Enhancing Observational Gait Analysis – Techniques and Tips for Analyzing Gait Without a Gait Lab

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Abstract: In settings where three-dimensional gait analysis is not feasible, observational gait analysis can provide important information about gait pathology. Among the validated scoring systems to organize the observations of gait, the Edinburgh Visual Gait Score (EVGS) is the most comprehensive and has the most favorable psychometrics. Improvements in mobile videography have created opportunities to obtain high-quality slow-motion video in a clinic setting. These videos can provide excellent documentation of gait pathology in the sagittal, coronal, and vertical planes. Free and low-cost video analysis software is now available on all mobile device platforms, allowing for slow-motion video analysis of gait with increased accuracy. By utilizing the appropriate technology with a validated scoring system, gait analysis outside the walls of a gait lab is possible. Though limitations of the mobile enhanced observational gait analysis technique require further study, the technique can facilitate improved documentation of gait pathology and improved communication between providers.

Key Concepts:

- Observational gait analysis can be improved by the use of validated scoring systems such as the Edinburgh Visual Gait Score (EVGS).
- Mobile device video with additional low-cost equipment can provide high-quality slow-motion video to improve observational gait analysis.
- Free or low-cost mobile applications for slow-motion video analysis and angle annotations can further refine the technique of mobile enhanced observational gait analysis.

Introduction

Gait analysis plays an integral role in diagnosis, surgical planning, and surgical assessment in a wide array of pediatric orthopaedic conditions. Three-dimensional gait analysis is the only available technology to objectively quantify gait and has dramatically improved our understanding of the biomechanics of gait pathology. Three-dimensional gait analysis, when coupled with consistent indications for multi-level surgery and access to experienced physical therapists, has been shown to improve gait and function in children with cerebral palsy (CP) at a medium-term follow-up.[1,2] A “gait lab” with trained personnel, appropriate equipment, and experienced clinicians for interpretation requires a substantial institutional commitment and capital expense. A substantial number of graduating fellows from POSNA accredited fellowship programs, practicing POSNA members, and international pediatric orthopaedic surgeons may be practicing in settings where three-dimensional gait analysis is not available. Additionally, some children may not be able to participate in a full three-dimensional gait study due to developmental delay or lack of cooperation. Visual assessment of gait, or observational gait analysis, can help bridge this practice gap. When observational gait analysis is enhanced with widely available and low-cost technology, it can improve the understanding of gait pathology and facilitate communication about gait deviations between providers and with patients.

