ON THE MUSCULAR ACTIVITY
OF THE PERFORMING VIOLINIST

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Abstract

Violinists seem more exposed to muscular strain and injuries than most of their fellow colleagues of the symphony orchestra. The purpose of the present study was to establish knowledge about the dynamic and static normalized EMG levels of six muscles (left and right upper trapezius, r. infraspinatus, r. deltoidus, r. pectoralis and r. ext. carpi radialis) during performance of a standardized set of basic bowing patterns. The sample consisted of 25 violinists, who were subdivided into the following two-times-two groups: females versus males and professionals versus advanced students. When comparing groups, their cyclic muscular patterns showed remarkable uniformity while significant differences were found in the EMG levels of some muscles. Significant dependence on skeletal properties such as arm length, etc., was also found. Since none of the subjects was suffering from any pain or injury, this study provides insight into the muscular dynamics and interaction to be expected from the experienced violinist under normal conditions.

Introduction

When starting this investigation, the team had some expectations on finding differences between the way professional violinists and violin students were using their shoulder and arm muscles when performing simple, basic bow strokes. A selection of 20 musical figures was constructed, all of which are typical of the patterns students work on trying to achieve a good sound. However, the most significant differences were not found between these two groups, but rather between people with short or long arms. When adjusting the statistical material for arm length, the differences between professionals and students apparently vanished. A comparison between female and male violinists did however stand this test.

Experimental procedure

In this experiment six sets of surface electromyographic (EMG) electrodes were attached to the subject, and their signals fed to a six-channel differential amplifier, after which they were rectified and integrated (time constant = 0.1 sec.) and recorded on an IBM PC at a rate of 100 Hz. Before recording the EMG levels during the "musical performance", levels of maximum muscular voluntary contractions (MVC) were recorded. These were performed while the subject was sitting in a chair, within a metal frame specially constructed to avoid the upper body moving out of angle. While playing, however, all subjects were standing. At least two maximum tests were recorded for each muscle. It would have been good to repeat this procedure at the end of the playing session, but since many subjects seemed to fear sore muscles to follow such a test (and one or two actually got it), this repetition was skipped. The reliability of the subjects' maximum MVC tests is hard to judge, but, because none of the subjects were suffering from any pain or injuries during the time of testing, our impression was that they all did their best to produce realistic maximum contractions. This paper will however show how the MVC levels may be made negligible in some analyses.

Of the 20 music examples (separated by double bars), 16 were continuously repeating figures. From each of those examples a selection of six seconds was recorded. All tests were played to an electronic metronome indicating a quarter-note tempo of 60 beats per minute, thus ensuring duration of one second for each bow-stroke cycle, so that exactly six complete cycles would be recorded each time. Without informing the subject of when, the signal from the metronome would be switched on, triggering the A/D card so that the recording started (see Figure #1). In this way the cycle of EMG levels could be made synchronous for all subjects to facilitate comparison in the time domain. The complete set of music examples is shown in Figure #2. The test music includes figures played at different dynamic levels, as well as on different strings and parts of the bow. In addition to the EMG registration, a questionnaire was filled out, and clinical measurements were made of arm length (distance from acromion to the lower end - processus styloideus - of ulna). More skeletal measurements, such as neck and scapula angles, etc., were taken, but will not be discussed here, as evidence of their effects on EMG levels was not found as solid as for arm length.

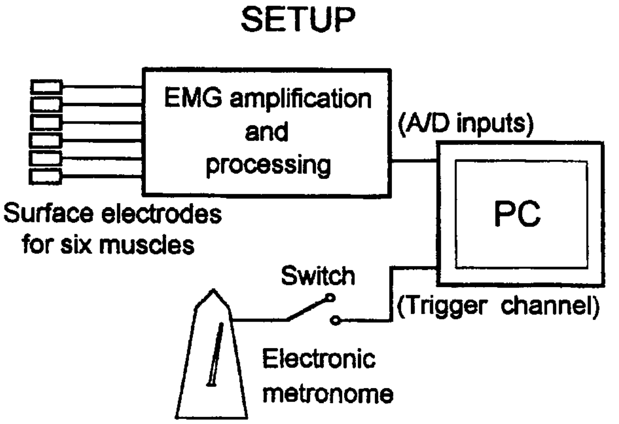

Figure #1:
While the subjects are playing in strict rhythm, the connection between the electronic metronome and the trigger input of the computer's A/D card is switched on, allowing a specified time window to be recorded.

