CLOSED-LOOP WEARABLE SYSTEM WITH AUGMENTED PROPRIOCEPTIVE FEEDBACK FOR PRECISE IN-HOME SQUAT TRAINING

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ABSTRACT

Squatting is a compound strength exercise, focusing on developing lower body strength, power, and muscular endurance. Incorrect squat angles can lead to back and leg injuries, highlighting the necessity of precise angle achievement during exercises and rehabilitation. Traditional methods rely on visual or muscle stimulus feedback, often leading to inaccuracies. Recent advancements utilize cameras and machine learning for movement analysis in labs, yet these solutions are not accessible for in-home training. A closed-loop, lightweight, wearable device was implemented for squat training. It features an accelerometer attached to the Biceps Femoris, measuring squat angle, and a vibrational motor placed on the Vastus Medialis. It offers real-time proprioceptive feedback. As the user nears the target squat angle, vibration intensity increases, aiding in achieving the correct posture. Results demonstrated the device significantly improved users' ability to reach the squat angle with an error dropped from 4.51±3.38° to 1.26 ± 1.04°, with significant improvement ($p = 0.016$) after 10 trials of training. This device offers a novel approach to in-home rehabilitation and sports training.

Keywords: closed-loop system, wearable device, proprioceptive feedback, squat training, motor rehabilitation

INTRODUCTION

While squatting is a fundamental exercise in the weightlifting community, it can also be a risky movement if performed incorrectly. Squatting is a compound strength exercise that emphasizes developing lower body strength, power, and muscular endurance. Achieving the optimal squat angle can present a significant challenge for all individuals. Doing a squat naturally relies on proprioceptive feedback; however, this feedback is often unreliable or inaccurate, as biomechanical assessments frequently reveal a discrepancy between perceived and actual depth [1]. Incorrect squat angles can lead to back and leg injuries, underscoring the importance of precise angle control during exercises and rehabilitation [1,2].

Various studies have explored strategies to address this challenge by providing feedback to the user during squat training. The most used feedback is verbal feedback provided by the trainer to provide information about the accuracy of squat accuracy. However, trainers monitoring squat techniques may face difficulties in accurately determining whether the target angle has been attained, due to variability in movement patterns and individual biomechanics [3,4]. Video-based methods [5] involve tracking squat angles with a camera, providing evaluation of a performance, which has shown to be helpful in achieving high squatting accuracy. Similarly, other researchers investigated the use of inertial devices to measure squat angles, reporting reliable evaluation in accessing squat accuracy [6].

While these methods are effective in providing accurate evaluation for squat quality, they did not integrate real-time sensory feedback, which is critical for squat training, into the process. Alternatively, one approach involves using physical touch as feedback [4], demonstrating improved squat accuracy when