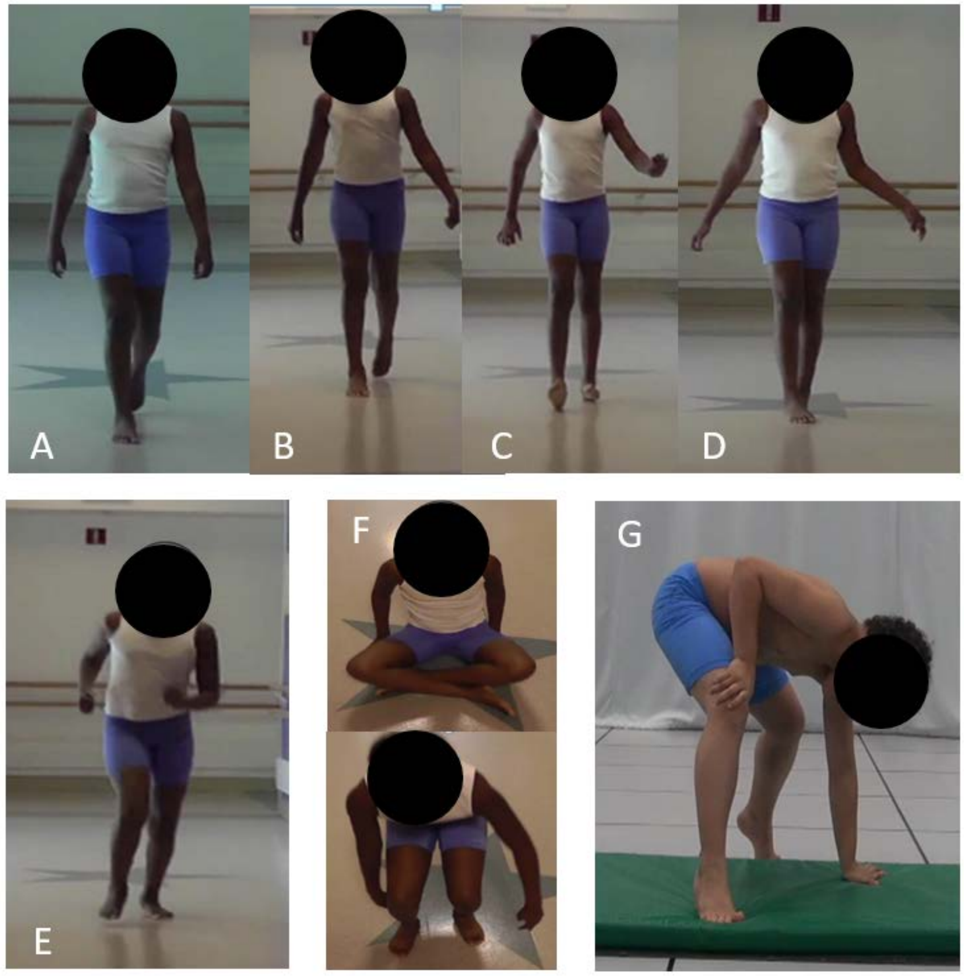

Figure 1. *The six-point screening gait exam includes typical speed walking (A), toe walking (B), heel walking (C), tandem walking (D), running (E), and arising from a seated position (F). Performing all six tasks in a typical manner can rule out significant orthopaedic problems. For the final screening test of arising from a seated position, a child with proximal muscle weakness will support their trunk with their hands as they rise, or a positive Gower's sign (G).*

Normal Gait and Identifying Common Gait Deviations

Human bipedal gait is mechanistically elegant. All humans walk in a remarkably similar fashion to maximize the energy efficiency in the face of gravitational and inertial forces.[3,4,5] An understanding of normal gait is essential for understanding pathologic gait, for selecting the proper intervention to address a particular gait deviation, and for determining the outcome following such interventions.

The gait cycle is divided into stance and swing phases for each limb, with a full gait cycle starting and ending with initial contact of the reference foot to the floor. The four stance sub-phases of loading response, mid-stance, terminal stance, and pre-swing allow for weight acceptance, promote limb stability in single limb support, maximize efficiency, and position the limb for swing phase. The three swing sub-phases of initial swing, mid-swing, and terminal swing promote limb clearance from the floor, maximize step length, and position the limb for stance phase.[5]

A six-point screening gait exam can be performed in a clinic hallway where the subject can be observed walking towards and away from the examiner. The subject should perform the six functional tasks of typical walking, toe walking, heel walking, tandem walking,

Table 1. Common Gait Deviations at Hip, Knee, and Ankle

Deviation	Gait Cycle Timing	Cause	Significance
Hip – Excessive Flexion	Initial Contact/ Loading Response	• Spasticity or contracture of hip flexors • Compensation for excessive knee flexion or ankle dorsiflexion	• Increase demand on knee and hip extensor muscle groups • Decreased limb stability
	Mid-swing	• Compensation for diminished knee flexion or ankle dorsiflexion	• Helps foot clearance
Hip – Internal Rotation	Mid-stance	• Increased femoral anteversion • Compensation for external pelvic rotation	• Intoeing gait pattern • Impaired forward progression • Disrupted patellofemoral mechanics
Knee – Excessive Flexion	Any phase	• Knee flexion spasticity/contracture • Impaired proprioception	• Decreased shock absorption in initial contact • Decreased stability in stance • Increased demand on knee extensors in stance • Poor foot position in terminal swing
Knee – Hyperextension	Mid-stance	• Secondary to excessive ankle plantarflexion • Impaired proprioception • Intentional to increase limb stability	• Decreased forward progression • Damage to knee ligaments
Ankle – Toe Strike	Initial Contact	• Inadequate knee extension in terminal swing • Inadequate dorsiflexion in terminal swing • Compensation for knee extensor weakness • Hindfoot Pain	• Diminished shock absorption (1st foot rocker) • Disruption of forward momentum
Ankle – Excessive Plantarflexion	Mid-stance	• Plantarflexor muscle group spasticity/contracture	• Disrupted stability in mid-stance (2nd foot rocker) • Disruption of forward momentum

running, and arising from a seated position on the floor (Figure 1). Performing these six tasks provides a broad screening exam that will identify deviations or deficits associated with all of the pathological processes that could disrupt gait in children. A child who can successfully perform all six tasks in a typical manner is unlikely to have a significant orthopaedic problem.

