Gait & Posture 39 (2014) 1005–1010

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Review

Summary measures for clinical gait analysis: A literature review

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ARTICLE INFO

Article history:
Received 28 June 2013
Received in revised form 28 January 2014
Accepted 2 February 2014

Keywords:
Gait analysis
Summary measures
Outcome
Locomotion

ABSTRACT

Instrumented 3D-gait analysis (3D-GA) is an important method used to obtain information that is crucial for establishing the level of functional limitation due to pathology, observing its evolution over time and evaluating rehabilitative intervention effects. However, a typical 3D-GA evaluation produces a vast amount of data, and despite its objectivity, its use is complicated, and the data interpretation is difficult. It is even more difficult to obtain an overview on patient cohorts for a comparison. Moreover, there is a growing awareness of the need for a concise index, specifically, a single measure of the 'quality' of a particular gait pattern. Several gait summary measures, which have been used in conjunction with 3D-GA, have been proposed to objectify clinical impression, quantify the degree of gait deviation from normal, stratify the severity of pathology, document the changes in gait patterns over time and evaluate interventions.

Introduction

Three-dimensional instrumented gait analysis (3D-GA) provides comprehensive data on normal and pathological gait, which are useful in clinical practice and scientific purposes because they provide objective information about joint motions (kinematics), time-distance variables (spatio-temporal data), and joint moments and powers (kinetics). It has been widely demonstrated that 3D-GA is an important method that is used to obtain crucial information for the determination of the level of functional limitation due to pathology and for its follow up evaluation over time. Furthermore, it can help to evaluate the rehabilitative intervention aimed at reducing the functional limitation due to pathology. However, a typical 3D-GA evaluation produces a vast amount of data, and despite its objectivity, makes it an instrument that is sometimes complicated to use and difficult to interpret. Specifically, comparative overviews are difficult. There is currently a debate regarding how to best use these data; for example, there is a perspective that the volume of information produced by 3D-GA could be an obstacle for its clinical use. Given the importance of 3D-GA in the management of many populations with movement disorders and because clinical decisions are generally also based on an interpretation of the complex information contained in these data, considerable attention should be directed towards GA data.

Within the last decade, there has been a growing clinical awareness of the need for a concise index, specifically, a single measure of the 'quality' of a particular gait pattern. Several gait summary measures, when used in conjunction with 3D-GA, have been proposed and used to objectify clinical impression, quantify the degree of gait deviation from normal, stratify the severity of pathology, document changes in gait over time and evaluate interventions.

The aim of this review is to summarise the studies on the most important and widespread summary parameters proposed by the literature, focusing on studies proposed for clinical applications and discussing the advantages and limits of these parameters.

Methods

To provide a comprehensive overview on gait summary measures, an electronic literature search was performed within the MEDLINE, CINAHL, EMBASE and Journal Citation Reports databases for articles published in english until December 2012 using the following keywords: locomotion, gait analysis, gait summary measures and biomechanics.

Results

From our research, only studies concerning gait summary measures were considered. The first attempt to define a summary measure was performed in 1979 by Tibarewala and Ganguli [1].

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http://dx.doi.org/10.1016/j.gaitpost.2014.02.001

In healthy adult males, a number of gait curves defined as "normal" gait curves were selected, and a "gait abnormality index" was developed to be used as a quantitative measure of human performance in locomotion, which would be suitable for application in pathological states. Some years later, a computer algorithm was developed to determine the group of electromyographic profiles for the soleus muscle during free speed-level walking in healthy individuals [2]. Next, Kerrigan et al. proposed two indices based on the pattern of the trunk during gait: the vertical displacement of the sacrum during walking [3], which was proposed as an estimation of the overall biomechanical performance of walking, and the biomechanical efficiency quotient (BEQ), which was computed from the average stride length, vertical displacement of the trunk during walking and sacral height during standing [4].

However, after these attempts, which remained isolated, most studies concerning summary measures for 3D-GA and their application in pathological states began in 2000 with the normalcy index [5]. For this reason, we begin our in-depth analysis from Schutte's study. Specifically, for each parameter, beginning from Schutte's study to the most recent study, a brief description is given of the data reduction technique used for the computation, the potential weaknesses/strengths and the main clinical/scientific experiences.

