Gait & Posture 29 (2009) 526–529

Contents lists available at ScienceDirect

Gait & Posture

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

GCMAS Best Poster Award 2008

Effect of sample size and reduced number of principle components on the Gillette Gait Index☆

Kirsten Tulchin *, Scott Campbell, Richard Browne, Michael Orendurff

Texas Scottish Rite Hospital for Children, Movement Science Laboratory, 2222 Welborn Street, Dallas, TX 75219, USA

ARTICLE INFO

Article history:
Received 24 June 2008
Received in revised form 23 December 2008
Accepted 6 January 2009

Keywords:
Gait analysis
Gillette Gait Index

ABSTRACT

The Gillette Gait Index uses principle components analysis of 16 variables to determine the deviation of an individual's gait compared to a normal control set. Previous literature has not reported on the effects of altering the size of the control set used to create the principle components, or described the effects of using less than the maximum number of principle components, 16, to calculate the Gillette Gait Index (GGI). Calculations of the GGI were determined for a group of 24 able-bodied normal subjects and 24 cerebral palsy subjects using 128 control subjects allotted into 15 subsets of varying sizes, from $N = 16$–128. A minimum of 40 controls were needed for GGI estimates to achieve less than approximately 20% error, and 96 controls were needed for less than 10% error, if all 16 principle components were used. With smaller control sets, an alternative method to increase the accuracy would be to use only those principle components that represent 95% of the variance. Caution must still be used when describing differences in GGI among groups, or changes in an individual's GGI over time. In addition, absolute changes in GGI should always be reported, as differences as great as 150 were seen in cerebral palsy patients across control groups, even when greater than 40 controls are used to create the principle components.

1. Introduction

The Gillette Gait Index (GGI), based on principle components analysis, was proposed in 2000 by Schutte et al. [1] to quantify the deviation of a patient's gait based on 16 kinematic and temporal/spatial gait parameters, relative to a normal control group. Principle components analysis provides two advantages: (1) it reduces a large number of variables in a dataset to a set of one or more linear combinations of those variables and (2) these linear combinations are uncorrelated to each other. The GGI has been correlated to a number of other assessment tools as well as the observational analysis of walking [2,3]. There has been significant debate on the validity of this tool. Bothner et al. [4] reported that a change of at least 85 in the GGI was required to assure that change occurred in cerebral palsy patients with 95% confidence. McMulkin and MacWilliams reported high variability in the values of the GGI when different normal populations from different labs were used, when applied to both a normal adult patient and to a series of three cerebral palsy patients [5]. Wren et al. [6] found differences in the GGI calculation based on how the specific subject's data was used, such as analysis of a single representative trial versus an ensemble of three trials.

Previous literature on the GGI used all 16 principle components, which therefore account for 100% of the variance in the original 16 variables. However, the number of principle components used in other applications is often less than the maximum number, and is based upon a desired percentage of variance explained [7]. In linear regression, the inclusion of redundant variables is known to cause major instability in the estimates of the regression coefficients. Including principle components that only add a trivial amount to the percent of variance explained may lead to a similar instability of the results. It is unclear what effect using fewer than 16 principle components may have on the value of an individual's GGI.

Little, if any, literature has addressed the question of whether there is a minimum sample size needed in the set of control subjects in order to have a reliable GGI tool. The hypothesis of this study was that the number of control subjects used in the calculation of the principle components can substantially affect the values of GGI for pathological populations, and that there is a minimum number needed to ensure a reasonable effectiveness of the GGI.

Therefore, the aims of this study were to: (1) describe the effects on the GGI of altering the size of the control set used to create the principle components, (2) determine the minimum number of controls needed to assure an accurate GGI in a patient population,

☆ Gait and Posture is the official journal of the Gait and Clinical Movement Analysis Society. The work presented in this manuscript won the "Best Poster Award" at the 2008 annual GCMAS conference.

* Corresponding author. Tel.: +1 214 5597580.
E-mail address: Kirsten.Tulchin@tsrh.org (K. Tulchin).
URL: http://www.tsrhc.org

0966-6362/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.gaitpost.2009.01.004

and (3) describe the effects of using less than the maximum number of principle components for the GGI by applying the amount of variance explained as the criteria for determining how many principle components to use.

2. Methods

2.1. Subject data sets

Data for 152 able-bodied healthy subjects ages three through adult were selected at random from a pre-existing controls database in the authors' gait laboratory. To assess the effect of the number of control subjects on the GGI, 15 sets of control subjects were created (control subsets). The first set consisted of $N = 16$ subjects. The second set added eight subjects at random to the previous 16 subjects, creating a set of $N = 24$. Subjects were continually added in groups of eight at random to the prior set, and subsets of $N = 32, 40, \ldots, 128$ were created. The remaining 24 subjects from the original 152 were retained as a separate group (normal group) to be used in later testing, and were not used in computing any principle components. The STATISTIXL© software add-in for Microsoft Excel was used to compute the principle components for each of the 15 subsets.

In order to assess the variability of the 16 raw gait measures as the number of controls used in calculating the GGI increased, the mean and standard deviation of each variable was computed for each control subset. Summations of the means and standard deviations across the 16 variables for each subset were used to calculate an overall coefficient of variation (CV) for the subset.

In addition, 24 subjects with a diagnosis of cerebral palsy were randomly selected from a database of patients who were previously seen in the gait laboratory for clinical referral (CP group). All cerebral palsy subjects were independent ambulators and had no surgical intervention within the 12 months prior to their gait analysis.

