Variability of Electromyographic Patterns for Level-Surface Walking through a Range of Self-Selected Speeds a

ABSTRACT—The surface electromyographic patterns of eight muscles and the foot-contact patterns exhibited by 25 normal persons between the ages of 20 and 40, were measured and studied. These persons were walking indoors on a level surface without shoes at several different self-selected walking speeds. The electromyographic patterns demonstrated a considerable amount of interindividual variability at each speed. There were definite trends in the number of individuals exhibiting each pattern type as walking speed increased. The foot-contact patterns showed a consistent sequencing of foot events at all speeds with the double-limb support stages and stance phase comprising a smaller percentage of the gait cycle as speed increased.

INTRODUCTION

Many investigations have been undertaken to study electromyographic (EMG) patterns during level walking. The major emphasis has been directed toward finding commonalities in patterns. The concepts and results have been summarized by Eberhart, et al. (1), Basmajian (2), and Perry (3). A partial compilation of the classical results is shown in Figure 1, which is an excerpt from Eberhart (1).

Population variabilities in EMG patterns have been noted (4,5), but more recently attention has been directed toward this fact (6,7,8,9). Paul has compiled the results of several reported investigations and demonstrated some significant disagreements on the phasings of particular major muscle groups including the quadriceps and hamstrings (7). The apparent disagreements may be attributed either to differences in investigatory protocol and EMG processing techniques or to actual interindividual (population) variations. The wearing of shoes, the type of walking, and the attempts to control speed or stride time are all experimental variables which can affect walking conditions. Walking speed is an experimental parameter which is critical and must be well defined or controlled. Several investigators have shown in small-sample studies that the phasing of activity in some muscles does change with walking speed (10,11,12). This can be expected since floor reaction forces and center of gravity dynamics are a function of walking speed (13,14,15).

Knowledge of the population variability of EMG patterns and how they are affected by walking speed is important. These normative data can provide a comparative basis for evaluating patients having locomotor disabilities (4,16). This leads to two major questions: What are the EMG patterns that can result in normal locomotion? How are these patterns affected by speed of progression? The need for answering these questions has been
discussed at conferences and workshops (17,18).

The object of the investigation reported herein was to study the population variability of electromyographic patterns in the normal adult population and to ascertain any changes that occurred as a function of different self-selected walking speeds.

**METHODS**

**Measurements**

The electromyographic and foot-contact patterns of 25 normal subjects ranging between 20 and 40 years of age were measured and studied. None had any history of neuro-musculo-skeletal disorders and all were active wage-earners or students. There were 13 females and 12 males in the group and their height and weight statistics appear in Table 1.

![Diagram of EMG patterns](image)

**FIGURE 1.** Electromyographic Gait Patterns. The average EMG patterns of several muscle groups is plotted as a function of normalized time. This data is from Eberhart (1).

The electromyograms of the eight muscles listed below were measured using miniature Beckman surface electrodes in a bipolar arrangement. The electrodes were connected to the differential amplifiers of an eight-channel Bio-Sentry telemetry system. The amplifiers have an input impedance of 500 kΩ and a common mode rejection ratio of 58 dB. Each output channel was filtered to remove motion artifact and high-frequency noise, using bandpass filters with cutoff frequencies of 40 Hz and 400 Hz. In addition, for each channel the integrated EMG was formed using a full-wave rectifier and Paynter filter with an integration period of 6 ms (19).

The electrode sites were found by palpating the muscle during a voluntary contraction and locating the portion of muscle presenting the largest surface area. The exception was the soleus; the electrodes were placed over the distal one-third of the muscle. The skin was always cleaned thoroughly with alcohol before electrode placement. The placements were tested for accuracy, “cross talk,” bad connections, etc. by requesting the subject to perform several test movements (e.g., voluntary contractions of a selected muscle vs. neighboring muscles) and a test walk. If any apparent malfunction was found, corrective action was taken and the test repeated. By careful placement of miniature electrodes, tests for cross-talk, and rejection of suspicious data, electromyographic patterns were obtained on individual muscles.