Normalcy index (NI) or gillette gait index (GGI)

The first index that enabled the characterisation of a patient's gait in a global sense with a widespread clinical acceptance is the normalcy index (NI) or gillette gait index (GGI) [5]. It uses multivariate statistical methods to quantify the extent by which a patient's gait deviates from that of an unimpaired control group. The NI is computed using standard multivariate statistical techniques (principal component analysis) applied to 16 3D-GA variables and. in particular, three temporal-spatial parameters (percentage of stance phase, normalised velocity and cadence) and 13 kinematic parameters (mean pelvic tilt, range of pelvic tilt, mean pelvic rotation, minimum hip flexion, range of hip flexion, peak abduction in swing, mean hip rotation in stance, knee flexion at initial contact, time of peak knee flexion, range of knee flexion, peak of dorsiflexion in stance, peak of dorsiflexion in swing and mean foot progression angle). The sum of the square of these 16 independent variables is interpreted as the deviation of the subject's gait from normal. Using this statistical method, it is possible to measure and represent as a single number the deviation of a pathological gait pattern from a normal average profile. Thus, the NI indicates the amount by which a subject's gait deviates from an average normal profile.

The NI appears to be the most extensively validated and commonly cited parameter and is widely used in clinical gait research and practice [6,7]. In particular, its use has been widely validated in cerebral palsy (CP) and idiopathic toe walker populations [5,8]. It has been shown to be effective when used to evaluate the range of pathology present in specific diagnoses, to compare a subject's gait to that of others with the same diagnosis, to track a subject's gait pathology over time, or to examine the effectiveness of an intervention.

Use of the NI to quantify the effects of specific treatments in children with CP has provided evidence that this index represents a valid instrument to quantify the effects of treatments that have a global effect on gait pattern, similar to multilevel orthopaedic surgery [9] and selective dorsal rhizotomy [8]. However, the NI did not exhibit the appropriate specificity and sensitivity when evaluating the effects of targeted interventions, such as AFO [10].

Moreover, the use of the NI in other pathological states, such as in children and adolescents with tumours in the central nervous system (CNS) [11], adults with a diagnosis of central nervous system pathology [12] and adult lower limb amputees [13], have shown that NI could also be used in these pathologies despite some limitations mainly due to the parameter choice [12].

Regarding concerns of the NI limits, a number of limitations have also been observed, and there has been a significant debate about the validity of this method [14]. First, these limitations include the arbitrary, unbalanced, and incomplete nature of the 16 univariate parameters that comprise the index. Their selection was driven largely according to the gait experience in CP but partly by convenience. The presented 16 variables are the 'best effort' of the authors. However, one can conclude that other 'better' sets of variables may be found. Second, the selected parameters included only kinematic variables; it is well known that the inclusion of kinetic variables is useful for a complete gait pattern assessment and in planning intervention. Third, only the characteristic points of the curves are included. These all make up a strong limitation.

According to the computation method, the NI requires an able-bodied gait dataset to establish the means and variance values of the control in each of the variables, and it was found to be strongly sensitive to lab-specific control data. McMulkin and MacWilliams [15] reported a high variability in the values of the NI when different normal populations from different labs were used, when applied to both normal adult individuals and to some patients with CP. They assessed the variation in the calculated NI values with different sets of control data. Differences in the underlying control data generated large differences in the computed NI values for both the pathological and able-bodied subjects. While the NI was shown to be reliable within a single control dataset, it is unknown to what extent its values may differ when using different underlying control sets. Another challenge connected to the NI is the question of whether there is a minimum sample size required in the set of control subjects in order to have a reliable NI tool. If all 16 principle components were used, a minimum of 40 controls were required to achieve an error of less than approximately 20%, and 96 controls were needed for an error less than 10%. Alternatively, using only those principal components that represent 95% of the variance may provide NI values that are more accurate with smaller control sets. However, caution must be taken when using the NI, as even with greater than 40 controls, the differences in the NI score for an individual CP subject may be as high as 150 based solely on the control set.

Hip flexor index (HFI)

Starting from the strong limitation of the NI, which is the inclusion of only the kinematic variables, a new index was developed considering the principal component analysis applied to five kinematic and kinetic variables: maximum pelvic tilt, pelvic tilt range, maximum hip extension in stance, percentage of stance phase in which the final crossover of the hip flexor moment curve from extension to flexion occurs—'timing of crossover'—and peak late stance hip flexor power. A single index number was derived, which accurately describes the overall hip function during gait [16]. Importantly, this does not belong to the same category of GGI (and of the next summary measures) due to its clear focus on a single joint/anatomic level.

The HFI is a valid tool that is used to objectify clinical impressions of a change in hip function and might thereby assist researchers with statistical and outcome analyses of interdependent and redundant gait variables. The HFI measure of postoperative change in hip function corresponded well with the subjective clinical outcome 75% of the time. However, importantly, the main limit of this index is that it is too joint-specific; a change in hip flexor function toward 'normal' may or may not signify a global improvement in the patient's gait. No correlation was made