Static and dynamic parts of the EMG signal

Although the relation between static muscular contractions and injuries is not yet fully understood, the general concept seems to be that static use of the muscles has to take responsibility for a good part of the occopationally-related injuries. Because "static muscular use" is very rare in the true sense of the words, the present authors wanted to see how great part of the muscular activity was related to true dynamic use (e. g., for moving a limb from one position to the other) as compared to "static use" (e. g., keeping the limb in the position where the dynamic contractions start). In terms of EMG levels, the latter would be the minimum level, from which the signal raises and moves around the mean EMG value. However, in a cyclic activity, the absolute minimum may be a bit spurious: a better estimate will be the minimum after averaging the levels of several cycles. Figure #3 demonstrates the routine utilized in the present experiment. For less cyclic activities, the 5th or another percentile may be used as the "static" level.

Figure #2:
The test music consists of twenty short examples (each between double bars). These demonstrate basic bow-strokes at different strings, and at different positions on the bow.

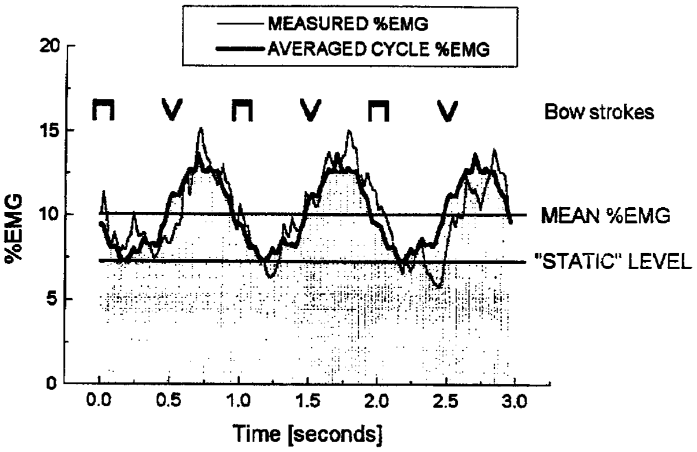

Figure #3:
In order to find a "static" or averaged-minimum level, six of the one-second-long %EMG cycles are averaged over points one second apart, and the minimum of the resulting cycle chosen as the "static" level. The ratio "Static/Mean %EMG" gives some statistical advantages.