**TABLE 1.** Average and Standard Deviation of Subjects’ Height (HT) and Weight (WT)

<table>
<thead>
<tr>
<th></th>
<th>HT (cm)</th>
<th>WT (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females</td>
<td>160 ± 8.2</td>
<td>55.8 ± 5.3</td>
</tr>
<tr>
<td>Males</td>
<td>174 ± 6.9</td>
<td>72.8 ± 9.9</td>
</tr>
</tbody>
</table>
The foot-contact patterns were measured without shoes using footcovers and a B&L Engineering Foot-Pattern Telemetry System. The footcovers consist of elastic stockings worn over the subjects' bare feet. Conductive rubber soles are glued to the stockings, and metal contacts are fastened at the appropriate points on the bottom of the sole using double-sided adhesive tape. (The tape not only holds the contact in place but also insulates it from the conducting sole; a circuit terminating in a contact is activated when the conducting surface of the walkway electrically connects that metal contact and the rubber sole.) The footcovers fit securely and comfortably, and subjects did not perceive any risk of slipping.

The subjects walked indoors on a metal-covered walkway which is 8 meters long. An electric eye system demarcated the middle 5 meters of the walkway; only the data recorded within that middle section was studied. (The electric eye system placed an impulse on the chart recorder whenever one of its two beams was transgressed.) The time of travel between the two beams was used to calculate walking speed.

All measurements were recorded on a 14-channel Hewlett-Packard analog magnetic tape recorder and a Consolidated Electronics oscillographic recorder. The specific protocol was:

1. Electromyograms of the following muscles on the right lower extremity were measured: tibialis anterior (TA), peroneus longus (PL), gastrocnemius (GAS), soleus (SOL), rectus femoris (RF), vastus lateralis (VL), medial hamstring (MH), and gluteus medius (GM).
2. Foot-contact patterns of both feet were measured simultaneously.
3. Each subject, after being fully instrumented, made several traverses of the walkway in order to become acclimated to the experimental setting.
4. Each subject was requested to walk at his preferred free, fast, slow and very-slow walking speeds on the walkway. (A specific subject reproduced each of his or her chosen speeds very closely.) Several traverses of the walkway at each speed were required in order to ensure that measurements of all signals were made for a minimum of 10 full gait cycles, i.e., 10 strides. Two sets of measurements were made at each speed because the Bio-Sentry System has only five EMG channels. The EMG from the tibialis anterior and gastrocnemius muscles were recorded during both sets to check that the subject was walking with consistent patterns.

Analysis

The kinetic parameters of speed, stride length, and stride frequency (strides/second) were calculated for men and for women and compared with parameter values in the existing literature. Since height has been shown to be an important factor, these parameters will be presented mainly in terms of relative speed (speed/height) and relative stride length (stride length/height) (21).

A normal person walking at a constant speed demonstrates a very consistent gait pattern with only slight stride time variations. The typical range of variations is 3 percent of a person's average. A few persons had a 5-percent range but only while walking at very-slow speeds. Because of this, the data from the cycle whose stride time was closest to the subject's average was selected to represent that person's pattern.

A muscle was considered to be active when its integrated EMG exceeded a threshold level. This threshold was chosen as that level which is 10 percent greater than the peak magnitude of the background noise. Any EMG measurement which was contaminated with 60 Hz noise or with "crosstalk" from another EMG was eliminated from the study. (This mostly happened with the thigh EMG.) Nevertheless, for each muscle there remained a minimum of 20 eligible patterns from the 25 subjects. The foot-contact patterns and the times of onset and cessation of all muscle activities were measured from the time of initial contact and normalized by the stride time.

The population averages for each speed designation were achieved by averaging the normalized event times from the individual gait patterns. For instance, the average time of initial contact of the fifth metatarsal was calculated by averaging the normalized times of initial contact for all subjects. The population EMG patterns were calculated in the same manner except that the individual patterns were first classified according to their general characteristics. Characteristics used to classify the patterns were features such as monophasicity, biphasicity, duration of activity, etc.

