Evaluation of the VA-Rancho Gait Analyzer, Mark I

ABSTRACT—One hundred thirty-six normal subjects were studied using the VA-Rancho Gait Analyzer, Mark I. The objective of the study was to evaluate the Gait Analyzer calibrating function used to normalize the single limb support data. The results obtained from our normal population demonstrated a relationship of single stance time versus velocity which was different from that employed in the Gait Analyzer, especially at the slower gait velocities. This discrepancy was attributed to the difficulty in obtaining normal gait data at slow velocities and to the smaller population used to determine the calibrating function. Minor adjustments to the calibrating function when a larger data base becomes available will result in a more generally applicable calibrating function. It is concluded, however, that gait patterns which deviate considerably from the norm would be more appropriately described in terms of absolute measurements.

In recent years, gait analysis has evolved into a clinically useful method for evaluating patients with central and peripheral neuromuscular disorders (2,4,6,7,8,10,11,12), amputations (5, 13, 14), and total joint arthroplasties (1,3). However, economic, technical and space limitations preclude the establishment of gait analysis laboratories at all but a few large institutions throughout the country. The VA-Rancho Gait Analyzer, Mark I, was developed to provide quantitative measurements of gait while minimizing both initial expenditure and operating costs. In order to provide readily interpretable, normalized scores, the instrument has been calibrated with data from a normal population. It is of primary importance, therefore, that the normal population be accurately described. The objective of this study is to verify the calibration of this instrument by statistically comparing data obtained from normals in our surroundings to the normal data programmed into the Gait Analyzer.

Single stance time (SST) is the principal measurement parameter because it reflects (i) the patient’s ability to support load on each leg, (ii) the symmetry of gait when comparing right and left sides, and (iii) the degree of normal bipedal gait rhythm when examined in relation to velocity (4,6). The justification for examining free walking velocity, in addition to determining its relation to SST, is that it is an indicator of overall performance and efficiency of gait (1,6).

Instrumentation

The Gait Analyzer, Mark I, was developed by the Pathokinesiology Service at Rancho Los Amigos Hospital under a Veterans Administration contract. The instrumentation consists of footswitches, a manual or automatic start/stop controller, a waist-pack recorder, and a calculator. The footswitches are worn as insoles in the shoes and indicate when the foot is weight-bearing. The start/stop controller may be either manually or automatically operated and is used to initiate and stop recording of data for the
prescribed 6 meter walking distance. The manual control is a hand-held momentary pushbutton switch used by the operator who walks along with the subject. The automatic control consists of a photoelectric switch which is attached over the deltoid insertion and which is triggered by stationary light sources located at the start and end of the 6 meter walking distance. The recorder, which attaches to a waist belt, tallies the right and left foot-floor contact time information and records the elapsed time so that average velocity may be calculated for the 6 meter distance. The recorder is connected to the calculator following each run and the right and left single stance times as a percent of normal (%NSST), and the average velocity over the 6 meters, are calculated for each trial.

The calculator is programmed with a relationship between absolute SST and velocity determined by the Rancho Group for 43 normal male and female subjects (9). For each measured velocity the calculator internally determines the expected SST for a normal individual and uses that value to normalize the measured SST for the subject’s right and left sides following each trial. For example, in Figure 1 subjects A and B have the same absolute SST while walking at 40 centimeters per second and 108 centimeters per second, respectively. The measured SST for subject B is the same as the expected SST for a normal subject, yielding a %NSST of 100 percent. For subject A, however, the measured SST of 0.5 second, when compared to an expected SST of 1.1 seconds, yields a %NSST of 45 percent.

RESULTS

There were no significant differences between trials at a given speed for any of the three speeds and no difference between the %NSST for the right and left sides. As a consequence, the last trial at each speed was selected as representative of the subject’s performance at that speed, and the average of the right and left %NSST for each subject trial was employed in the analysis.

If the relationship between SST and velocity used to calibrate the Gait Analyzer were valid for our normal population, then the %NSSTs recorded from our subjects would be symmetrically distributed about a zero slope line at 100 percent. A linear regression of %NSST versus velocity for our subjects (Fig. 2), however, yielded a slope of .196 which was significantly different from the predicted zero slope (p(.0001). Thus, the relationship between absolute SST and the velocity for our total population differs significantly from the relationship used to calibrate the Gait Analyzer. As a consequence, the SST-versus-velocity relationship for our normal population was analyzed in greater detail. The %NSSTs measured for our normal population were converted into absolute SSTs using the inverse of the calibrating function which was made available to us by the Rancho group.

In addition to the Gait Analyzer calibrating function which reflects the SST-versus-velocity relationship of 43 males and females combined, Perry et al. (9) also determined calibrating functions for the female and male populations separately. The calibrating functions relating SST to velocity (v) which they found to be most suitable had the form

\[
SST = \frac{1}{a(v+b)^n-c}
\]

with \(a = .319, b = 21.4, \) and \(c = 1.48\) for the females and \(a = .267, b = 14.9, \) and \(c = 1.03\) for the males. These descriptions permit the comparison of the measured SSTs for our normal females and males to the respective values predicted by the Rancho group in the above equations.