2.2. Effect of the number of control subjects

The GGI was calculated for the subjects in the normal group and the CP group using the principle components computed using each of the 15 control subsets. In addition, the GGI was calculated for each of the control subjects used to compute the principle components. For example, an individual GGI was calculated for each of the 16 controls used to compute the principle components for the $N = 16$ subset.

Based on the 16-variable model used for the GGI, the expected value for the control subsets was $16 \times (n - 1)/n$, where n = the number of control subjects used in the principle component calculation, which is asymptotically equal to 16 [5]. For the CP group, the expected GGI value for each subject was estimated as the calculated GGI using the control subset of $N = 128$. Changes in the calculated GGI across control subsets were evaluated, as well as the percent difference between the expected GGI and the calculated GGI.

To assess repeatability, the 128 controls used in the 15 subsets were divided into two groups of 64 controls. The above procedures were followed for the seven control subsets of $N = 16, 32, \ldots, 64$ within each group. For each of the 24 CP subjects, the difference between the GGI calculated from each of the two groups was calculated. The maximum individual difference within the CP group was determined for each of the seven subsets.

2.3. Effect of using fewer principle components to calculate the GGI

To assess the effect of using less than all 16 principle components (or accounting for 100% of the variance), the percent of explained variance was used to exclude the principle components with the least explained variance. GGI calculations for the CP group were calculated using only the principle components that accounted for 80%, 90%, 95% and 99% of the total variance. The number of principle components that explained these percentages of variance differed, depending upon the number of control subjects used in computing the principle components.

3. Results

The standard deviations seen across the 16 raw gait variables did not illustrate any trends of increasing or decreasing variability as the control subsets increased. The CV ranged from 19.9% to 20.9%. It should be noted that several gait variables had high CVs due to the relative small mean values, as in the mean pelvic rotation where mean values were between -1° and 0°, and standard deviations were approximately 3°.

The average GGIs for the 15 control subsets were asymptotic to 16 as the control subsets increased (Fig. 1). The average GGI ranged from 14.0 to 15.9 across the control subsets. In the normal group the mean GGI also approached 16 as the control subsets increased (Fig. 1), with the average GGI ranging from 23.4 to 16.5.

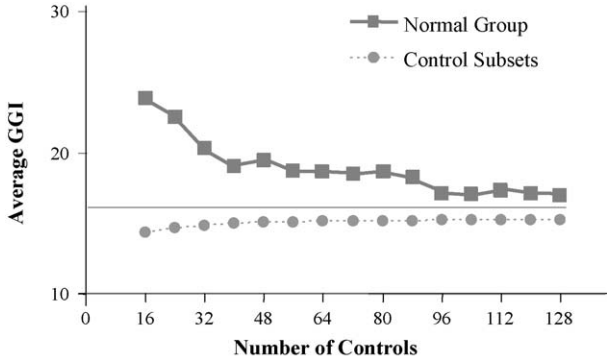

Fig. 1. Normal group and control subset GGI averages: the average GGI of the 15 control subsets, as well as the normal group, were asymptotic to 16.

In the CP group the average GGI ranged from 405 to 283, and approached a value of approximately 290 as the Control Subsets increased (Fig. 2). Similar to that seen with the normal group, the average GGI in the CP group decreased with increasing number of control subjects. The standard deviation across subjects also decreased as the control subsets increased and showed a trend towards leveling off at approximately 130.

Assuming that the expected value of the GGI in the normal population to be approximately 16, the percent difference between average GGI and expected GGI was calculated for the normal group across all control subsets. Two plateaus were seen, with the first occurring at approximately 40 control subjects (Fig. 3). The maximum percent differences between calculated and expected value for an individual was greater than 10% for all control subsets

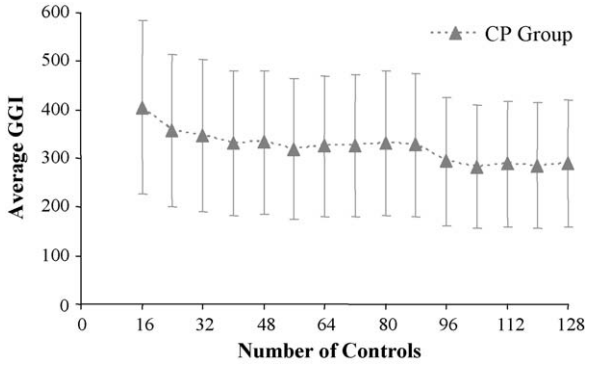

Fig. 2. The average GGI of the CP group leveled off at approximately 290 as the control subsets increased. Standard deviation bars are included to illustrate that some of the variability was due to differences in the severity of the gait disturbances within the CP group.

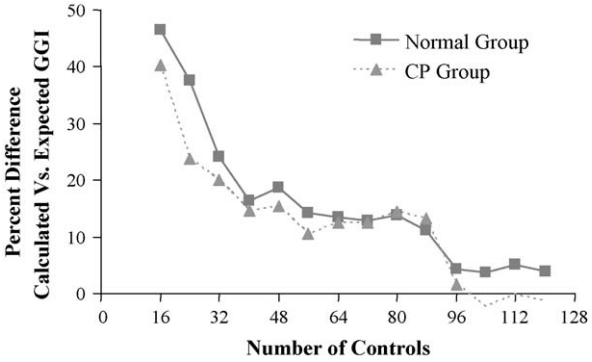

Fig. 3. Percent difference between expected and calculated GGI in the normal and CP groups followed similar patterns as the control subsets increased.