The system measures when the heel, head of 5th metatarsal, head of 1st metatarsal and large toe make contact with the walking surface. These are encoded as deflections of 1, 2 and 4 units, and oscillation of 1 unit, respectively. Several parts in contact result in a simple sum of units.
Terminology

There is a standard nomenclature which divides the gait cycle into stance and swing phases of the reference lower extremity and further describes these phases. The stance phase is described by the times of specific events. These are: initial-contact, foot-flat, midstance, heel-off and toe-off. The swing phase is divided into time spans which denote acceleration (early-swing), mid-swing, and deceleration (late-swing) of the limb (22). Using this nomenclature to describe the muscular synergy patterns is cumbersome because of the mixed style; event descriptors are usually used in stance phase whereas time spans are used in swing phase. It is more convenient to utilize time spans for describing patterns, therefore the stance phase is subdivided into time spans bounded by event times. (Dubo, et. al., (23) also found this necessary, and a revised terminology was adopted during a recent workshop on Gait Analysis (24).) The stance phase consists of:

1. A loading stage, which extends from initial-contact to the end of double-limb support (DLS);
2. An initial midstance stage, which extends from the beginning of single-limb support (SLS) to the time when the body is over the supporting limb;
3. A terminal mid-stance stage, which endures for the remainder of SLS; and
4. An unloading or preswing stage, which coincides with the second DLS stage.
RESULTS

Kinematic Parameters

The statistics for the speeds of walking for the four self-selected speeds are listed in Table 2. The relative stride lengths and stride frequencies are graphed in Figures 2 and 3, respectively. Note that the range of self-selected speeds used by the subjects does not extend to the full range of relative speeds of which people are capable (26).

TABLE 2.
Averages and Standard Deviations of Speeds for Males and Females

<table>
<thead>
<tr>
<th>RELATIVE SPEED (SEC⁻¹)</th>
<th>Very-Slow</th>
<th>Slow</th>
<th>Free</th>
<th>Fast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>.25 ± .08</td>
<td>.39 ± .07</td>
<td>.56 ± .13</td>
<td>.80 ± .16</td>
</tr>
<tr>
<td>Females</td>
<td>.23 ± .08</td>
<td>.41 ± .10</td>
<td>.61 ± .10</td>
<td>.81 ± .11</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ACTUAL SPEED (M/S)</th>
<th>Very-Slow</th>
<th>Slow</th>
<th>Free</th>
<th>Fast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>.43 ± .14</td>
<td>.68 ± .13</td>
<td>.98 ± .21</td>
<td>1.39 ± .29</td>
</tr>
<tr>
<td>Females</td>
<td>.37 ± .12</td>
<td>.66 ± .16</td>
<td>.98 ± .14</td>
<td>1.31 ± .17</td>
</tr>
</tbody>
</table>

Foot-Contact Patterns

The foot-contact patterns for 23 of the 25 subjects had identical sequencing at all walking speeds. The onset sequence was heel, fifth metatarsal, first metatarsal, and toe. The offset sequence followed the same order. (In Figure 4 is shown one of these patterns.)

The two exceptions were subjects DB and RS. DB had a bilateral equinus gait and as a result had the fifth metatarsal contacting before the heel at all speeds. RS had a valgus right foot; the first and fifth metatarsal onset events were simultaneous at all speeds. These latter patterns were grouped with the predominant patterns for statistical calculation, since these two subjects had neither abnormal medical histories nor conspicuously different EMG patterns.

The population averages of the bilateral foot-contact patterns for all subjects while walking at very-slow, free, and fast speeds are shown in Figure 5. (All patterns for slow speeds were omitted from the figure for the sake of conciseness.) Males and females are not treated separately since their statistics are the same. The variability of event times for the right foot is depicted by the double-headed arrow centered around and located below the event occurrences. Most of the events have a small variation. The exceptions are the toe-contact and heel-off events.
As walking speed increases, there are certain trends in the different phases of the gait. Figure 6 summarizes these trends.

Electromyographic Gait Patterns

The subject population averages for the EMG patterns measured at very-slow, free, and fast walking speeds are shown in Figure 7. The average speeds (S) and stride times (ST) for each speed are printed on the bottom of the graphs. The double-limb (DLS) and single-limb (SLS) support of stance phase (and the swing phase) are shown on the same line which designates percentages of the gait cycle.

