Interpreting sources of variation in clinical gait analysis: a case study

Short Communication

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All authors were fully involved in the study and preparation of the manuscript and all material within has not been, and will not be, submitted elsewhere for publication. GJB conceived the study and contributed to drafting the article, SLK performed the data analysis and contributed to drafting the manuscript, and LRR contributed to critically revising the manuscript.

Highlights

- Gait analysis is an important tool in identifying and evaluating movement deviations
- Three forms of gait deviations exist: experimental, genuine and intentional
- Gait analysts should separate these gait deviations both subjectively and objectively
- A didactic description and means of interpreting gait deviations are provided

Abstract

Objective: To illustrate and discuss sources of gait deviations (experimental, genuine and intentional) during a gait analysis and how these deviations inform clinical decision making.

Methods: A case study of a 24-year old male diagnosed with Alkaptonuria undergoing a routine gait analysis. A 3D motion capture with the Helen-Hayes marker set was used to quantify lower-limb joint kinematics during barefoot walking along a 10 m walkway at a self-selected pace. Additional 2D video data were recorded in the sagittal and frontal plane. The patient reported no aches or pains in any joint and described his lifestyle as active.

Results: Temporal-spatial parameters were within normal ranges for his age and sex. Three sources of gait deviations were identified; the posteriorly rotated pelvis was due to an experimental error and marker misplacement, the increased rotation of the pelvis in the horizontal plane was genuine and observed in both 3D gait curves and in 2D video analysis, finally the inconsistency in knee flexion/extension combined with a seemingly innocuous interest in the consequences of abnormal gait suggested an intentional gait deviation.

Conclusions: Gait analysis is an important analytical tool in the management of a variety of conditions that negatively impact on movement. Experienced gait analysts have the ability to recognise genuine gait adaptations that forms part of the decision-making process for that patient. However, their role also necessitates the ability to identify and correct for experimental errors and critically evaluate when a deviation may not be genuine.

Keywords

Gait analysis; Alkaptonuria; osteoarthritis; malingering

Introduction

Gait analysis (GA) is becoming increasingly important and its efficacy becoming more apparent in clinical decision making [1,2]. Gait data used to describe the movements of body segments driven by forces, consists of 3D joint angle, moment and power curves of the ankle, knee, hip and pelvis plotted against the gait cycle between consecutive initial contacts with the ground. Interpretation of gait data essentially entails finding the reasons why a patient's curves differ from those in a normal gait database. Deviations can occur for three reasons: *experimental factors, genuine causes and intentional changes.* A deviation due to *experimental error* most commonly arises from inaccurate and inconsistent placement of reflective markers over anatomical landmarks [3,4] but can also include technical aspects such as occluded markers or tracking errors. A *genuine* deviation is a trusted abnormality that is a consequence of the patient's biomechanical or neuro-musculo-skeletal constraints and are in accord with the patient's clinical history. Finally, *intentional, or non-habitual,* deviations are most difficult to recognise but they must be identified so that they can be ignored. A malingering patient deliberately alters movement due to a vested interest in generating false evidence of abnormal gait which may be of benefit to them [5].

The results of the patient presented here exhibited all three types of gait deviations. This prompted a didactic description of how the different deviations are approached and interpreted.

Methods

Patient

A young male diagnosed with alkaptonuria (AKU) was referred for GA (further details are withheld to prevent identification of the patient with this rare disease). Alkaptonuria is an autosomal recessive congenital metabolic disease caused by reduced activity of an enzyme (homogentisate 1,2-dioxygenase). This results in the accumulation of homogentisic acid throughout the body leading to debilitating health problems including discolouration of eyes, ears, bone and degradation of cartilage (ochronosis) ultimately resulting in severe osteoarthritis. While AKU is present from birth, with the exception of black urine, typical symptoms start to manifest after the mid-30s [6,7,8]. Our patient reported no aches or pains in any joint and led an active lifestyle. Additional investigations (MRI) did not identify any lower limb, spinal or upper limb abnormalities.

Experimental procedure

Ten Qualisys Oqus cameras (Qualisys, Gothenburg, Sweden) were used to collect kinematic data sampling at 120 Hz. Two video cameras sampling at 25 Hz were used to collect frontal and sagittal plane recordings. A Helen-Hayes marker set [9] was used to capture kinematic data. The patient was instructed to walk barefoot at a self-selected pace along a 10 m walkway, with a total of 10 trials collected. Qualisys Track Manager (Qualisys, Gothenburg, Sweden) and Visual3D (C-Motion, Rockville, MD, USA) programs were used to track and process the kinematic data, including cubic spline interpolation and filtering of marker positions using a 2^{nd} order low-pass Butterworth filter with a cut-off frequency of 6 Hz. Joint angles for both limbs were time-normalised to the gait cycle. Speed-matched reference data (N=11, age range 23-60 years) were plotted for visual comparison and coefficient of variation (CV) calculated for key peak sagittal plane values for each joint.

