 0.10% BAC and the methodology, results and discussion are available in the first part of this publication series (Study I). All findings related to alcohol intoxication level and visual effects on postural control are discussed in detail in Study I.

Although torque variance was captured in both the anteroposterior and lateral directions, only anteroposterior torque variance is considered here since the main direction of movement from calf vibration is in an anterior-posterior direction [15]. Torque variance, normalized for individual anthropometrical differences in mass and height, was used as quantitative measurement of postural stability, since this value correspond directly to the energy used towards the support surface to maintain stability [16], which in turn corresponds to the efficiency of standing [17].

2.3. Sensitivity assessment

Vibration perception (rapidly adapting mechanoreceptive sensation) of the plantar surface was measured using a biothesiometer electronic device (Model EG electronic BioThesiometer, Newbury, Ohio, USA) that generated a 120 Hz vibration of varying amplitude (in μm). The vibration was applied to the plantar surface of the first distal phalanx (big toe), the fifth distal phalanx (little toe), the first proximal phalanx (base of big toe), the fifth proximal phalanx (base of little toe) and the tuberosity of calcaneous (heel). Subjects were asked to indicate to the examiner whether they were able to feel the vibration "Yes" or "No" [18]. Three readings in ascending intensity and descending intensity were made until the subject could no longer feel the vibration, and the mean was then calculated.

Tactile sensitivity (slowly adapting mechanoreceptive sensation) was measured with a Semmes-Weinstein pressure aesthesiometer (Semmes-Weinstein Monofilaments, San Jose, USA). The aesthesiometer comprised of 20 nylon filaments of equal length, with varying diameter. The filaments were applied to the plantar surface of first distal phalanx (big toe), the fifth distal phalanx (little toe) and the tuberosity of calcaneous (heel). Subjects were instructed that when the filament was placed on any of the positions above, they should report to the examiner whether they felt it on the "big toe", "little toe" or "heel." Tactile sensation threshold was determined by presenting suprathreshold filaments initially, then applying thinner and thinner filaments until the subject could no longer detect them [18]. The examiner then applied thicker filaments until the filament was detected. The touch threshold was determined from three ascending and descending steps and is presented as Semmes-Weinstein size (sw).

Table 1
Mean and standard deviation (SD) of mechanoreceptive sensation.

Mechanoreceptive sensation	Mean sensation (SD)
Vibration perception [μm]	
Big toe	0.68 (0.65)
Little toe	0.62 (0.73)
Base of big toe	0.51 (0.43)
Base of little toe	0.47 (0.45)
Heel	0.39 (0.26)
Tactile sensitivity [sw]	
Big toe	3.39 (0.38)
Little toe	3.27 (0.36)
Heel	3.75 (0.37)

2.4. Statistical analysis

The effects of alcohol intoxication ('Alcohol': 0.00%, 0.06% or 0.10% BAC; (degrees of freedom (d.f.) 2), availability of visual information ('Vision': eyes closed or eyes open; d.f. 1), plantar sensation ('Sensation: exact), and when applicable the period of vibration ('Period': periods 1–4; d.f. 3) and their interactions on the torque variance values under quiet standing and during balance perturbations were analyzed using a GLM univariate ANOVA (General Linear Model univariate Analysis of Variance) test on log-transformed values (Altman, 1991). Log-transformed torque variance values were used in the GLM ANOVA analysis because the torque variance values did not have a normal distribution profile when tested with the Shapiro–Wilk statistical test. In the analysis, p-values <0.05 were considered statistically significant.

Correlation analysis was performed between sensitivity scores and anteroposterior torque variance at 0.00%, 0.06% and 0.10% BAC using Spearman correlation test. In the analysis, p-values <0.05 were considered statistically significant. $p < 0.1$ were considered as indications of trends. Non-parametric statistical tests were used as the Shapiro–Wilk test revealed that the values were not normally distributed.

3. Results

All findings related to alcohol intoxication level and visual effects on postural control are discussed in detail in the first part of this publication series (Study I). Sensation values are presented in Table 1.

3.1. Effect of vibration perception sensitivity on postural control

The vibration perception in all recorded parts of the foot significantly affected the recorded stability in quiet standing as reflected by the influence on total and high frequency spectrum (HF) torque variance (Table 2A). Base of big toe and base of little toe vibration perception also significantly affected the low frequency spectrum (LF) torque variance. There was no evidence of interaction between vibration perception, alcohol and vision, suggesting that these factors affect quiet stance stability independently.

The vibration perception in all recorded parts of the foot was found to significantly affect the recorded stability in all spectral categories during balance perturbations (Table 2B). There was a significant interaction between alcohol intoxication level and vibration perception at all recorded positions on torque variance in all spectral categories, suggesting an increased influence of vibration perception on the stability with increasing alcohol levels. Moreover, there was a significant interaction between vision and vibration perception mostly on high frequency spectrum torque variance, suggesting lower influence of vibration perception on the stability with eyes open.

3.2. Correlation between vibration perception sensitivity and postural control

The vibration perception predominantly correlated significantly with recorded stability when intoxicated at 0.10% BAC and mainly with recorded total and high frequency spectrum torque variance during tests with eyes closed and during balance perturbations (Table 3). In other words, the correlation values illustrate that at high alcohol intoxication levels the subjects with poorer vibration perception (i.e. high threshold values) had predominantly much poorer stability (i.e. higher torque variance values) compared with those with better vibration perception sensation, especially during balance perturbations. If trends ($p < 0.1$) are also included in the result presentation,