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HOW MANY STRIDES ARE REQUIRED FOR THE ANALYSIS OF ELECTROMYOGRAPHIC DATA IN GAIT?

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ABSTRACT. This study was conducted to obtain information on the number of strides of EMG data needed per subject in a gait study. Ten strides of EMG data were cumulated on eight subjects for each of the soleus, rectus femoris, biceps femoris, vastus medialis and tibialis anterior muscles. The linear envelope of the EMG, normalized in time and amplitude, demonstrated a very high level of stability for a given subject, relative to the variability that was found across subjects. It was concluded that three strides of EMG data per subject provides information as reliable as that obtained from twelve strides.

Key words: gait, electromyography

The study of human locomotion is very demanding for its aspects of data processing and analysis. Investigators have generally compromised by using data from very few subjects, from very few strides, and employing only one or two dependent measures whether it be temporal, kinematic, kinetic or electromyographic (EMG) in nature. As a consequence of this it is usually assumed that the use of one stride, or of a minimal number of strides per subject offers representative data for a given subject. However, justification for the number of strides does not appear to have been quantified. The choice of a "typical" stride has been arbitrary (8) and the choice of three (2), five (9), ten (6), or twenty (5) pooled to render a representative average score for a subject has not been validated.

The present study investigates the problem of the choice of the number of gait cycles required to adequately analyse EMG data as processed in the form of an average linear envelope. It will be performed in the context of a reliability study using the intra-class correlation coefficient (7, 10).

METHODS

Eight subjects participated in the study as volunteers. Their average age was 24.5 years (SD = 4.3). None presented a history of either a neurological or musculo-skeletal dysfunction. They were evaluated for their dominance with the "Harris test of lateral dominance" (3). The EMG data were subsequently collected from the following muscles of the dominant lower limb: soleus, rectus femoris, biceps femoris, vastus medialis and tibialis anterior.

The subjects were required to walk on a walkway 10 meters long, 1.2 meters wide and 0.3 meters high. Every subject selected their own natural (2) cadence of walking ($\bar{X} = 106.1$, SD = 3.3 steps/min), which was kept constant with the use of a metronome. This procedure was preferred rather than imposing a uniform cadence on all subjects. The latter may have amplified or attenuated the variability in the muscular recruitment profiles which would not have been representative of the natural way of walking of some of the subjects.

Beckman surface electrodes were used for the EMG signal. They were placed on the belly of the muscle longitudinally to the muscle fibers. Super-imposed signals from pressure sensitive switches placed under each heel were also recorded. These served to disclose the gait cycle defined as the event occurring in time, in-between two consecutive heel-strikes from a given leg. Thus six channels of signals were transmitted by telemetry (FM, model 370 Biolink Telemetry System, Biocom Inc., Culver City, Cal.). A frequency range of 15 to 180 Hz (3 dB point) for the signals transmitted was allowed by this system. All signals were recorded on FM tape using an eight channel FM tape recorder (Hewlett Packard, model 3968A).

The EMG signals were transformed into linear envelopes by first, full-wave rectifying the raw signal and filtering the result, using second order low pass filters (6 Hz). This processing of the signal rendered an envelope which represents a moving average profile of the activity of the muscle in time and which has been demonstrated to be similar to the tension curve produced by a muscle (4). The linear envelope and footswitch signals were digitized at a rate of 50 Hz, using a NOVA II computer (12 bits A/D).

The digitized version of the envelope was further processed in two ways. First, the real (ms) time of each gait cycle was normalized (0 to 100%) so that pooling of the data across strides and across subjects could be feasable. Second, the amplitude of the envelope, expressed in mV was transposed as a percentage of a maximum voluntary contraction (MVC) that had been obtained for each mus-

Table I. *Summary of the two-way ANOVA performed on the average values computed from the linear envelopes of the muscles investigated*

S = subjects; Str = strides; F = F ratio: significant results at $p<0.001$ are marked by an asterisk; R^2 = coefficient of determination; R_I = intra-class correlation coefficient

Muscle	Factor	F	R^2	R_I
Soleus	S	71.410*	0.885	0.967
	Str	0.210		
Rectus Femoris	S	208.290*	0.952	0.980
	Str	1.080		
Biceps Femoris	S	60.380*	0.858	0.942
	Str	0.800		
Vastus Medialis	S	326.360*	0.968	0.986
	Str	1.350		
Tibialis Anterior	S	39.160*	0.764	0.841
	Str	2.390		

cle (2). These MVC were performed isometrically in a mid-range position of the distal articulation and were maintained for a period of three seconds. The EMG signal produced by such MVC was transformed into a linear envelope and the average amplitude of a one second segment of this envelope, expressed in mV, became the normalizing factor for the linear envelope data for each specific muscle, for each subject.