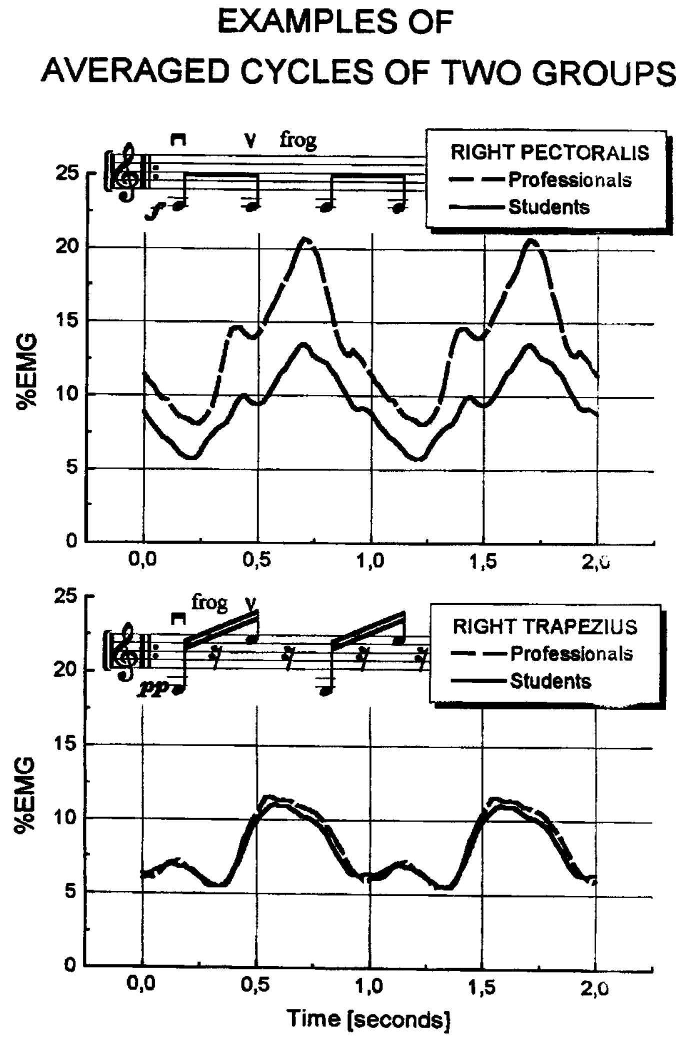

Figure #4:
Using the averaging technique described in connetction with Figure #3, individual subjects or groups may be efficiently compared. Throughout this study, the EMG cycles show great uniformity, although their magnitudes might differ considerably.

Uniformity in the cyclic EMG patterns between subject groups

The last 16 music tests were performed cyclically (with periods of one second), thus facilitating analysis based on EMG cycles averaged in the time domain. Because mechanical force was never measured in this study, all references to EMG levels are based on %EMG, i. e., EMG relative to the EMG level at maximum MVC. A striking uniformity between subjects on the averaged %EMG cycles for each music test, was early evident in the experiment. Even more so when comparing averages of whole subject groups, one to the other. Figure #4 shows two such comparisons between professionals and students (for music tests #11 and #26, respectively). The upper part, referring to %EMG levels at right pectoralis during a simple movement performed forte (loud) on the G-string (right arm high) shows a great difference in dynamic use, but mainly in the magnitude. (One cause for this might even be that the professionals play louder than the students.) The lower part compares the action of the right deltoidus for the two same groups during a music test where the violin is bowed on its lowest and highest strings alternately. The difference between the two groups is here hardly noticeable. Most comparisons between the groups (professionals/students or females/males) fall between this two examples as far as quantitative differences are concerned, and correlate usually well, also in qualitative respects.