In children with CP, gait deviations may be classified as primary or secondary. Primary gait deviations are due to the underlying neuro-orthopaedic impairments such as spasticity, muscle contractures, or torsional deformities. Secondary gait deviations are biomechanically driven by the primary gait deviation. For example, a primary deviation of excessive ankle plantarflexion in mid-stance results in the secondary gait deviation of knee hyperextension due to the effect of ankle position on the direction of the ground reaction force. Interventions to improve gait should be directed towards primary gait deviations, with the understanding that secondary gait deviations will resolve spontaneously following correction of the primary deviation.[6] The most common gait deviations and their functional significance are summarized in Table 1.

Technology for Improving Observational Gait Analysis

Observational gait analysis can be substantially improved with technology to obtain and annotate high-quality video.[7] High-quality video allows for the complex analysis and interpretation to occur outside of a busy clinic setting, creating the time and mental space to appreciate subtle gait deviations.

Patient Preparation

For optimal visualization, the child should be dressed in fitting shorts with additional tight sleeveless top for girls. Ideally, the child's upper thoracic spine, anterior and posterior superior iliac spines, femoral condyles, and medial and lateral malleoli should be visible and marked with high-contrast 3D markers. The patellae, tibial tubercle, and Achilles tendon should be also be marked with a high-contrast skin marker (Figure 2).

Figure 2. *Surface marking of the upper thoracic spine, posterior and anterior superior iliac spines, medial and lateral femoral condyles, patella, medial and lateral malleoli, and Achilles tendons allow for improved observational gait analysis. Images copyright www.gaitanalysis.org and Ramiro Olleac, MD*

Room Setup for Optimal Video Acquisition

A walkway of at least 30 feet (10 meters) in length allows for an adequate number of strides for coronal plane observation, a distance that can be easily accommodated in most outpatient clinic hallways. High-quality sagittal plane video, however, is the key to proper observational gait analysis and requires at least 10 feet from the subject. Finding this larger space for proper sagittal plane video will be well worth the time and space investment. The space should have bright lighting to reliably track skin markings. To minimize light flicker with slow-motion video, consider a location illuminated with natural light, halogen bulbs, or traditional tungsten bulbs rather than fluorescent or light emitting diode (LED) lights. A plain light-colored

Figure 3. *A. A three-camera mobile videography setup can allow for visualization of gait in three planes. B. A two-camera setup omitting the vertical video capture can allow a single individual to obtain sagittal (1) and coronal (2) video. Images copyright www.gaitanalysis.org, Vedant Kulkarni, MD, and Ramiro Olleac, MD*

background that contrasts with skin tones enhances visibility. Additionally, having a floor marked with intervals or with tiles of a known size allows for determination of time distance parameters.

Camera Considerations

We recommend using the slow-motion video capture mode on mobile devices, as the wide-angle lens and choice of frame rates are well suited for observational gait videos. A frame rate of 60 frames per second (fps) or higher prevents blurring of the limb in swing phase. Stabilized video without jitter is key, and this can be achieved with a low-cost tripod or hand-held gimbal. A two-camera setup can capture simultaneous sagittal and coronal video with a single camera operator, whereas a three-camera setup allows for adding vertical video capture (Figure 3). The subject should occupy no less than two-thirds of the field of view at all times. Minimizing the use of zoom allows for better appreciation of subtle stride-to-stride variability because the subject's position relative to the floor is maintained throughout the video.

Sagittal Plane Video

To minimize the parallax between camera and limb, we recommend sagittal video captured by an observer who tracks the subject using a gimbal-mounted mobile device camera. This allows the subject to remain centered on the camera for all strides, minimizes motion artifact, and allows for video collection in a smaller space. The camera should be centered on the subject's knee to allow for adequate perspective of all body segments. If space is a limiting factor, obtaining the subject's video in portrait mode (Figure 3B), rather than the widescreen landscape mode (Figure 3A), allows the camera to be even closer to the subject.

Coronal Plane Video

A tripod mounted mobile device can capture adequate coronal plane video without a camera operator. If the coronal plane video is obtained by a camera operator, the resulting video will be higher quality because real-time adjustments in zoom and focus can be performed to maintain the appropriate field of view as the subject moves closer to the camera.

Vertical Video Acquisition

Transverse plane gait pathology can be difficult to quantify with sagittal and coronal video alone. Vertical video acquisition requires a stepladder and an additional gimbal. A gait progression imprint will require a black vinyl rug and talcum powder (Figure 4). Obtaining this vertical video simultaneously with sagittal and coronal video will require another trained videographer.