For each of the eight subjects, ten gait cycles of data were analysed. The sampling and normalization procedures allowed for comparison of the data in either a within or between subjects manner. The sample points of each linear envelope were averaged, rendering an average amplitude value representing the level of the EMG signal under the envelope. These amplitude values were analysed using a two-way analysis of variance (ANOVA), one within (strides) and one between (subjects) factor. To investigate the level of reliability of the data (within subject relative to between subjects), first, the intra-class correlation (R_I) (10) was obtained for this average value computed for sets of ten envelopes per subject. As this index approaches 1.0, high stability of the intra-subject data is indicated. Second, a matrix of expected (R_E) intra-class correlations was generated (7), relating the number (N_s) of subjects and the number of strides (N_t), so that their inter-relationship could be studied. According to this technique the following formula was composed:

$$R_E=\frac{\text{MSS}}{\text{MSS}+\text{MST}/K+\text{MSE}/N\cdot K}, \text{ where}$$

MSS = mean square for subjects
MST = mean square for strides
MSE = mean square error
K = number of strides
N = number of subjects

All the mean squares of the present formula (R_E) were taken from the ANOVA tables computed with the data from eight subjects and ten strides for each subject. Using the suggested formula and the obtained mean square values from the ANOVA tables, a 12×12 matrix of expected intra-class correlation (R_E) was computed for each muscle. This was done by allowing N and K take values from 1 to 12. These computed R_E are less conservative than the R_I usually obtained (10) thus, slightly inflated, but care has been taken here to remain within the context of a conservative procedure (1).

RESULTS

A summary of the results of the two-way ANOVA procedures used to analyse the average value computed under the linear envelopes across subjects for a given muscle is presented in Table I. The R_I values obtained were calculated using the procedure recommended by Zar (10). It can be seen from this table, that for every muscle investigated, a difference between subjects is obtained when the average value, as expressed in % MVC, is computed under each linear envelope. The importance of the difference found is quite marked as depicted by the values reached by the coefficient of determination (R^2). Concomitantly, the R_I levels obtained, reflect the high intra-subject stability of the data relative to the between subjects variation.

Table II presents a R_E matrix summary computed for the investigated muscles. Very high values of R_E are obtained even for a minimum number of strides and subjects. Strong results are shown even in the first cell of the matrix. This first cell, however (1 subject, 1 stride) is theoretical in nature and is unrealistic in terms of a ratio composed of between and within subject variability. It can, however, be observed that an increasing number of strides and subjects offers higher R_E values as expected. Nevertheless, it is also clearly shown that a minimal

Table II. *Summary of the expected intra-class correlation coefficients (R_E) obtained for different combinations of numbers of strides (Str) and of subjects (S)*

These combinations are presented for the average measure taken on the linear envelopes of a given muscle

Muscle	1Str/ 1 S	3 Str/ 3 S	5 Str/ 5 S	10 Str/ 10 S
Soleus	0.886	0.989	0.997	0.999
Rectus femoris	0.954	0.995	0.998	0.999
Biceps femoris	0.859	0.983	0.994	0.999
Vastus medialis	0.969	0.996	0.999	0.999
Tibialis anterior	0.765	0.958	0.981	0.993

amount of data obtained from three subjects, three strides for example, would offer very highly reliable information.

DISCUSSION

The results of the present study indicate that from stride to stride, one subject does not vary in an important fashion (as seen in our R_I values). Thus a minimal number of strides ($N=3$) per subject, would offer very reliable EMG data for this subject. It could even be stated that only one stride would be sufficient to give a representation of the peculiarities for this subject within a given condition (8). What the ensemble average of a few strides might be doing is averaging out the step to step variability, that is caused by posture control and support by the weight bearing limb. In this way, an overall profile of the EMG pattern in gait would be obtained, freed of the step to step adaptation effects.

CONCLUSION

The quantity of data required to properly depict and appreciate differences in gait that exist between subjects for a given muscle has been studied. As the intra-subject variations are usually small, compared to the variations found across subjects, it can be postulated that the data collected from one stride in each of twelve subjects, would be as reliable as the data collected in twelve strides in each of twelve subjects, to depict individual differences. Furthermore, to evaluate the variations for a given muscle, for a given subject, relative to the variations found between subjects, the data collected on three strides in each of three subjects would be as reliable, for all practical purposes, to the one collected on twelve strides in each of twelve subjects.

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REFERENCES

1. Bartko, J. J.: The intraclass correlation coefficient as a measure of reliability. Psychol Rep *19:* 3, 1966.
2. Dubo, H. I. C., Peat, M., Winter, D. A., Quanbury, A. O., Hobson, D. A., Steinke, T. & Reimer, G.: Electromyographic temporal analysis of gait: normal human locomotion. Arch Phys Med Rehabil *57:* 415, 1976.
3. Harris, A. J.: The Harris Test of Lateral Dominance. 2nd ed. The Psychological Corporation, New York, 1955.
4. Inman, V. T., Ralston, H. J., Saunders, J. B., Feinstein, B. & Wright, E. W.: Relation of human electromyogram to muscular tension. EEG Clin Neurophysiol *4:* 187, 1952.
5. Knutsson, E.: Gait control in hemiparesis. Scand J Rehabil Med *13:* 101, 1981.
6. Knutsson, E. & Richards, C.: Different types of disturbed motor control in gait of hemiparetic patients. Brain *102:* 405, 1979.
7. Kroll, W.: Reliability of a selected measure of human strength. Res Quart *33:* 410, 1962.
8. Pedotti, A.: A study of motor coordination and neuromuscular activities in human locomotion. Biol Cybern *26:* 53, 1977.
9. Rainaut, J. J. & Lotteau, J.: Télémétrie de la marche. Rev Chir Orthop *59:* 5, 1963.
10. Zar, J. H.: Biostatistical Analysis. Prentice-Hall Inc., Englewood Cliffs, N.J., 1974.

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