There is a great amount of interindividual variability at each speed as well as changes in the pattern types as speed changes. Thus, the main characteristics of each muscle's activity are classified into primary and secondary major patterns. The percentage of subjects having a particular major pattern at the designated speed is denoted by the number located to the right of that pattern. The primary patterns are plotted above the secondary ones. Not all subjects in a particular primary or secondary group demonstrated that group's entire pattern exactly. Such a variation, typically in the form of an additional period of EMG activity, is plotted in Figure 7 as a dashed line; the number printed directly above or below the dashed line indicates the percentage of subjects (relative to the number in the group) who demonstrated that variation. Note that percentages for the patterns equal 100 percent except for those of the leg muscles in Figure 7a. At very slow speed, two subjects had very conspicuously different patterns, as will be described below.

a. Tibialis anterior. The tibialis anterior is active both during the stance-to-swing and the swing-to-stance transitional stages. In approximately 25 percent of the subjects it was also active during a portion of midstance. During very-slow speed walking the TA was monophasic while during faster speeds it could be multiphasic.

b. Peroneus longus. The peroneus longus is primarily active during stance phase. Transitional stage activity is variable but becomes more prevalent as walking speed increases.

c. Gastrocnemius. The gastrocnemius is mainly a stance phase muscle. As walking speed increases it tends to become active earlier during stance phase, and actually becomes active during the late-swing at fast speeds. Stance-to-swing transitional stage activity accompanies the earlier onset of activity and when it is present it forms a second period of activity.

d. Soleus. The qualitative behavior of the soleus is the same as that of the gastrocnemius except that there is no stance-to-swing transitional activity.

e. Hamstring. The hamstring is mainly active during the late-swing, loading, and initial midstance stages. In some subjects there is a second period of activity during the stance-to-swing transitional stage. A trend exists toward a shorter period (or absence) of activity during late-swing at slower walking speeds.

f. Rectus femoris. The rectus femoris is always active during the late-swing, loading, and initial midstance stages. In approximately 25 percent of the subjects this period continues throughout midstance. Among another 50 percent of all subjects, a second period of activity occurs during the stance-
to-swing transitional stage.

g. **Vastus lateralis.** The vastus lateralis is also mainly active during the late-swing, loading, and initial midstance stages. In a minority of subjects there is also activity during the stance-to-swing transitional stage. At very-slow and free walking speeds this is observed as two separate periods of activity. However, at fast speeds the two periods are merged and one long period of activity is observed.

h. **Gluteus medius.** The gluteus medius is mainly a loading and midstance stage muscle. This period of activity extends into the late-swing stage for some subjects. As walking speed increases this lengthened period is more prevalent. A second period of activity during the stance-to-swing transitional stage occurs in a minority of subjects. Its prevalence also increases with walking speed.

Two subjects, RW and MS, had EMG patterns that were vastly different from those presented for the legs during very-slow speed walking. These patterns showed reciprocal bursts of activity between the plantarflexor and the dorsiflexor muscles. (Figure 4 shows the pattern for subject RW.) Even though the peroneus longus is active during the 55 percent to 60 percent period of the gait cycle, its intensity was greatly reduced.

Because of the diversity and trends in the EMG patterns, it was decided to test the correlation of any pattern type with sex. A 2 X 2 contingency table was made for every pattern type at each walking speed.

Table 3 shows the frequency of occurrence data for the soleus muscle at free speed. This table is testing whether or not males are more prone to exhibit activity during the loading stage. A modified chi-squared test was used to test the statistical significance of any correlation (25). None of the correlations were statistically significant at the 5 percent level.

### TABLE 3.
Frequency of Occurrence of Loading Stage Activity in Soleus during Free Speed Walking

<table>
<thead>
<tr>
<th>Activity</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>No</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>13</td>
</tr>
</tbody>
</table>

**FIGURE 7 (right)** Population Electromyographic Patterns. The average EMG patterns for subjects walking at very-slow (a), free (b), and fast (c) speeds are plotted as a function of relative time.
DISCUSSION

Kinematic Parameters

Examination of the statistics listed in Table 2 show that there is a dispersion of relative speeds for each self-selected speed category. Notice from the standard deviations that the values overlap categories, that is, one person's free speed can be another person's fast speed, etc. For all categories except very slow, the female's relative speed is slightly greater. When the actual speeds are calculated, the female's walking speed is less in most categories, though equal at free speed. Comparison of these speed statistics with results from other laboratory studies with barefooted subjects shows good agreement (22,26,27). As Drillis has remarked, a laboratory setting induces shorter step lengths, thus causing slower speeds (28). Another indication of this fact can be obtained by comparing the data from two studies of Finley et al. (29,30). The free walking speed of women was 33 percent lower in the laboratory than in an urban setting.

