AI in Neurorehab: Pose Estimation Makes Gait Analysis Easier and More Accessible

Dr. Jan Stenum was five months into his postdoc with Dr. Ryan Roemmich at the Center for Movement Studies at the Kennedy Krieger Institute and the Department of Physical Medicine and Rehabilitation at the Johns Hopkins University School of Medicine in Baltimore, Maryland, when the COVID-19 pandemic shut down the laboratory in March of 2020. During the months leading up to the shutdown, Dr. Stenum had started a project on gait rehabilitation in people with Parkinson's disease using a specialized treadmill capable of pivoting up-and-down or jerking side-to-side in response to the gait pattern of the person walking on the treadmill. The goal was to create unusual walking scenarios on the treadmill to promote longer steps to counteract the short, shuffling steps which are a common symptom of Parkinson's disease. Pandemic restrictions made a return to the laboratory appear far off in the future. What's more, the project required participants to wear a face mask connected to a tube collecting expired air to measure oxygen consumption—an unfavorable setup considering the airborne coronavirus. The project was abandoned for the time being.

It turned out that the ensuing lull set the course for a new line of work from Drs. Stenum and Roemmich. As it happened, the lockdown coincided with work coming from computer science researchers on the use of artificial intelligence (AI) in computer vision algorithms. The so-called *pose estimation* algorithms that the scientists were developing were capable of automatically tracking anatomical landmarks, such as hips, knees, or ankles, in video recordings of people doing various activities like walking, running, dancing, skiing, surfing, fencing, or playing tennis. Computer scientists had spent years "training" pose estimation algorithms to detect human anatomy: thousands and thousands of images had been labelled by hand and used as training input for the algorithm. With a vast variety of poses in the training set, the pose estimation algorithm had learned to automatically detect anatomical landmarks in newly recorded videos that the algorithm had no prior knowledge of. Now pose estimation algorithms had become so accurate that they were leaving the world of computer science and making their way into other scientific disciplines.

Convening over Zoom, it was clear to Drs. Stenum and Roemmich that pose estimation was a significant advancement with relevance to clinicians and researchers interested in gait rehabilitation. A clinician could record a video of a patient with their smartphone and receive a full-body gait analysis with the help of pose estimation. Such an approach could make gait analysis much more readily available and improve clinicians' ability to track gait over time in patient populations. Full-body gait analysis has generally been restricted to gait laboratories with expensive equipment such as high-speed cameras, or to strapping multiple inertial measurement unit (IMU) sensors to the body. These inertial measurement unit sensors measure acceleration, orientation, angular rates, and other gravitational forces using accelerometers, gyroscopes, and sometimes magnetometers, but they are time-consuming to use. Pose estimation offered an easy solution to the drawbacks of other methods: simply record a video with a smartphone or tablet with no expensive or extra equipment required.

The first question that Drs. Stenum and Roemmich wanted to answer was how accurately does pose estimation analyze gait? An important question, given that clinicians and researchers would want to know if they could trust the results obtained from pose estimation. But now that the laboratory had shut down Drs. Stenum and Roemmich had no way to collect the data to answer this question. By a happy coincidence, it turned out that a paper with the exact type of data needed for a validation study of this sort had recently been published by a group of computer scientists in Poland: a group of study participants walked on a walkway with simultaneous video recordings from multiple viewpoints and gold-standard measurements from a three-dimensional, 10-camera motion capture system. Based on the Polish group's work, Drs. Stenum and Roemmich published their first paper investigating use of pose estimation for human gait analysis in April of 2021. The paper showed that spatiotemporal parameters of gait (such as gait speed, step length, and step time) and lower-limb hip, knee, and ankle angles calculated using a three-dimensional motion capture system were comparable to measurements obtained using video analyzed with pose estimation. The errors in pose estimation were generally below minimally clinically important differences, showing that pose estimation gave reliable gait analysis metrics.

Subsequent papers from Drs. Stenum and Roemmich expanded on the use of pose estimation. In many clinical settings, it is difficult to find a space that is wide enough to capture a side-view of a person walking—would a front view of a person walking down a hallway suffice? This was a hard problem to solve, given that a person appears smaller as they walk down the hallway away from a stationary camera. Many months were spent pondering how to get distance-based metrics like step length and gait speed from a video captured with just a front view. The answer came from Renaissance art that introduced the concept of linear perspective to bring life-like depth to paintings. The same rules that Renaissance masters had used to create the illusion of depth could be inverted to calculate depth-changes from the size of a person as they walk down a hallway. It was a particularly satisfying workday when Drs. Stenum and Roemmich realized that the depth problem was solved using a simple method developed centuries ago in the name of art—a true eureka moment!

The interest from the clinical and scientific communities has been tremendous. To increase the reach of the project, Drs. Stenum and Roemmich employed an open-science ethos to make the tools that they have created available for others to use. The code that Dr.Senum wrote for the project was made available at GitHub together with a manual with best practices for video recordings and step-by-step instructions for the code. The code is GUI-based, meaning that the user will see windows pop-up for each step of the workflow and use the mouse to point and click—it requires no previous coding background to run. Other researchers have used the code in projects as varied as motor development in children with autism spectrum disorder and the biomechanics of head load carriage and its relationship to human evolution. The range of projects nicely shows the success of the open-science approach.

Drs. Stenum and Roemmich continue to collaborate with a range of clinical and research colleagues throughout the Kennedy Krieger Institute and Johns Hopkins communities, as well as those at external institutions. They are working on developing a variety of different software workflows that groups can use to perform their own video-based assessments of their particular movement patterns of interest. As one example, Drs. Stenum and Roemmich have been collaborating with colleagues in the Department of Neurology at Johns Hopkins Medicine to provide video-based motor assessments for persons with Parkinson’s disease, a topic that was covered (alongside their gait work) at Dr. Roemmich’s recent presentation at the 2024 ASNR Annual Meeting.

It is becoming clear that these video-based approaches to measure human movement represent an important opportunity to make quantitative, objective motor assessment significantly more available to rehabilitation clinicians and researchers. This work is expanding rapidly, and the trend will almost certainly continue as enthusiasm for artificial intelligence-based solutions grows. As these technologies develop, it will be critical for developers to work hand-in-hand with clinicians to ensure that these exciting technologies reach their full potential for actual clinical implementation.