and vice versa. This lack of correlation between the degree of cutaneous vasocostriction induced by noradrenaline infusion and the degree of vasocostriction induced by neurally released noradrenaline is inconsistent with a supersensitivity mechanism, since one would then expect an increased effector response to noradrenaline independent of its source.

Present results thus support the conclusion of Mathias (10) that supersensitivity to noradrenaline does not explain the increased vasomotor responses in tetraplegic patients. The regulation of cutaneous blood flow, however, is complicated and includes not only sympathetic vasococontractor activity (5) but also vasodilatory mechanisms (2). One possible explanation for the increased vasocostriction following sympathetic nerve activity below the level of the lesion in spinal patients would be a disturbed balance between vasocostriction and vasodilator mechanisms in the absence of supraspinal control.

ACKNOWLEDGEMENTS

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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 informa-
tion 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 or muscle. The linear envelope of the EMG, normalized in time and amplitude, was selected as a 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 at most 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 represent 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 pre-

seated a history of either a neurological or musculo-skel-
etal dysfunction. They were evaluated for their domi-
nance with the "Harris test of lateral dominance" (11). 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 (F = 106.1, SD = 3.3 steps/min), which was kept constant with the use of a metronome. This procedure was pre-
ferred 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.

Reinman surface electrodes were used for the EMG signal. They were placed on the belly of the muscle longitudinally to the muscle fibers. Superimposed 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, i.e. between two consecutive heel-strikes from a given leg. Thus six chan-
nels of signals were transmitted to telemetry (model 370 Biolink Telemetry System, Biocam Inc., Culver City, Cal.). A frequency range of 17 to 180 Hz (±3 dB points) 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 3986A).

The EMG signals were transformed into linear enve-
lopes 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 pro-
cessed in two ways. First, the raw (ms) time of each gait cycle was normalized (0 to 100%) so that pooling of the data across strides and across subjects could be feasible. 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.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Factor</th>
<th>R²</th>
<th>R²</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soleus</td>
<td>S</td>
<td>0.885</td>
<td>0.967</td>
<td></td>
</tr>
<tr>
<td>Rectus</td>
<td>S</td>
<td>0.952</td>
<td>0.980</td>
<td></td>
</tr>
<tr>
<td>Femoris</td>
<td>Str</td>
<td>1.091</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biceps</td>
<td>S</td>
<td>0.858</td>
<td>0.942</td>
<td></td>
</tr>
<tr>
<td>Femoris</td>
<td>Str</td>
<td>0.800</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vastus</td>
<td>S</td>
<td>0.968</td>
<td>0.986</td>
<td></td>
</tr>
<tr>
<td>Medialis</td>
<td>Str</td>
<td>1.350</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tibialis</td>
<td>Str</td>
<td>0.764</td>
<td>0.841</td>
<td></td>
</tr>
</tbody>
</table>

**RESULTS**

A summary of the results of the two-way ANOVA procedures used to analyze the average value computed under the linear envelopes across subjects for a given muscle is presented in Table I. The R² 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 (R²). Concomitantly, the R² levels obtained, reflect the high intra-subject stability of the data relative to the between subjects variation.

Table II presents a R² matrix summary computed for the investigated muscles. Very high values of R² 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, (subject 1, stride 1) 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 R² values as expected. Nevertheless, it is also clearly shown that a minimal amount of data obtained from three subjects, three strides for example, would offer very 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 R² 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, free 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 variability of 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.

**REFERENCES**

The present work has been done at the Department of Kinesiology of the University of Waterloo. It was supported by Medical Research Council Grant (MT-4343). Acknowledgements are made to Mr. John Carins for his technological contributions and to Richards Wells and Jacques Bubet for their assistance in the analysis of the data.

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Table 1. Summary of the two-way ANOVA performed on the average values computed from the linear envelopes of the muscles investigated. S = subjects; Str = stripes; F = F ratio; significant results in p < .05 are indicated by asterisk; R2 = coefficient of determination; R2 = intra-class correlation coefficient

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Factor</th>
<th>F</th>
<th>R2</th>
<th>R2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorens</td>
<td>S</td>
<td>S 71.40*</td>
<td>0.885</td>
<td>0.967</td>
</tr>
<tr>
<td>Rectus</td>
<td>S</td>
<td>328.29*</td>
<td>0.952</td>
<td>0.980</td>
</tr>
<tr>
<td>Femoros</td>
<td>Str</td>
<td>1.098</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biceps</td>
<td>S</td>
<td>60.38*</td>
<td>0.858</td>
<td>0.942</td>
</tr>
<tr>
<td>Femoros</td>
<td>Str</td>
<td>0.800</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vastus</td>
<td>S</td>
<td>126.50*</td>
<td>0.968</td>
<td>0.986</td>
</tr>
<tr>
<td>Medialis</td>
<td>Str</td>
<td>1.350</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tibialis Anterior</td>
<td>S</td>
<td>39.16*</td>
<td>0.764</td>
<td>0.841</td>
</tr>
</tbody>
</table>

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RESULTS

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