As has been shown in other studies, the increase in walking speed is accomplished by an increase in both stride frequency and stride length (13,26,31). These results are corroborated in Figures 2 and 3. Figure 2 shows the relative stride length vs. relative velocity statistics with a superimposed average curve from Grieve (26). These are in good agreement. Figure 3 shows the stride frequency vs. relative velocity statistics with a superimposed average curve from Dean (32). For a given relative velocity the subjects exhibited a greater average stride frequency. This is consistent with other observations and data summarized by Dean because the curve is based on walking with subjects wearing regular heeled shoes—the wearing of shoes decreases cadence for a given walking speed.

Foot-Contact Patterns

The foot-contact patterns demonstrate a bilateral symmetry and no change in the sequencing of foot events with respect to speed. In the two subjects who exhibited different patterns, there seemed to be no clear correlation between these exceptions and the electromyographic patterns. For instance, subject RS, who has a valgus right foot, was always in the group which has peroneus longus activity during late swing or early stance; however, so were several other subjects who had the predominant foot-fall pattern.

The relative timing for most of the foot events is fairly consistent as indicated by the small standard deviations. Only two foot events, toe-contact and heel-off, have a large range of times. In several subjects the toe did not contact the walking surface until the middle of stance phase. This was usually, but not always, concomitant with the prolonged activity of the tibialis anterior muscle. There was no noticeable correlation between heel-off and any of the other kinematic parameters or EMG patterns.

As walking speed increases, the stance and double-limb support phases decrease in relative and actual time. In contradistinction, the swing phase duration increases in relative time though it, too, decreases somewhat in actual time. The reduction in stance phase duration is about five times greater than that of swing phase. These population averages, which are graphed in Figure 6, are in agreement with the results of other investigations (33,34).

On the average, some of the events on opposite feet occur concurrently. During very slow speed walking, heel-off on one foot occurs at heel-on of the contralateral foot. During free speed walking the ipsilateral first metatarsal head onset and contralateral first metatarsal head offset are concurrent. Whereas, at fast walking speed, a person will make contact of the fifth metatarsal concurrently with the offset of the opposite first metatarsal.

Given the consistency in the sequencing and the relatively small standard deviations of time of most of the foot events, the foot-fall pattern of the majority of normal individuals is a stereotyped pattern.

Muscle Synergy Patterns

The EMG patterns found at various walking speeds will be discussed with respect to the classically accepted patterns as exemplified in Figure 1.

a. Tibialis Anterior Most of the subjects studied displayed the classical patterns of the tibialis anterior muscle at all speeds. The exception was that 24 percent to 28 percent of the subjects had some activity during midstance with 19 percent having had midstance activity at all speeds. Midstance activity during free speed walking has been observed (23).

b. Peroneus Longus The peroneus longus muscle was found to be extremely variable in its activity. This variability was also observed by Walsmley (5). As walking speed increases, the percentage of subjects exhibiting swing-to-stance stage activity increases from 14 percent at very slow, to 26 percent at free speed, to 68 percent at fast speed. Those subjects incorporating late-swing stage activity at one speed also utilized it at a faster speed. This trend was not observed for the other transitional stage.

\[\text{The term "stride," employed by the authors in such expressions as} \]

\[\text{stride length, stride time and its inverse, stride frequency, refers to} \]

\[\text{the complete gait cycle of two consecutive steps—not to a single} \]

\[\text{step.} \]
In some subjects the peroneus longus had a pattern similar to the tibialis anterior, but in other subjects its pattern was more like the plantarflexor muscles. Perhaps more insight could be gained about the function of the peroneus longus if the EMG of tibialis posterior were recorded simultaneously. The tibialis posterior is more of a true antagonist of the peroneus longus than any of the other muscles recorded.

c. Gastrocnemius The EMG of the gastrocnemius muscle during very-slow speed walking is consistent with the classical descriptions. However, as a person walks faster there is a trend for the gastrocnemius to become active earlier in stance and even during late-swing. Several other investigators have shown this type of activity at free or fast speeds (10,12,23,35). At free speed, 21 percent of the subjects displayed this early activity. At fast speed, this is more conspicuous with 58 percent of the subjects displaying such activity.