It must be noted that during the experimental procedure the patient expressed interest in GA; he specifically asked about the possible consequences and impacts on his life if an abnormal gait was identified.

Results

Walking speed (1.30 m/s), stride length (1.46 m) and cadence (105 steps/min) were well within normal ranges for his age and sex [10]. The CV vas markedly greater for knee flexion during loading than any other sagittal plane peak variable (Table 1). This prompted further detailed investigation of each walking trial to discover the source of variation. Furthermore, the visual offset towards posterior pelvic tilt and increased range of motion in the transverse plane prompted investigation into the observational 2D video to corroborate these findings.

Experimental deviation

The pelvic tilt is markedly lower than the expected ~10° anterior tilt that is typically seen in young healthy individuals [11] but with relatively low CV (Figure 1 and 2a, Table 1). After inspection of sagittal plane (side view) video data it was clear that the sacrum marker was placed too low. This resulted in an apparent offset to posterior pelvic tilt (Figure 1 and 2a) and a consequential apparent offset to hip extension.

Genuine deviation

The patient did not report any aches, pains or injuries therefore we did not expect many gait deviations. However, there is a large range of motion in pelvic rotation (Figure 1 and 2b). This

deviation is consistent between repeated walks in the 3D gait report (both visually and in reported CV) and was also visible in observational video.

Intentional deviation

The most noticeable finding in this patient's gait was the unusual and inconsistent right knee flexion/extension angle. This is clear both visually (Figure 1) and in the substantially large CV (Table 1). With the exception of an extension offset during stance phase, a gait profile close to the normal reference was achieved in some trials (Figure 1 and 2c). However the majority of trials showed no evidence of loading response knee flexion in early stance (0-30% of gait cycle) together with resultant plantarflexion offset of the ankle and extension offset of the hip.

Discussion

It is essential for gait analysts to correctly identify the types of deviations that can occur to avoid interpreting non-genuine data. It is imperative to understand the technical aspects of biomechanical analyses, particularly in cases where gait reports assist in determining treatment interventions for patients. The typical biomechanical model used in such analyses is the Helen-Hayes model [9] with limitations (such as cross-talk between planes at the knee and hip) widely acknowledged [12]. Erroneous hip and pelvic curves can arise from inaccurate marker placement of the notoriously challenging sacrum marker and the two markers on the left and right anterior superior iliac spines (ASIS). In this patient, the lack of supporting evidence from video of a posteriorly tilted pelvis (Figure 2a) indicates errors in marker placement. There was no evidence of spinal deformities and he had very little excess soft tissue. As such the ASIS markers were easily palpated and identified, therefore, by process of elimination, the offset to

posterior pelvic tilt must be due to inaccurate positioning of the sacrum marker. Mentally, gait analysts can 'shift' the pelvic tilt curve and the hip flexion/extension curve upwards. However, the same effect can be achieved in the analysis software by offsetting the 3D position of the sacrum marker in the local reference system of the pelvis, resulting in corrected pelvic tilt (Figure 2a) and hip flexion/extension curves. This was achieved by creating a virtual landmark, offset from the original marker co-ordinates, and subsequently used in the computation of the pelvis segment. We acknowledge this offset was an arbitrary correction, which in itself can introduce some quantitative error and potentially lead to missed-diagnosis if not all sources of information are rigorously critiqued prior to correction. However, this experimental error was corrected for in order to align the 3D gait curves with 2D observational analysis without the need to verify this finding in a repeat assessment.

The final gait abnormality, an intentional deviation, is more complex to identify. This requires the ability of the skilled analyst to critically question gait data through both subjective and objective analysis. The combination of analyses avoids any bias regarding selective removal/evaluation of individual trials, particularly in the case of perceived intentions of the patient. The patient was able to flex his knee during early stance in a similar pattern to speed-matched control data during some trials (Figure 2c). However the patient had no history of knee injury or any pain during the GA to explain this variation and apparent non-habitual gait, and the seemingly innocuous interest in possible consequences of the GA report indicated a potential ulterior motive. The ability to recognise such a deviation is invaluable when assessing the functional status of patients, particularly when the information may have implications for disease management and treatment, including potential benefit claims.

The present report highlights the three sources of gait deviations and provides didactic examples of the integration of subjective and objective interpretations of gait curves and observational video. The role of an experienced gait analyst is to not only recognise genuine deviations that may require further investigation or inform a treatment plan, but also to identify and correct for technical errors as well as have the ability to recognise when a deviation may not be genuine.

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GJB received a grant from the National Alkaptonuria Centre and SLK was employed from the same grant income. LRR is Director of the National Alkaptonuria Centre.

