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Measurement and management of errors in quantitative gait data

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Abstract

Gait analysis is a valuable tool in the evaluation of children and adults with movement disorders. The data produced from gait analysis, however, is not necessarily free of errors. The purpose of this study was two-fold: (i) to estimate the errors associated with quantitative gait data; and (ii) to propose a method for incorporating the knowledge of these errors into the clinical interpretation process. An experimental protocol was designed that allowed within-subject, within-observer and between-observer errors to be computed at each point in the gait cycle. The estimates were then used in a practical scheme for detecting significant deviations in joint angles. The results of this study provide a means for managing error, while simultaneously improving the rigor and objectivity of clinical interpretations.
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1. Introduction

Clinical gait analysis is the standard of practice for evaluating patients with gait abnormalities. The ability of clinicians to discern findings that are meaningful from those that are insignificant or artifactual is therefore essential. In most clinical laboratories, patient gait data is compared to the average response of able-bodied control subjects (control data). This data is often referred to as normal data. The control data provides a reference for the study of pathological gait patterns. Comparison of patient data to control data forms the basis for clinical decisions, as well as the standard by which the success of surgical intervention is measured. Consequently, the question frequently asked by clinicians is: "How many degrees does—have to deviate from the control before it is significant?" If experimental errors conceal important gait deviations, meaningful information will be lost. On the other hand, if the limitations of the method are not understood, small deviations may be considered meaningful, thereby leading to "over-interpretation".

Natural variability exists in the gait of able-bodied persons, and can be attributed to many factors including age,

height, and walking speed [1–4]. Natural variability, however, should not be confused with experimental error. Many specific sources of experimental error are widely known and well characterized. For instance, the effect of thigh coordinate system alignment on hip rotation, knee varus/valgus, and knee flexion/extension angles has been documented [5]. Overall experimental error has also been examined in recent studies. The work of Gorton et al. quantified errors arising within and between observers, laboratory sites, and commercial gait analysis systems [6]. The Gorton study exposed many unexpectedly large sources of experimental error. However, the study was not designed in a manner that allowed precise quantification of intra-subject, -observer and inter-observer errors. The errors in gait data inevitably lead to confusion over the proper diagnosis and course of treatment. Skaggs et al. studied this problem and found only slight to moderate agreement between physicians' interpretation of gait data [7]. It is likely that the differences in interpretation are due, at least in part, to the interpreters' inability to consistently separate those deviations that are statistically significant from those that are possible artifacts.

Two error estimates are germane to gait analysis: an estimate of the standard error of the control data and an estimate of the standard error of an individual patient's data. In clinical gait analysis, it is common to see the standard deviation

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4. Discussion

The errors in quantitative gait data were evaluated using a repeated measures experimental design and standard statistical analyses. The values presented here are only valid for the laboratory that was studied. A laboratory with a different number of persons involved in the clinical testing, a different set of testing protocols, or a different biomechanical model, would be likely to find somewhat different results. Nevertheless, the errors measured here show trends, and have general magnitudes, that are likely to be consistent across laboratories and commercial gait analysis systems. Furthermore, the methodology presented is widely applicable.

Using gait data to enhance clinical decision-making requires three distinct tasks. The first is to identify significant gait deviations. The second is to decide whether the deviations reflect primary pathology, secondary symptoms, or compensatory mechanisms. The third is to decide if and how the deviations can be treated. Among clinicians, there is considerable disagreement in the surgical decisions made using gait data [7]. This is due in large part to differences in treatment philosophy. However, the confounding effect of methodological errors and the lack of objectivity in assessing the significance of deviations certainly contributes to this inconsistency. Some of the most frequently used variables are also those that exhibit the greatest errors (e.g. hip rotation and foot progression for the planning of femoral and tibial derotational osteotomies). It is clear that the reduction of methodological errors must be a high priority in gait analysis. To reduce errors, however, it is first necessary to identify their source. Measuring inter-trial, -session, and -therapist errors aids in identifying the angles and portions of the gait cycle most susceptible to methodological shortcomings.

While improving accuracy is an important goal, accurate data is of little use if it is injudiciously interpreted. The point-by-point assessment approach gives an unbiased technique for identifying significant deviations during routine interpretation sessions. Clinical significance may then be subjectively judged, aided by the knowledge of statistical significance and inherent methodological errors. Clinical significance is often subjectively defined by a spectrum of factors including: functional changes in a patient's gait, changes in the desired direction of correction and the magnitude of the observed change. There is no objective way to decide on the clinical significance of a statistically significant finding. For example, modest improvements in mid-stance dorsiflexion may have statistical significance but not provide the patient with any tangible functional advantage. On the other hand, the same magnitude change during swing phase may allow the patient to attain foot clearance that was lacking prior to intervention. Evaluating statistical significance is therefore only the first important step necessary to make rational decisions based on quantitative gait data.

One important limitation of the proposed method is the use of point-by-point comparisons. The value of a joint angle at one time is not independent of values of that angle at other times. Several variables, including walking speed, can influence the magnitude, pattern and timing of joint angle data. It is, therefore, possible that what appears to be a deviation in magnitude may actually constitute a shift, contraction or dilation of the gait cycle. Time normalization reduces, but does not eliminate, this effect. The bootstrap method attempts to account for these effects in a more robust manner [8]. The bootstrap method generally produces larger (more conservative) error estimates than the point-by-point method. Another means for dealing with the interdependence of the data is to use a Bonferonni adjustment; assuming that each point in the gait cycle is influenced by every other point, or by some number of neighboring points [9]. As with the bootstrap method, the Bonferonni adjustment produces a more conservative estimate of significance. These methods differ almost exclusively in the computed degree of significance, not in the regions of the gait cycle identified as most deviant. Therefore, the question of interdependence comes down to the degree of certainty required to designate a deviation as statistically significant. Degree of certainty also influences the choice to report Type I versus Type II errors.

This study is similar to many statistical analyses in that the answer obtained depends partly on the way the question is asked. Regardless of whether or not statistical significance is computed, whether Type I or Type II errors are reported, or whether a $P < 0.05$ or $P < 0.01$ level is chosen for significance, the error estimates computed with this methodology reflect the reliability of the calculated gait data. If only for this reason, the method has value for the clinical gait community.

Technical advances will continue to improve the reliability and validity of gait data. The results described here quantify some strengths and weaknesses of the standard clinical gait model. In doing so, they provide a valuable means for directing quality assurance and model improvement efforts. The use of error estimates in clinical gait analysis can improve the rigor and objectivity of clinical interpretation by shifting the focus to gait deviations that exceed the level of experimental uncertainty.

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