Figure 4. *A. A stepladder is used to obtain the appropriate field of view. B. The gimbal's tilt feature can help track the subject. C, D. A black vinyl rug walkway with talcum powder can improve identification of the gait line of progression and foot progression angle. Images copyright www.gaitanalysis.org and Ramiro Olleac, MD*

Mobile App Slow-Motion Annotation

In addition to high-quality slow-motion video capabilities, mobile devices have several free or low-cost applications that allow for frame-by-frame joint angle measurement (Figure 5).

Scoring Systems for Observational Gait Analysis

Observational gait scoring systems provide both a structure for systematic analysis and an objective score that can be used to compare gait between subjects and between time points. Of the available scoring systems, the Edinburgh Visual Gait Score (EVGS) is the most comprehensive and has the best psychometrics.[8] The EVGS assigns a score from 0 (normal) to 2 (deviation $\geq \pm$ 4.5 SD from mean) to 17 joint-gait phase combinations, for a maximum score of 34 per limb[9] (Table 2). The reliability of EVGS is better for distal segment scores, for observers with more experience in gait analysis, and for children with less gait impairment.[10,11] The minimal clinically important difference (MCID) in EVGS score has been published at 2.4.[12]

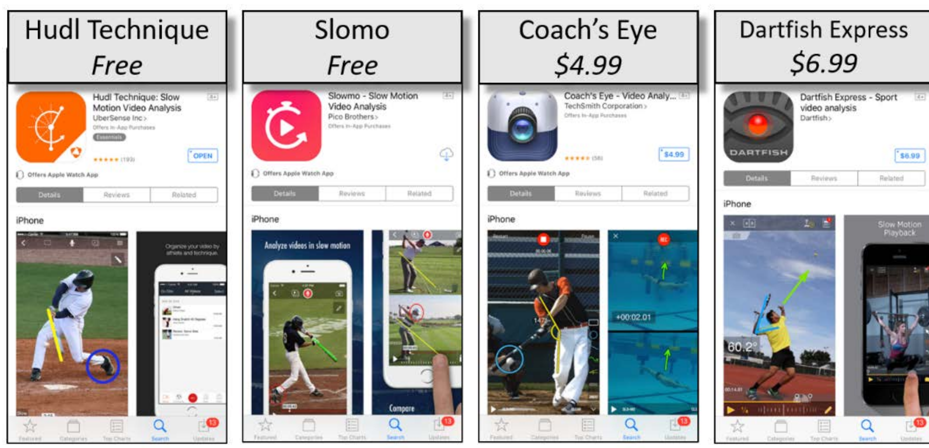

Figure 5. *Free and low-cost mobile video annotation applications*

Our understanding of the limits of observational gait analysis using the EVGS system is evolving. In one study where the kinematics and observational video were obtained on the same day rather than simultaneously and joint angle assessments were made without a dedicated video annotation tool, the agreement between three-dimensional gait analysis and EVGS was found to be between 52-73%.[10] To better understand the true error of the mobile app enhanced observational gait analysis technique, a preliminary study with 10 children

	Stance			Swing
	Initial Contact	*Mid-Stance*	*Terminal Stance*	*Mid-Swing*
				
Edinburgh Visual Gait Score (EVGS) Observations	Peak Hip Flexion (S) Peak Knee Extension (S) Foot Contact (S)	Max Trunk Position (S) Max Trunk Shift (C) Max Pelvis Obliquity (C) Pelvis Rotation (T) Knee Progression Angle (T) Heel Lift (S) Hindfoot Varus/Valgus (C) Foot Progression Angle (T)	Peak Hip Extension (S) Peak Knee Extension (S) Max Ankle Dorsiflexion (S)	Peak Knee Flexion (S) Max Ankle Dorsiflexion (S) Foot Clearance (S)

Table 2. *The Edinburgh Visual Gait Score (EVGS) includes 17 observations of the limb in the sagittal (S), Coronal (S), and Transverse (T) planes. Illustrations copyright www.gaitanalysis.org and Vedant Kulkarni, MD*

with CP captured slow-motion video on a mobile device and three-dimensional kinematics simultaneously.[13] The quantitative video measurements made using the Dartfish Express app (Dartfish, Fribourg, Switzerland) were compared to the quantitative kinematic data for each of the EVGS variables (Figure 6). The mobile enhanced observational gait analysis had excellent overall reliability between raters (ICC 0.95), had good reliability compared with three-dimensional gait analysis (ICC 0.89), and a mean error of 7.02 degrees (SD 6.86 degrees) when compared with three-dimensional kinematics. The technique had higher errors with transverse plane measurements, with an error of 12.85 degrees for foot progression angle and 10.33 degrees for knee progression angle. When rotational deviations brought the joint out of plane with the camera, the reliability of the technique was reduced. While it cannot replace the objective data obtained from three-dimensional kinematics, observational gait analysis structured by the EVGS system using slow-motion video allows for more refined interpretation of visual gait than a cursory gait analysis in a clinic hallway.