Author contributions

GJB conceived the study and contributed to drafting the article, SLK performed the data analysis and contributed to drafting the manuscript, and LRR contributed to critically revising the manuscript.

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Table 1. Peak joint angles (Average ± SD) and coefficient of variation (CV) for key variables at the ankle, knee, hip and pelvis.

13.	Joint angle (°)	CV
Peak ankle dorsiflexion	13.78 ± 0.71	5.15
Peak ankle plantarflexion	-12.64 ± 2.11	16.70
Knee flexion in loading	6.68 ± 8.16	122.16
Knee flexion in swing	66.54 ± 2.53	3.80
Peak hip extension	-19.75 ± 1.04	5.26
Hip flexion in loading	27.15 ± 2.35	8.65
Peak anterior pelvic tilt	4.80 ± 0.63	13.17
Peak posterior pelvic tilt	2.05 ± 0.62	30.33
Peak upwards pelvic obliquity	3.94 ± 0.53	13.50
Peak downwards pelvic obliquity	-2.75 ± 0.78	28.31
Peak pelvic protraction	8.73 ± 2.03	23.24
Peak pelvic retraction	-9.51 ± 2.31	24.33

Figure legends

Figure 1. A typical kinematic gait report depicting angles of the ankle, knee, hip and pelvis (from top to bottom) in the sagittal, frontal and transverse planes (left to right). Thin black lines with shaded area represent average (± standard deviation) patient data and thick black lines represent speed matched control data.

Figure 2. Joint angle curves illustrating all three deviations: experimental error (top), genuine deviation (middle) and intentional change (bottom) with our interpretation of the data. Shaded areas represent the average (± standard deviation) for the patient and thick black lines represent speed matched control data.

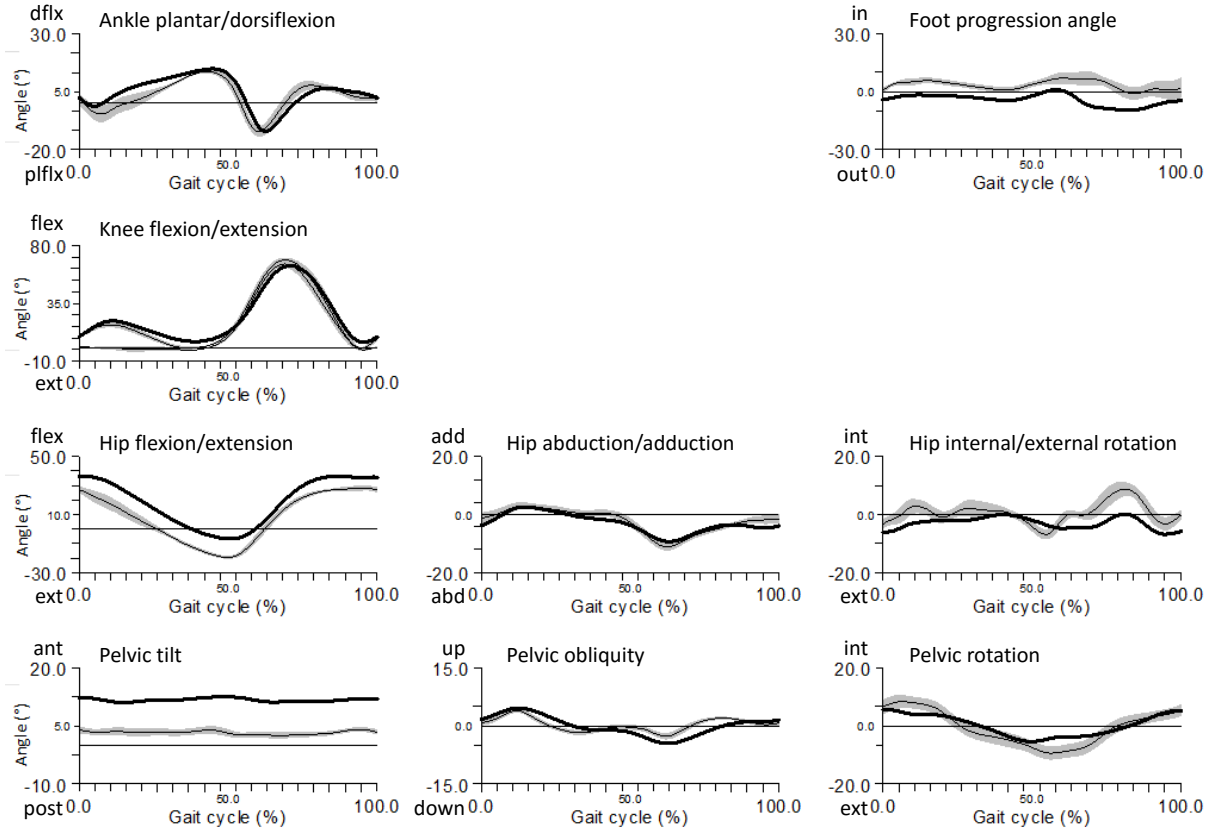
dflx
Ankle plantar/dorsiflexion
30.0
5.0
-20.0
plflx
Angle (°)
0.0
50.0
100.0
Gait cycle (%)
in
Foot progression angle
30.0
0.0
-30.0
out
flex
Knee flexion/extension
80.0
35.0
-10.0
ext
flex
Hip flexion/extension
50.0
10.0
-30.0
ext
add
Hip abduction/adduction
20.0
0.0
-20.0
abd
int
Hip internal/external rotation
ant
Pelvic tilt
-10.0
post
up
Pelvic obliquity
15.0
-15.0
down
int
Pelvic rotation