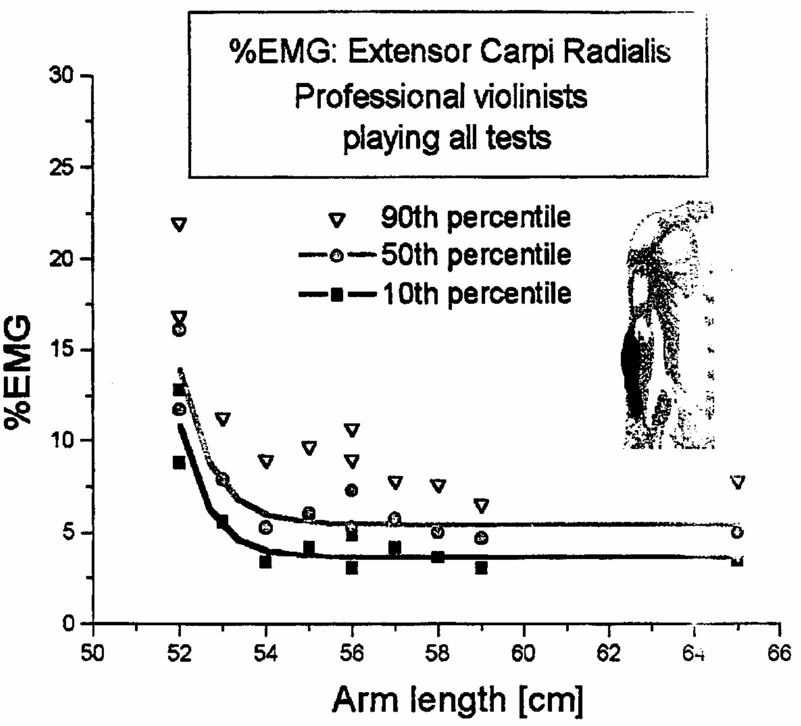

Figure #5:
The average %EMG for right extensor carpi radialis demonstrates high values for violinists with arms shorter than 54 cm. The trend is the same for both professional and student subjects, but only shown for professionals here, because their deviations are smaller.

The effect of arm length

For some muscles, the arm length seems to influence the %EMG levels considerably. This is true for all groups, but a striking picture can be seen for the right extensor carpi radialis of the group of professionals (Figure #5). Here a sigmoidal curve-fitting was chosen because it illustrates the tendency best: players with short arms compensate by using certain muscles more. Figure #5 gives the 10th, 50th and 90th percentiles averaged over all the test-music examples. To play a page of music like Figure #2 takes three minutes and twelve seconds, during which time the violinist under normal circumstances is given no opportunity to relax by taking his arms and instrument down. (When testing, there was a break for each double bar.) This lack of opportunity may be one of the major causes of occupationally-related injuries for musicians, even when the EMG levels themselves are not alarmingly high. Nonlinear regression curves like the one shown in Figure #5 are not well fit for analyses unless their underlying physics can be explained convincingly: for statistical purposes, they are all too easily adaptable to any given set of samples. However, when a certain parameter space demonstrates a noticeable difference in characteristics, it is tempting to isolate a certain region and perform normal, linear 1st-order-regression analyses there. In some of the analyses that follow, the total sample has been subdivided in two groups: violinists with "short" or "long" arms, meaning arms shorter and longer than the total sample's mean length of 57.5 cm.

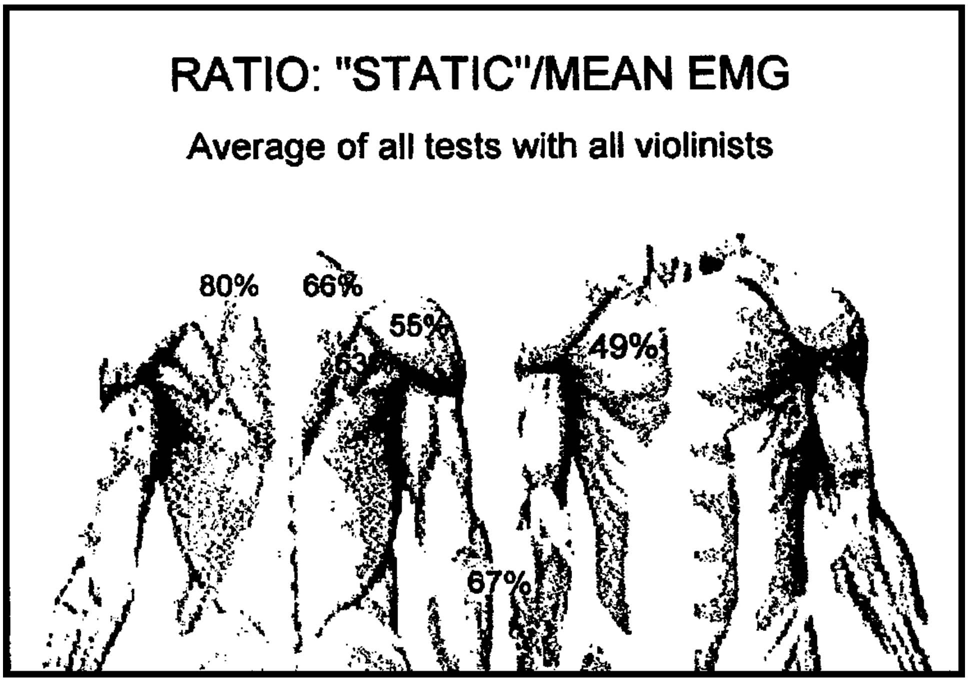

Figure #6:
The ratio "static"/mean EMG shown for all the muscles examined in the present study. From left to right: left trapezius, right trapezius, infraspinatus, deltoidus, extensor carpi radials and pectoralis.

