Intensive balance training can improve vestibular system function and ability to maintain balance

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Introduction
Training of balance and posture is important for many activities in everyday life and prevention of falls, and also for orientation in space (Judge, 2003). Adult mammalian nervous system, including that of humans, has a remarkable capacity for morphological and functional alterations in response to learning and experience (Draganski & May, 2008; Pascual-Leone et al., 2005). One way to induce these plastic changes in the adult human nervous system is by training, either mental or physical. Experience causes permanent changes in dendritic spines and their synapses; while some of them are being formed and stabilized, others degrade due to inactivity (Holtmaat et al., 2006; Trachtenberg et al., 2002). Morphological brain changes have been found to correlate well with changes in functional abilities. Plasticity of balance centers has been investigated in both health and disease; previous studies have reported significant changes in grey matter volumes in the brains and corresponding functional improvements in both healthy and subjects with Parkinson’s disease in response to balance training (Taubert et al., 2010; Sehn et al., 2014). These studies have, however, used the training method which consisted of only one training per week and the training task that is not very demanding for the vestibular system, due to absence of turning activities. The aim of this study is to determine if more intensive and comprehensive balance training can improve vestibular system function and general ability to maintain balance.

Method
Sample
The study sample consisted of 50 subjects with normal or corrected-to-normal vision aged between 18 and 30, who were matched by all criteria and randomly assigned into two groups: treatment (n = 25, mean age = 24.4 years; SD = 2.8 years; 12 females and control) and control (n = 25, mean age = 23.2 years; SD = 2.5 years; 12 females).

Treatment
In order to maximally stimulate the systems involved in maintenance of balance, including the vestibular system, we have decided to use subjects with no previous experience in slacklining and appointed a professional trainer who would help them to acquire this difficult skill during one month of intensive training.

The subjects from treatment group were asked to learn to slackline over four consecutive weeks with three 60-minute-trainings in each week. The control group subjects were asked not to get involved in any activity that could potentially improve their balancing abilities during this one-month period. The length of the slackline was 3 meters, chosen with the purpose of stimulating participants to make turns multiple times during each training, in addition to walking backwards and forwards.

Data acquisition
Before and after this one-month period the following methods were applied for data acquisition:
- Clinical balance tests (GGT test)
- Orientation test (triangle completion task)
- Distance perception test

These tests were mainly targeted towards assessment of the systems involved in maintenance of balance and orientation in space.

Statistical analysis
Initial analysis was performed using multivariate general linear model (mGLM) or multivariate analysis or variance (MANOVA). This was followed by dependent t-tests which have been used to compare means of the two time points for each of the three measures in the treatment group.

Results
Multivariate analysis revealed the following:
- Clinical Balance Test (GGT) – Significant group effect (Wilks’ λ = 0.753, F(1, 49) = 16.06, p < 0.001) and non-significant group-time interaction effect (Wilks’ λ = 0.961, F(1, 49) = 1.975, p = 0.166)
- Orientation test – Non-significant group effect (Wilks’ λ = 0.999, F(1, 610) = 2.321, p = 0.128) and non-significant group-time interaction effect (Wilks’ λ = 0.999, F(1, 610) = 0.716, p = 0.398)
- Distance perception test – Significant group effect (Wilks’ λ = 0.945, F(1, 151) = 8.798, p = 0.004) and non-significant group-time interaction effect (Wilks’ λ = 0.999, F(1, 151) = 0.162, p = 0.688)

Within group pairwise analysis using t-tests demonstrated significant improvements in the treatment group from pre- to post-test as follows (see Figure 1):
- Clinical Balance Test (GGT) - on average by 5.12 points (95% CI from 2.5-7.74 points, t = 4.03, p < 0.001).
- Orientation test - strong tendency towards improvement by 8.39 centimeters (95% CI from -1.07-17.85, t = 1.745, p = 0.082).
Discussion
The main finding of this study is that intensive balance training in the form of 1-month slacklining can significantly improve ability to maintain balance and function of the vestibular system in the spatial orientation and distance perception tasks.
This finding within the training group has been expected and is not a surprise. Many previous studies have also demonstrated improvements in response to various treatments aimed towards improving balancing abilities (Ledin, Kronhed, Möller & Möller, 1990; Kupfmüller et al., 2011; Wolf et al., 1996). Additionally, we have shown that training systems involved in balance using intensive slacklining as a method leads not only to specific improvements in the area of balancing but also in the areas of spatial navigation and distance perception. Such finding can potentially be very interesting for persons who suffer from disabilities in which hippocampus is affected and thus one's ability to navigate in space, such as in Alzheimer's disease.
Surprising was that we could not detect significant interaction effects on any of our measures. This counts as a limitation of this study; it could be that employing multiple persons for the testing purposes has contributed to such outcome, together with a relatively small sample size. Future studies should be also focused on not repeating these points.
The main benefit of this study for both clinical and non-clinical applications is its contribution to our understanding about effects this and similar training treatments may have on one’s ability to maintain balance, navigate in space, and perceive distance. Similar training methods could be designed with the purpose of improving these functions of the vestibular system for the people in need.

![Improvements in the training group between pre- and post-test](image)

Figure 1. Improvements in the training group between pre- and post-test (in units of measurement, 1 - pre-test, 2 - post-test)