Figure 1

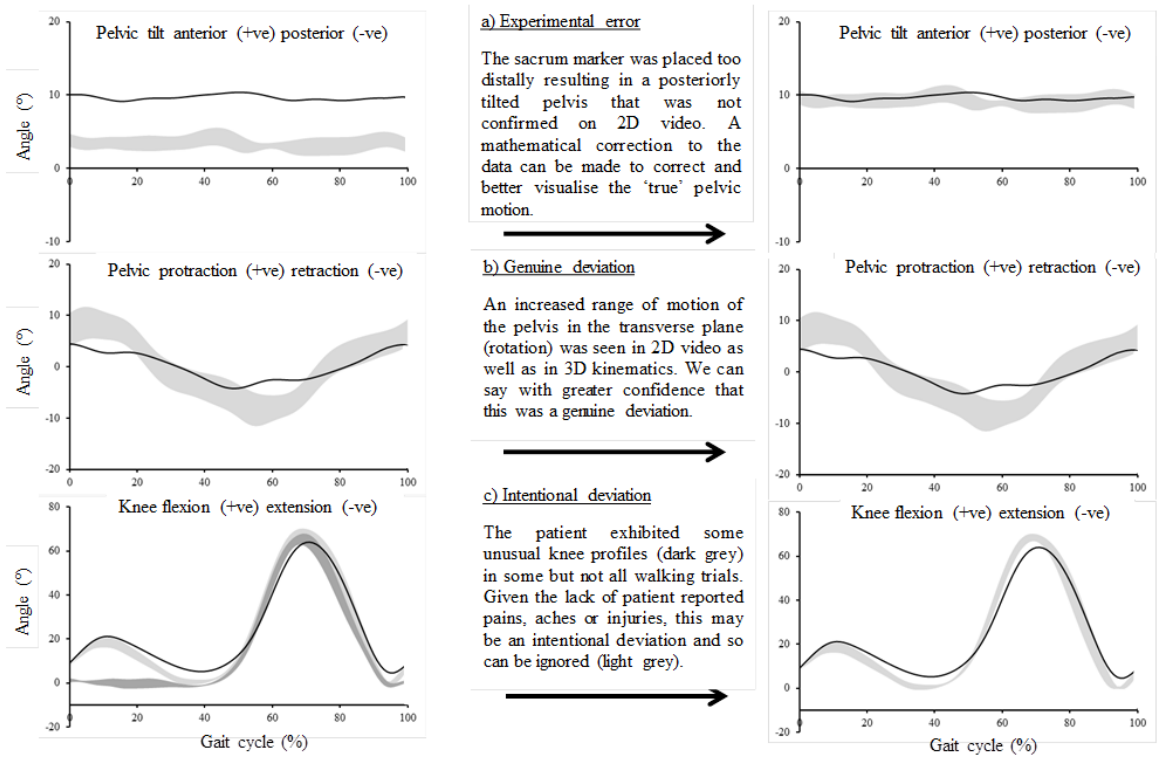
Pelvic tilt anterior (+ve) posterior (-ve)
Angle (°)
Pelvic protraction (+ve) retraction (-ve)
Angle (°)
Knee flexion (+ve) extension (-ve)
Angle (°)
Gait cycle (%)
a) Experimental error
The sacrum marker was placed too distally resulting in a posteriorly tilted pelvis that was not confirmed on 2D video. A mathematical correction to the data can be made to correct and better visualise the 'true' pelvic motion.
b) Genuine deviation
An increased range of motion of the pelvis in the transverse plane (rotation) was seen in 2D video as well as in 3D kinematics. We can say with greater confidence that this was a genuine deviation.
c) Intentional deviation
The patient exhibited some unusual knee profiles (dark grey) in some but not all walking trials. Given the lack of patient reported pains, aches or injuries, this may be an intentional deviation and so can be ignored (light grey).
Pelvic tilt anterior (+ve) posterior (-ve)
Pelvic protraction (+ve) retraction (-ve)
Knee flexion (+ve) extension (-ve)
Gait cycle (%)

Figure 2