d. Soleus The soleus muscle is active within stance phase except at fast walking speeds. At very-slow speed most of the subjects have the classical period of activity whereas 23 percent of them have a shortened period. As walking speed increases, the soleus commences activity earlier in the gait cycle. At fast speed, late-swing stage activity is exhibited. The early onset of soleus activity in some subjects walking at free speed has been previously reported (12,35,36).

e. Hamstring Muscle Group The hamstring group EMG patterns exhibited at free speed are in agreement with the classical patterns. Some investigators do not report finding any stance-to-swing transitional stage activity (7,10). The activity during the late-swing stage becomes less prevalent as walking speed decreases. Those who did not have this activity at free speed also did not have it at very-slow speed walking.

f. Rectus Femoris The primary pattern of the rectus femoris agrees with the classical quadriceps pattern except that the second period of activity occurring during the stance-to-swing transitional stage is not exhibited by everyone. The secondary pattern has a very prolonged single period of activity which extends through midstance and sometimes through the unloading stage. There are not any speed trends in patterns used by any one subject.

g. Vastus Lateralis The vastus lateralis pattern of activity at free speed agrees with the more recently published results (8,12). The main trend exhibited was that the subjects exhibiting biphasic pattern at free speed tended to exhibit the longer duration monophasic pattern at fast speed.

h. Gluteus Medius Classically the gluteus medius is active from late-swing stage through midstance. This period of activity is exhibited by a majority of subjects at free and fast walking speeds. However, many subjects also demonstrated a second period of activity during the stance-to-swing transitional stage or lacked activity during late-swing stage. In general, activity during the stance-to-swing transition did not seem to be a function of speed and was consistent for an individual. The activity during the late-swing period tended to become less prevalent at the slower walking speeds.

The two subjects who displayed the reciprocal bursting of antagonistic muscular activity, RW and MS, were walking with relative speeds of 0.15s⁻¹ and 0.20s⁻¹, respectively. This reciprocity is demonstrative of hesitancy in motion. This hesitancy is indicative of the instability of motion that can occur at such slow speeds (25).

Although there were no statistically significant correlations between pattern types and sex, a few trends did develop. The significance level for these trends was between 10 and 20 percent. Males have a greater tendency to have: biphasic hamstring patterns at all speeds of walking, biphasic gluteus medius patterns at slower speeds of walking, and loading stage activity of the soleus at free speed. Actually these trends may also be an effect of stature, since the females were shorter than the males.

CONCLUSIONS

The electromyographic gait patterns of eight muscles in 25 normal subjects were studied. The results show that there is an intersubject variability and that the pattern types change with the speed of progression. The apparent disagreements among the results of several investigations of normal EMG gait patterns are a reflection of these variations.

Several nonclassical electromyographic synergy patterns were exhibited that emphasize the importance of speed of progression. During very-slow speed walking, two subjects exhibited the reciprocal activity between plantarflexor and dorsiflexor muscles. This phenomenon is often observed in hemiplegic gait. Also, in fast speed walking there is an overlap in time of activity between the plantarflexor and dorsiflexor muscles. This is often observed in the gait of persons with a spastic lower extremity.

The range of average relative speeds observed was between 0.24s⁻¹ and 0.8s⁻¹. Since people are capable of walking at relative speeds of 1.5s⁻¹, any future studies concerning speed dependence should include an expanded speed range. An effect of laboratory conditions seems to be a reduced stride length—perhaps another technique worth consideration is to measure the stride frequencies and stride lengths of potential subjects in an uncon-
strained environment—and then have them replicate them during any laboratory measurement sessions.

A weak correlation between EMG pattern types in some muscles and sex seems to be occurring. However, a study using a much larger subject population is needed to test its significance.

The gait patterns were analyzed in a fairly qualitative manner in order to determine general trends and variabilities. Expansion of this kind of study necessitates computerized data acquisition and processing systems and objective analytical techniques because of the volume of data involved. It is planned to continue this study with such systems and to incorporate the techniques of multivariate analysis and pattern recognition for data reduction and classification.

REFERENCES