Sonification Can Alter Joint Alignment for Personalized Rehabilitation: Evidence from a Controlled Pilot Study

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Introduction: In the evolving field of physical therapy, technological advancements such as sonification feedback, which converts physical movements into auditory cues, are improving patient care and rehabilitation outcomes [1]-[6]. Despite its potential, current methods lack customization to patient-specific needs, and its application in rehabilitation exercises is limited. Our study uses a recently developed real-time biofeedback prototype [7], based on our preliminary work [8], to bridge these gaps. We used wearable technologies and machine learning to personalize sonification feedback for improved joint alignment during exercises.

Research Question: How does sonification feedback impact joint alignment during rehabilitation exercises?

Methods: Twelve healthy adults (age = 26 ± 3.5 years, BMI = 24.3 ± 2.3 kg/m²) completed 30 trials of squats, lunges, and one-legged stances, both with and without sonification feedback. Trials were counterbalanced, with half of the participants starting with sonification to avoid order effects. For each condition, the exercises were randomized, and each exercise consisted of three repetitions. Sonification feedback was delivered through Sony WH-CH520 wireless headphones connected to StappOne (stAPPtronics GmbH, Sulz, AT) sensorized insoles, which provided a howling wind sound to signal balance imbalances detected by a Support Vector Machine (SVM) with a Radial Basis Function kernel. This machine learning model classified balance based on shifts in weight from the lateral to the medial side of the foot, with insole sensors transmitting pressure and acceleration data at 62.50 Hz. A 16-camera motion capture system (Nexus, 2.14, Vicon, Oxford, UK) and two force plates (AMTI, Watertown, MA, USA) captured full-body trajectory data at 120Hz and 1200Hz, respectively. These were used to analyze bilateral hip, knee, and ankle joint angles and moments. Data processing was performed using a custom BodyBuilder script, and the effects of sonification on exercise performance were compared using paired samples t-tests.

Results: Sonification feedback significantly altered biomechanical outcomes ($p < 0.05$), reducing hip and knee flexion during squats, decreasing internal rotation of the backside hip in lunges, and increasing ankle supination in the one-legged standing leg, as illustrated in **Figure 1.**

Discussion: In the study, sonification feedback significantly modified participants joint alignment during squats, lunges, and one-legged stands. Squats were less deep, suggesting a cautious adjustment to minimize joint stress. Reduced hip rotation during lunges could likewise decrease injury likelihood by avoiding excessive torsional forces on the joints. Increased ankle supination in one-legged stands might enhance balance by optimizing foot positioning, contributing to improved stability and ankle strain prevention [9]. The study reveals auditory feedback's potential in movement adjustment for personalized rehabilitation and injury prevention. Yet, conflicting results and increased variability signal a need for improved user experience and interface design, ensuring users can effectively interpret and act on biofeedback.

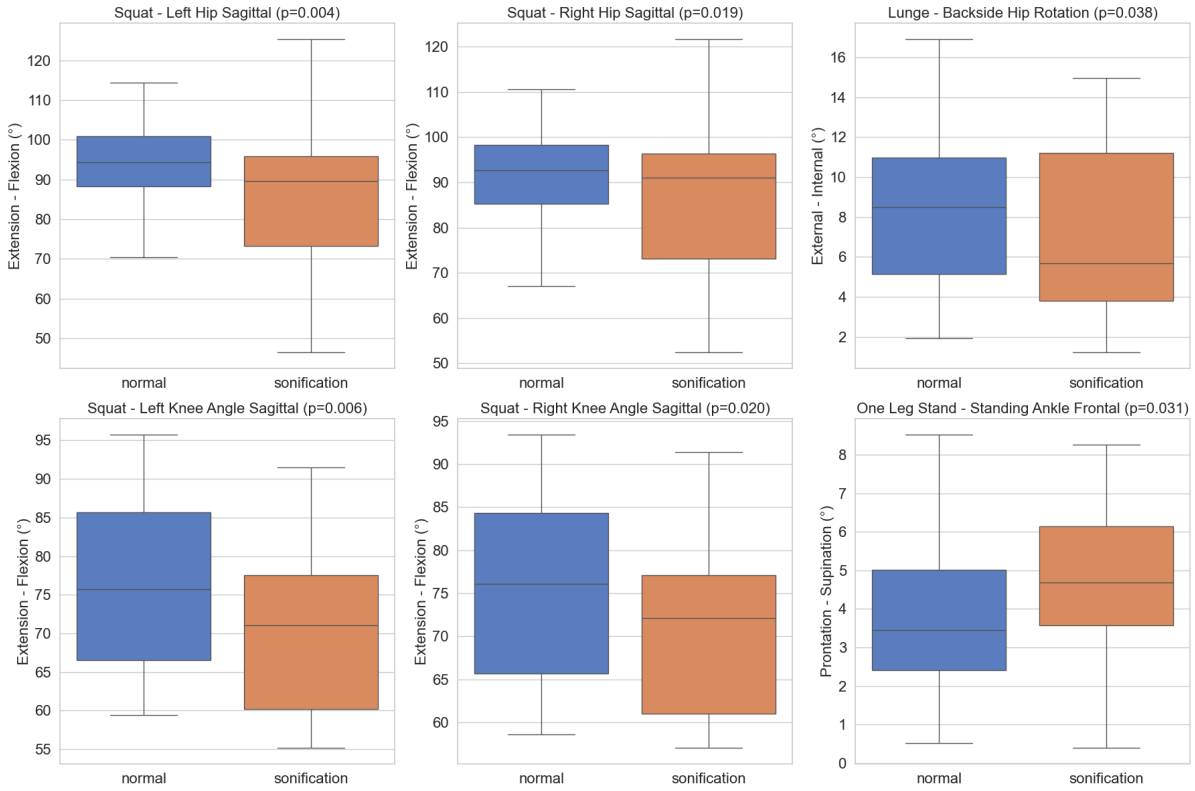

Figure 1: Box plots illustrating the impact of sonification feedback on joint angles during physical therapy exercises. Significant differences were observed with sonification by reduced flexion in the left and right hips and knees during squats, decreased internal rotation of the hip during lunges and increased ankle supination during one-legged stances.

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