The ratio "Static/Mean %EMG"

As mentioned earlier in this paper, the present authors wanted information on the ratio between static and dynamic parts of the EMG levels, or as presented here, between the static and mean parts, like they are demonstrated in Figure #3. Figure#6 shows these ratios for all the six muscles measured when averaged over all subjects and music tests: left trapezius (80%), right trapezius (66%), right infraspinatus (63%), right deltoidus (55%), right extensor carpi radialis and right pectoralis (49%). For the same muscles the mean %EMG levels were 5.5, 8.0, 8.7, 7.9, 6.7 and 7.5, respectively. One advantage with this rational expression is that the EMG level at maximum

MVC occurs both in the nominator and denominator, thus vanishing from the equation. Another advantage, compared to using the %EMG levels directly, is that the ratios show a good normal distribution, well fit for Student's t-tests, while the corresponding EMG levels usually show considerable skewness. Figures #7 and #8 show statistical analyses of the right deltoidus and pectoralis as functions of arm length.

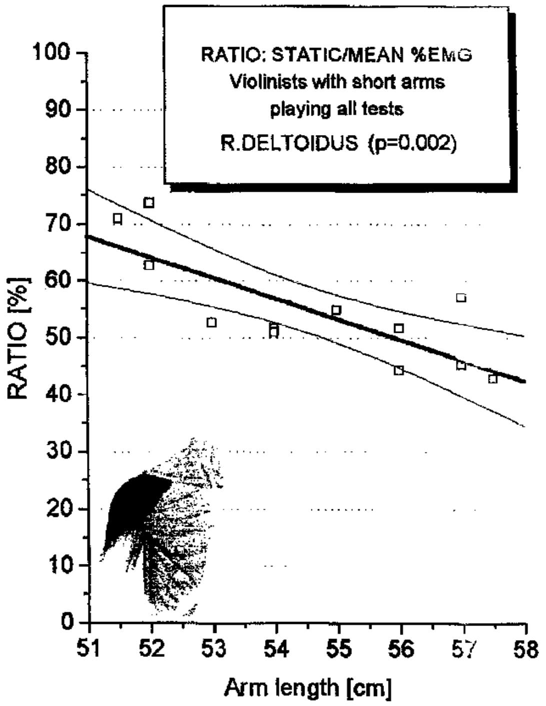

Figure #7:
For subjects with short arms (< 57.5 cm) the right deltoidus shows an increased degree of static activity (pulling the upper arm up on the right side of the body). This is true for both relative (ratio "static"/mean) and absolute %EMG levels.

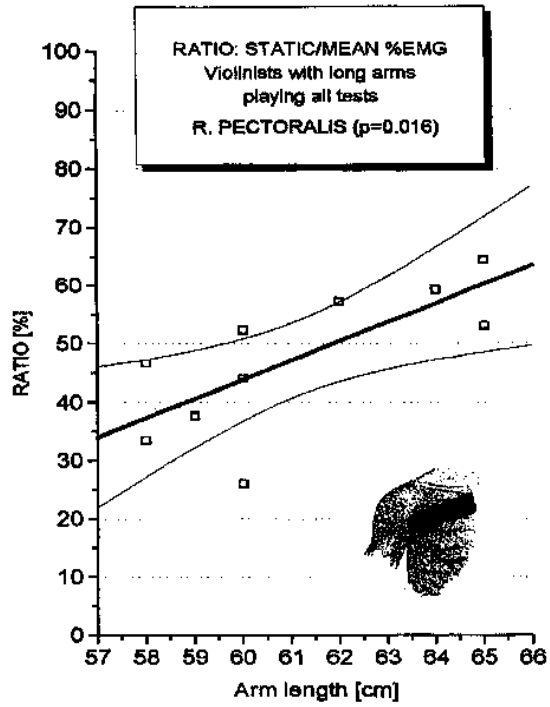

Figure #8:
For subjects with long arms (> 57.5 cm) the right pectoralis shows an increased degree of static activity (pulling the upper arm up, toward the head). This is true for both relative (ratio "static"/mean) and absolute %EMG levels.

