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Wearable sensor–based biofeedback for improving hip hinge mechanics and preventing low back injuries

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INTRODUCTION:
Low back pain (LBP) is among the most common musculoskeletal disorders worldwide and the leading cause of disability across all age groups, with most individuals experiencing at least one episode during their lifetime. Lifetime prevalence estimates range from 65–84%, and, in 2020, approximately 619 million people were affected globally—a number projected to rise to 843 million by 2050 [1-2]. Beyond daily and occupational activities, LBP is also prevalent in sports, particularly weightlifting, where spinal loading is substantial [3].
Maintaining a neutral spine during lifting is a widely recommended strategy to prevent lumbar injuries. However, achieving this posture during dynamic exercises is challenging, as it requires sufficient core stability, correct hip hinge mechanics, and continuous posture monitoring—factors difficult to assess in real training environments. To address this, the present work proposes a wearable system using two inertial measurement units (IMUs) on the pelvis and thorax, providing real-time visual and auditory biofeedback when unsafe lumbar flexion occurs. Previous validations demonstrated the system's accuracy for this application and revealed that nearly half of the participants performed lifting exercises with poor spinal posture [4], motivating this study to evaluate its effectiveness for lumbar injury prevention and for improving proper hip hinge mechanics through real-time biofeedback.

METHODS:
Twenty-one healthy adults (7 males, 14 females; 37 +/- 19 years) with no injuries or medical conditions affecting performance participated in the study. Two IMUs (MinIMU-9, Pololu Robotics & Electronics, Las Vegas, Nevada, USA, 26 Hz) were placed at S1 (pelvis) and T10 (thorax) to estimate pelvis and trunk orientations, respectively. Each session began with a 5-minute warm-up and sensor check. Participants performed a static standing pose to calibrate neutral spine posture, then completed five deadlift repetitions with a self-selected load, without biofeedback, to assess baseline lumbar deviation. After individualized guidance from a certified personal trainer, participants performed a 15-minute training session with real-time visual and auditory biofeedback. Finally, five additional repetitions without biofeedback were performed to evaluate improvements in lumbar control and hip hinge technique.

RESULTS:
This study further highlights the need for lumbar posture sensitization, as the overall pre-training mean lumbar flexion was 35°, with 62% of participants exceeding the safe lumbar flexion threshold (<30°). After the 15-minute biofeedback training session, post-training performance was significantly improved compared with baseline (95% CI [12.72°, 24.30°]), showing a mean reduction of 18.51° in peak lumbar flexion. Following training, all participants showed improvement, and 86% remained below the safe lumbar flexion threshold (<30°). Notably, all female participants achieved optimal average peak angles (<30°), whereas this was observed for 57% of the male participants. These differences may reflect both training-induced adaptations and inherent anatomical and biomechanical factors that influence individual ranges of motion. Future work will examine the long-term effects of this intervention, the need for periodic reinforcement, and its effectiveness compared with traditional coaching methods.

CONCLUSION:
The dual-IMU system with real-time biofeedback effectively reduced excessive lumbar flexion and improved hip hinge awareness. This approach shows promise for lower back injury prevention and for promoting a neutral spine during lifting.

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