智能可穿戴振动反馈系统可有效提升老年人与中风患者的平衡与步态

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背景: 跌倒及相关损伤会导致高死亡率和巨大的社会负担。平衡和步态障碍是导致跌倒的第二大主要原因，仅排在事故之后。足底皮肤表面处的触觉功能对保持平衡和步态控制至关重要，因为它可以连续地为人体提供有关身体运动的足部-地面接触特性的信息。受抑制的足底感觉会干扰老年人和患者的平衡和步态，并增加他们跌倒的风险。改善或补偿足底感觉可以是一种潜在的、用于增强平衡和步态的有效方法，这一机理在之前似乎并没有得到足够的关注。

仪器设计：本课题组开发了一系列新颖、轻便、可穿戴的振动触觉反馈系统。系统在足底皮肤表面处集成了薄膜压力传感器，以通过测量站立和行走期间的足底压力信息来补偿丧失或降低的足底感觉功能，并进一步即时为使用者在其他身体部位，例如躯干上部和手腕处，提供相应的身体运动状态信息。

实验方法：通过一系列的临床试验来系统验证是否补偿足底感觉功能可以改善各类人群的平衡和步态控制，包括：振动反馈系统对 30 名健康年轻人和老年人的站立姿势平衡的影响（实验一），及振动反馈系统对 8 名中风患者步态的影响（实验二）。研究采用重复实验的设计来比较受试者在仪器打开和关闭时的平衡和步态状况。并通过测量受试者在静态站立期间的足底压力中心偏移参数，行走期间的足底压力分布，和时空步态参数来客观评估受试者在不同实验条件下的姿势平衡和步态控制。

实验结果：与仪器关闭时相比，在仪器开启时，健康年轻人和老年人在站立期间表现出显著减少的身体摆动。偏瘫中风患者则在仪器开启时，其步态表现出患侧足内翻症状的减轻，前足内测足底压力的增加，及步态对称性的提升。

讨论和结论：本研究的实验结果支持了可穿戴振动触觉反馈系统在增强平衡和步态控制方面的有效性，并进一步表明补偿足底感觉是改善老年人和患者平衡和步态控制的一种有效方法，这将激发该领域的相关未来研究。集成足底压力传感器的设计可以允许该仪器同时检测左、右腿的运动状况。该振动触觉反馈系统的可穿戴特性还允许它既可以在室内也可以在室外环境中使用，这进一步使得它们适合在未来作为日常生活中的平衡辅助器具。未来研究可以考虑探讨该类振动触觉反馈系统在更多样化、更具代表性的人口中，进行更复杂的日常活动时的影响，如上/下楼梯和跑步等。

关键词：平衡；步态；智能；可穿戴；振动触觉反馈；老年人；中风患者

Smart Wearable Vibrotactile Biofeedback Systems Could Enhance Balance and Gait Control in Older Adults and Patients with Stroke

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Background: Falls and consequent injuries contribute to high mortality rate and significant society burden. The second leading cause of falls is balance and gait disorder, which just comes after the accident. Tactile sensation at plantar surface of the foot is crucial in maintaining balance and gait control, as it continuously provides information about the foot-ground contact characteristics that related to body motion. Declined plantar sensation could disturb balance and gait, and consequently, increase the risk of falls in aged population and patients. Therefore, improving/supplementing plantar sensation could be one potential effective approach to enhance balance and gait, which appears to not have been achieved enough attention before.

Design of the device: A series of novel wearable and lightweight vibrotactile biofeedback systems, integrated with thin-film force sensors at plantar surface of foot, have been developed to supplement plantar sensation by measuring plantar force during standing and walking, and further providing instant corresponding body motion cues to the user at other body parts, e.g. upper trunk & wrist.

Methods: Clinical trials have been conducted to systematically investigate if supplementing plantar sensation could improve balance and gait performance in various populations, including: effect of biofeedback system on standing postural balance in 30 healthy young and older adults (Study 1), & effect of biofeedback system on gait performance in 8 patients with stroke (Study 2). Repeated measures design has been adopted to compare participant's balance and gait performance between with and without the devices turning-on. Measurement of center-of-pressure parameters during static standing, plantar pressure distribution during walking, and spatiotemporal gait parameters have been used to objectively assess subject's postural balance and gait control in different experimental conditions.

Results: Healthy young and older adults revealed significant less postural sway during standing upon turning on the device, as compared to the condition of standing with device turning-off. Patients with hemiplegic stroke revealed less foot inversion and more plantar pressure at the medial forefoot of the affected side, and better gait symmetry during walking with the biofeedback system turned-on.

Discussion and Conclusion: The findings of the studies supported the effectiveness of biofeedback system in enhancing balance and gait control, indicating that supplementing plantar sensation is one effective approach in improving balance and gait control in aged population and patients, which inspires future research in this field. Integrating plantar force sensors allows the device to detect motion of both left and right legs. The wearable characteristic of vibrotactile biofeedback systems also allows them to be used in both indoor and outdoor settings, which further makes them appropriate to be as balance aids in daily life in the future. Future studies could consider investigating the effect of vibrotactile biofeedback systems on more complicated tasks, such as ascending/descending stairs and running, in more diverse and representative populations.

Keywords: Balance; gait; smart; wearable; vibrotactile biofeedback; elderly; stroke