Topic: Balance Assessment and Fall Risk Prediction from Earables using Machine Learning

Balance assessment is an important issue for older people, given that up to half of the adults over the age of 65 report balance problems [1]. Patients with a neurological disease such as Parkinson's or Alzheimer's are even more susceptible to balance problems that limit their safe mobility. When balance is compromised, the risk of falling increases significantly and therefore fall is often assessed in clinical settings [2]. The fear of falling is often assessed using the Falls Efficacy Scale-International (FES-I), which is a 16-item questionnaire that evaluates an individual's fear of falling during daily physical and social activities, primarily to assess subjective balance confidence [3]. Objective balance, and therefore also fall risk assessments, often rely on force plates and motion capture systems, both of which provide precise metrics for postural stability and sway [4]. Force plates measure the displacement of the center of pressure during static or dynamic tasks, while motion capture systems track the 3D positions of markers, which can then be used to compute the 3D kinematics and center of mass, enabling detailed biomechanical analyses [5]. For instance, Sun et al. [6] assessed fall risk in multiple sclerosis patients by combining force plate sway metrics with FES-I scores, categorizing participants into four risk levels and using a random forest classifier to link objective balance data with subjective fall confidence. While force plates and motion capture systems are highly accurate, they are expensive, require specialized laboratory setups, and are unsuitable for everyday use, leading to growing interest in wearable technologies such as inertial measurement units (IMUs) [5].

IMUs are lightweight, and studies have shown that they are capable of deriving sway characteristics comparable to those measured by a force plate [7]. IMUs, which are compact and cost-effective, are increasingly used in balance assessment. Typically placed on the lower back or feet, IMUs measure acceleration and angular velocity during balance tasks which can be used to estimate sway parameters [5]. Saadeh et al. [8] developed a method for the prediction of falls using a single wearable accelerometer placed on the waist. The system employed a support vector machine trained on patient-specific baseline data, which is individualized reference data derived from each patient's typical patterns of acceleration peaks, velocity, and body sway. This approach enabled the identification of deviations from these norms, signaling an increased fall risk. Consequently, the system facilitated real-time prediction of falls, allowing for timely interventions to mitigate risks. The study by Tang et al. [9] embedded IMUs in shoes to gather motion data during balance and mobility tasks. The researchers employed support vector regression to predict clinical measures, specifically the Berg Balance Scale, from the collected spatiotemporal gait parameters. This approach effectively linked objective measurements from wearable technology to established clinical balance assessments.

For most of these approaches, the user is required to wear an additional sensor, hindering long-term user engagement. To increase user involvement, sensors should be seamlessly integrated into daily life, as exemplified by ear-worn devices, or earables, such as hearing aids or earbuds. These devices are already part of everyday use, offering an ideal platform for unobtrusive mobility and balance assessment [10].

This thesis investigates the potential of earable devices as a novel approach to integrate clinical assessment tools, e.g. FES-I with wearable technology for real-world use. The first objective of this master thesis is a similar approach to Sun, R. et al. [6] by using the force plate data and machine learning to predict the fall risk, defined by the FES-I questionnaire, in order to validate the given dataset. The second step is to technically validate the use of IMUs by correlating specific features relevant to the balance assessment of IMUs and force plate data. Important features can be derived from the time domain, the frequency domain, and the sway [11]. The third objective is to use the IMU data to predict the fall risk as given by the FES-I score. The performance of different feature-based machine learning models will be evaluated. This work will use a previously recorded dataset. The dataset includes 72 participants, 32 diagnosed with Parkinson's disease, and 40 healthy controls. Five different static balance tasks were performed, each with eyes opened and eyes closed and data was recorded using ear-worn IMUs and force plates. Several clinical instruments to assess mobility impairment, falls risks and cognitive performance were applied (FES-I, MoCa, TUG, SPPB, UPDRS).

The proposed work consists of the following parts:

- Literature review of the use of force plates and wearables for balance assessment and fall risk predictions.
- Extraction and statistical comparison of meaningful features from force plates and ear-worn IMUs [11].
- Implementation and evaluation of feature-based ML classifier to predict fall risk based on features from the force plates [6].
- Implementation and evaluation of feature-based ML classifiers to predict fall risk using ear-worn IMUs.
- Comparison of fall risk prediction results for both sensor modalities.
- Optional: Retrain and evaluate feature-based ML models to predict other clinical scores (MoCa, UPDRS, TUG, etc.).

The thesis must contain a detailed description of all developed and used algorithms as well as a profound result evaluation and discussion. The implemented code has to be documented and provided. An extended research on literature, existing patents and related work in the corresponding areas has to be performed.

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