Our data were compared with Perry’s by obtaining linear regressions between the measured SSTs and the expected SSTs predicted from the above equations for males and females, respectively. The slopes and intercepts of the regression lines for females and males were significantly different (p(.0001) from
FIGURE 1.
SST versus velocity for 43 normal males and females. Points A and B illustrate two subjects who walk at different velocities but have the same single stance time. Drawing is reprinted with permission from Perry et al. 1976 (Rancho Los Amigos Hospital). No. 9 in the "References" to this paper. (Copyright 1976)

FIGURE 2.
%NSST versus velocity for the combined population of 136 females and males. The dashed line at 100 percent represents the expected value for a normal group. The solid regression line illustrates the non-zero slope obtained for our population.

FIGURE 3.
Female measured SST versus expected SST as predicted by the relationship of Perry et al., 1976; using the coefficients \( a = 0.319, b = 21.4, c = 1.48 \). The broken line is the locus of complete agreement between the two variables and has a slope of one and intercept of zero. The solid regression line for the data has a slope = .654, intercept = .136 and \( r = .879 \).

FIGURE 4.
Male measured SST versus expected SST as predicted by the relationship of Perry et al., 1976; using the coefficients \( a = 0.267, b = 14.9, c = 1.03 \). The broken line is the locus of complete agreement between the two variables and has a slope of one and intercept of zero. The solid regression line for the data has a slope = .670, intercept = 144 and \( r = .899 \).

a slope of one and intercept of zero for the line showing complete agreement between measured and expected SSTs (Fig. 3 and 4). Since the measured SSTs were not in agreement with the expected values predicted from Perry's formulations, alternative relationships between SST and velocity were investigated.

For our normal females and males the correlation coefficients between SST and \( 1/v^x \) were determined for \( x = 2,1,0.5 \) and 0.25 (Table 1) and were found not to vary greatly for these four functions. Two mathematical functions were investigated as calibrating functions for our normal subjects; the
above equation as described by Perry et al. (9) and the same equation with the exponent changed from one-half to one. Using a minimum mean squared error criterion, Perry’s equation gave the better fits. The values for the coefficients for our normal females and males are listed in Table 2. Using these coefficients, linear regressions of predicted SST versus measured SST of our normal females and males both yielded slopes of one and intercepts of zero with correlation coefficients of .87 and .90, respectively. The male and female calibrating functions determined for our normals are plotted in Figures 5 and 6, respectively, along with the corresponding functions determined by Perry et al. (9). The major observable differences are that our calibrating functions demonstrate SSTs below those of Perry et al. (9) at the lower velocities and that our functions for both sexes are asymptotic at approximately 30 centimeters per second.

In addition to the analyses discussed above, the correlations between the variables of age, height and weight were examined versus SST. None of these variables were found to correlate with the measured SSTs.

**DISCUSSION**

Our results demonstrate that the calibrating function used in the Gait Analyzer, Mark I, was not valid for the combined female and male populations studied at our institution. Furthermore, when considered separately, a comparison of the SST versus velocity relationships for females and for males demonstrated similar deviations from the corresponding relationships determined by Perry et al. (9).

There are two major differences between the calibrating functions determined for our females and males and those determined by Perry et al. (9). First, SST differences of 19 percent and 17 percent exist at the lowest measureable velocities of 42 and 52 centimeters per second, respectively. Second, the calibrating functions determined for our normals are asymptotic at approximately 30 centimeters per second as compared to the formulations by Perry et al. (9) which theoretically will permit a gait velocity which approaches zero. A clear-cut explanation is not presently available to explain the discrepancy observed at the lower velocities, although two factors are felt to contribute to this lack of agreement. First, our combined population of 136 individuals is obviously much greater than the 43 females and males used by the Rancho group. Secondly, it is extremely difficult to obtain normal gait data at velocities less than 45 centimeters per second because individuals are not able to walk naturally at such low speeds. Consequently, to define a relationship between SST and velocity at the slower velocities it is therefore necessary to extrapolate the function into a range of velocities in which normal gait does not exist.

In addition to the differences in SSTs which exist at the slower velocities, the asymptotes of our calibrating functions theoretically suggest that the SST-versus-velocity relationship does not exist below 30 centimeters per second for either sex—i.e., forward progress at velocities less than 30 centimeters per second cannot be considered walking.

Thus, there is a dilemma. Pathological gait is frequently observed at velocities below the range of normal gait; i.e., below the lower limit of 40 centimeters per second experienced during this study.
and also below the theoretical minimum of 30 centimeters per second predicted by our calibration function. We feel it is inappropriate to provide normalized measurements in a velocity range where normal gait does not exist. It would be more appropriate in these instances to provide measures of absolute SSTs such that various gait pathologies may be individually described. It is not necessary to provide normalized measurements for all gait abnormalities. However, it should be understood that it is extremely useful and convenient to have normalized measurements in the majority of cases.

TABLE 1.
Correlation coefficients between SST and $1/v^x$ for four values of $x$.

<table>
<thead>
<tr>
<th>$x$</th>
<th>2</th>
<th>1</th>
<th>0.5</th>
<th>0.25</th>
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<tr>
<td>Females</td>
<td>.86</td>
<td>.88</td>
<td>.87</td>
<td>.87</td>
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<tr>
<td>Males</td>
<td>.88</td>
<td>.89</td>
<td>.89</td>
<td>.88</td>
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TABLE 2.
Coefficients determined for normal males and females.

<table>
<thead>
<tr>
<th></th>
<th>$a$</th>
<th>$b$</th>
<th>$c$</th>
</tr>
</thead>
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<tr>
<td>Females</td>
<td>.18</td>
<td>-29.4</td>
<td>-.67</td>
</tr>
<tr>
<td>Males</td>
<td>.155</td>
<td>-30.1</td>
<td>-.664</td>
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REFERENCES