Adjusting the statistics for arm length

Table #1 gives an example of spurious statistics occurring when the arm length is not compensated for. When comparing the two groups, professionals and students, the %EMG of right pectoralis is significantly ($p<0.01$) higher for professionals than for students. This is true also for every category when the music tests are subdivided in different categories such as "Long notes" (the first sixteen bars), "On the G-string", "On the E-string", "Détaché" (bars 17 through 24), "Arpeggio" (bars 25 through 32), "Pianissimo", "Forte", "By the frog" and "By the tip". However, when adjusting for arm length by subtracting the 1st-order-bestfit regression values based on all subjects, no statistical evidence of difference is found in any of these bow-stroke categories. The explanation should be sought in the fact that the professionals in average had 2.9 cm shorter arms than the students. For differences between the genders the situation is different: the female subjects had in average 3.0 shorter arms than the males, but the significant ($p<0.01$) difference for right extensor carpi radialis and the ($p<0.05$) difference for the right deltoidus remain valid after the regression adjustment. The %EMG values for these muscles prove higher for females in both cases. Student's t-tests adjusted for unknown, unequal variances suggest an average difference of 5.1 (4.3) %EMG for the right extensor carpi radialis when the arm length is compensated (not compensated) for. The corresponding figure for the right deltoidus is 5.8 (4.7).

ADJUSTMENT FOR ARM LENGTH:

	Statistics without compensation for arm length	Statistics with compensation for arm length
PROFESSIONALS VERSUS STUDENTS Average arm lengths: Prof. (10): 56.1 cm Stud. (11): 59.0 cm	**R. PECTORALIS:** 50th, 75th and 90th percentiles, "dynamic average" and mean do all indicate significantly ($p \leq 0.02$) higher %EMG in the professionals.	**R. PECTORALIS:** No indication ($p \leq 0.05$) of differences between the groups.
WOMEN VERSUS MEN Average arm lengths: Women (7): 55.5 cm Men (15): 58.5 cm	**RIGHT EXTENSOR CARPI RADIALIS:** 10th, 25th, 50th, 75th and 90th percentiles, mean, static and dynamic average do all indicate significantly ($p \leq 0.01$) higher %EMG in the women. **R. DELTOIDUS:** Some indication ($p \leq 0.05$) of higher %EMG in the women.	**RIGHT EXTENSOR CARPI RADIALIS:** 10th, 25th, 50th, 75th and 90th percentiles, mean, static and dynamic average do all indicate significantly ($p \leq 0.01$) higher %EMG in the women. **R. DELTOIDUS:** Some indication ($p \leq 0.05$) of higher %EMG in the women.

Based on the Wilcoxon-Mann-Whitney rank sum test of two (distribution-free) populations. (G.K.Kanji *"100 Statistical Tests"*, SAGE pulications 1994.)

Conclusions

A sample of 25 injury-free violinists was investigated, of which 3 female and 8 male professionals, and 8 female and 6 male advanced students, ranging from 18 to 65 years of age. Significant differences in (normalized) %EMG levels were found between the gender groups for the right extensor carpi radialis and right deltoidus. When dividing the subjects in groups with arm length shorter and longer than the arithmetic average, significant dependence on arm length was found for the right deltoidus, trapezius and infraspinatus (for violinists with short arms), and for the right pectoralis (for violinists with long arms). This study suggests that arm length should be taken into account when comparing EMG levels of different groups.

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