The Limits of Observational Gait Analysis

Observational gait analysis is a two-dimensional assessment of a three-dimensional movement pattern.[14] While it is possible to visualize the subject in the coronal and sagittal planes with observational gait analysis, visualizing the alignment and motion in the transverse plane can be challenging.[5,15] A transverse plane skeletal malalignment or a dynamic gait deviation may result in rotation of joints out of the sagittal and coronal planes of visualization, creating a false visual impression of alignment and range of motion.[16] This is a common problem in children with CP who have increased femoral anteversion and associated increased pelvic and hip rotation during the stance phase of gait.[17] Observational gait analysis is also limited in subjects who have offsetting deviations between the femur and tibia, termed "miserable malalignment"(Figure 7).[18,19] Deviations in

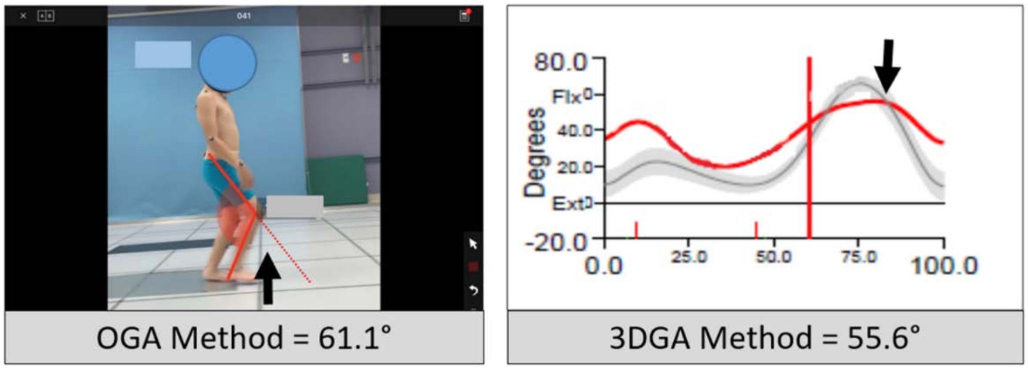

Figure 6. *Measurement of peak knee flexion in swing using mobile enhanced observational gait analysis (OGA) compared with three-dimensional gait analysis (3DGA). Images copyright www.gaitanalysis.org and Vedant Kulkarni, MD*

the hip and pelvis can be particularly challenging to recognize with observational gait analysis given the lack of surface landmarks to determine rotation. Two-dimensional observational gait analysis should be used with caution for clinical decision-making in these situations and a referral for quantitative three-dimensional gait analysis should be considered when multi-planar deformities are appreciated. While vertical video capture may help identify these transverse plane deviations to a trained observer, the accuracy and reliability of this technique has not been studied. Finally, structured observational gait analysis can at best provide an estimation of joint kinematics of one gait cycle and should not be seen as a substitute for a full three-dimensional gait study that can provide kinematics (joint movement), kinetics (joint forces), dynamic pedobarography (foot pressure mapping), electromyography (surface or fine wire), and oxygen consumption for multiple gait cycles and multiple trials.

Conclusion

By combining low cost and readily available technology with the validated EVGS system of measurement, mobile enhanced observational gait analysis has the potential to improve recognition of subtle gait pathology and improve communication and documentation in settings where three-dimensional gait analysis is not available or possible. Additional study is required to understand the role of mobile-enhanced observational gait analysis in clinical decision-making. Pediatric orthopaedic surgeons utilizing observational gait

Figure 7. *A. In this child with CP, the apparent hip abduction seen in the coronal plane (curved red arrow) is a combination of increased external pelvic rotation, hip flexion, and hip internal rotation while the apparent left knee valgus (straight red arrow) is knee flexion seen out of plane. B. In a child with "miserable malalignment," the neutral foot progression angle (green arrow) is a consequence of offsetting femoral anteversion and external tibial torsion. As in the child with CP, this child has apparent hip adduction (curved red arrow) and knee valgus (straight red arrow) that are due to out-of-plane limb visualization. Images copyright www.gaitanalysis.org and Jon Davids, MD*

analysis should be aware of the limitations of this technique, particularly for quantifying transverse plane or multi-planar gait deviations.

Additional Resources

Videos, scoring guides, and additional resources on both mobile enhanced observational gait analysis and three-dimensional gait analysis can be found at: www.gaitanalysis.org/moga.

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