INTRODUCTION

• Approximately 23% of those deployed suffer from mild traumatic brain injury (mTBI) with dizziness and balance problems as common symptoms [1, 2].
• Vestibular rehabilitation can speed up return to duty and improve quality of daily living. It is effective for mTBI [3] as well as vestibulo-ocular dysfunction in older adults [4, 5].
• Wherever possible, it is encouraged that Warfighters start mTBI rehabilitation in the field, often without expert vestibular care.
• Errors in exercise execution may not get corrected in a timely manner, impacting perception of self-improvement and progress in rehabilitation.
• There is a need to identify errors, coach proper techniques and provide immediate feedback, administered by any trained healthcare provider.

PROJECT OBJECTIVE

To optimize performance of vestibular rehabilitation exercises by defining and applying machine learning based methods to detect the most common errors and integrate corrective cues to reduce error and hit the targeted parameters for vestibular rehabilitation

VORx1 EXERCISE

• Vestibular Ocular Reflex (VORx1) exercise is part of vestibular rehabilitation.
• The patient focuses on a stationary object while smoothly turning their head in either a repeated pitch or yaw movement [7].

EXERCISE ERRORS

• Errors in exercise performance can be categorized as two types [6]:
  1. Target errors: errors in which the patient is not acquiring the targets of the exercise sufficiently, such as range of motion, which aid in speed training.
  2. Constraint errors: errors defined when the patient fails to maintain postural or kinematic constraints during the exercise, such as jerky head movement.
• Target errors can be identified with standard data analysis algorithms. Constraint errors can be harder to measure particularly due to the variability between different patients.
• Machine learning is a more robust method to identify common mistakes.
• Commonly made mistakes by patients during the VORx1 exercise were identified by a trained vestibular physical therapist in a previous study on 10 healthy adults [8]:
  1. Making jerky instead of smooth head motions;
  2. Rotating the head too large a range of motion;
  3. Tucking the chin (for pitch) or rolling the head (for yaw);
  4. Large amounts of body movement.

THE VESTIBULAR REHABILITATION APP™

• We have developed a mobile application which provides at-home vestibular rehabilitation exercises in a game-based interaction format [12].
• This app records user’s movement during exercises and provides clinicians with remote monitoring via summarized, actionable data.
• The system is inexpensive and portable, and provides a quick, engaging, and reliable mechanism to partake in vestibular rehabilitation.
• We utilized this app to collect motion data (IMU) during VORx1 exercises.

MACHINE LEARNING FOR ERROR DETECTION

• IRB approval was obtained from internal IRB board.
• Seven healthy subjects (five male and two female, age 35 ± 13)
• Subjects performed the VOR x1 exercises (yaw and pitch) using the Vestibular Rehabilitation App with an IMU sensor placed on the forehead:
  1. Subjects performed each game correctly.
  2. Subjects received each of the commonly made mistakes.
  3. Subjects mixed up mistakes and correct motions.
• Raw IMU sensor and video data were collected and stored in a database.
• Machine learning methods were developed to classify the errors made during gameplay:
  1. A time series labeling pipeline for visualization and manual segmentation of post IMU data was conducted for a ML model.
  2. A simple three-layer convolutional neural network (CNN) model was trained with TensorFlow (www.tensorflow.org) that was inspired by human activity classification [13].
• Post hyperparameter optimization and model conversion to TensorFlow Lite runtime was used to deploy on the Android platform.

EFFECTIVENESS MACHINE LEARNING ERROR DETECTION

• During the CNN model development, classification displayed a high convergence (>99%) with the dataset in an 80/20 split for training and validation, with validation following closely with training accuracy.
• A separate test dataset was held from model development process and used to measure model performance.
• The model correctly classified 76% of the four errors and normal gameplay in the test dataset.
• An F1 score (statistical measure of model accuracy) of 0.59 was observed for the body movement mistakes, suggesting poor precision and recall. F1 scores for jerky motion, too large range of motion, and added chin motion were 0.91, 0.92, and 0.79, respectively, showing better precision.
• When the body motion case was omitted in a retrained CNN model, correct classification accuracy increased to from 76% to 88%.

SUMMARY

• Machine learning algorithms can be used to identify some, but not all, errors made during VOR exercises.
• Jerky head motion and incorrect range of motion can be identified with high confidence. The algorithms were unable to detect movement of the whole body from the single head-mounted sensor.
• Removing body motion from the CNN improved the ability to detect more subtle erroneous movements such as tucking the chin or rolling the head.
• Detecting excessive body motion may require a second sensor to be placed on the upper body or use of camera based whole-body motion tracking technology.
• Our model could be improved with more testing and training data, as well as training and testing on a larger sample.

This technology can be used to provide immediate feedback on exercise performance to Warfighters with TBI and vestibular deficits. This technology can accelerate recovery and help continue and successfully progress vestibular rehabilitation efforts in any remote locations.

ONGOING AND FUTURE WORK

• We have integrated the model into our app such that it runs in the background of the vestibular rehabilitation exercise games.
• If the model detects a common mistake with confidence above a certain threshold, the user will be alerted about what kind of error they have made.
• We have replaced the sensor based motion capture by camera-based motion capture and will evaluate the ability to detect errors in whole body motion with this improved approach.


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