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Surface electromyography of forearm and shoulder muscles during violin playing

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Keywords: surface EMG; musicians; violinists; string players; muscle activity; muscular load; shoulder; pain; anthropometry

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Abstract

The aims of this study were to explore muscle activity levels during different violin repertoires, quantify the general levels bilaterally in upper extremity muscles, and evaluate associations between muscle activity and anthropometrics characteristics. In 18 skilled violin players surface EMG was recorded bilaterally from trapezius (UT), flexor digitorum superficialis (FDS), extensor carpi ulnaris (ECU), extensor digitorum communis (EDC), and extensor carpi radialis (ECR) during A and E major scales played in three octaves and Mozart’s Violin Concerto no. 5. To compare side differences the static, median and peak levels of muscle activity were calculated from an amplitude probability distribution function (APDF). This study demonstrated that scales played as standardized tasks can be used to estimate the average muscle activity during violin playing. Comparing results from scales and the music piece revealed a similar muscle activity across all muscles in the music piece and E major scales. The static, median and peak EMG levels were higher in left than in right forearm muscles with left ECU presenting the highest peak load of 30% MVE. Females demonstrated a higher muscle activity than males, but this was in accordance with differences in anthropometric measures.
1. Introduction

Observing a classical symphony orchestra, playing looks effortless, but to the performing musician the reality is often the opposite (Andersen et al., 2013; Paarup et al., 2011). Musicians are in a competitive occupation demanding precise and repetitive movements of their upper extremities comparable to professional athletes (Andersen et al., 2013; Paarup et al., 2011). However, classical musicians are often overlooked and limited health research has been conducted to understand the occupational exposures, health-related consequences, and efficient prevention of playing-related health problems in musicians (Rensing et al., 2018, Visentin et al., 2011, Kok et al., 2016). Not surprisingly, a Danish study of 342 professional classical musicians revealed that musicians have a two to three times higher prevalence of musculoskeletal disorders in the upper extremities compared to the general workforce and that ≥ 86% experienced musculoskeletal problems within the last year (Paarup et al., 2011). Particularly violinists who comprise the largest proportion of musicians in a symphony orchestra, are exposed to awkward working postures with elevated arms and asynchronous arm movements and higher levels of musculoskeletal problems than found in musicians with lower arm positions (Nyman et al., 2007).

For instrument playing, focus has always been on producing the optimal sound; the teaching is based on apprenticeship as a teaching method aiming towards a perfect sound and pitch (Palac et al., 1992). In spite of the natural variation in anthropometry among the symphony orchestra musicians the design of the instruments relates more to sound and traditions than ergonomic features, forcing the musician to adapt to the instrument. The anthropometrics of musicians have previously been suggested as a predictor of kinematic movement changes and change in muscle activity and is described in the literature as individual performance styles (Visentin et al., 2015). Previous studies have shown that longer neck and arm length amongst violinists are correlated with higher levels of muscle activity (Levy et al., 1992., Guettler et al., 1997). Playing the violin is a
complex task with bow strokes performed with the right arm burdening it with a dynamic pattern combined with a static hand grip and the left forearm and hand moving over the fingerboard with rapidly changing, well-controlled movements while the upper arm is held in a static position to stabilize the violin between the shoulder and jaw. Different studies are describing the specific violin demands focusing on different musical repertoire as either scales or music pieces, which have different requirements for sound, speed and use of techniques which can impede the comparison amongst these studies (Rensing et al., 2018; Schemmann et al., 2018; Visentin et al., 2011). Furthermore, most of the existing literature have a unilateral focus describing the right arm activity i.e. determining muscle activity with surface electromyographic (sEMG) and kinematic behavior in the right arm during bow strokes despite different demands for left and right arm during music performance (Rensing et al., 2018; Schemmann et al., 2018; Tulchinsky et al., 1994; Turner-Stokes et al., 1999; Shan et al., 2004; Wolf et al., 2019; Möller et al., 2018; Cattarello et al., 2017).

To optimize the training and playing in order to prevent work-related injuries a thorough understanding of muscle activity during different specific music tasks and the simultaneously bilateral muscle recruitment patterns is needed. The aims of this study were to 1) explore the muscle activity levels during different violin repertoires (playing defined scales and a specified music piece), 2) quantify the general levels bilaterally in upper extremity muscles, 3) evaluate association between muscle activity and anthropometrics characteristics.
2. Methods

2.1. Participants and recruitment

Inclusion criteria were violinists recruited from a music conservatory, a symphony orchestra and via social medias, ≥18 years of age and who could play the protocolled repertoire. Exclusion criteria were 1) life-threatening health disorders, 2) pacemaker, or 3) severe eczema on neck and upper extremities. All were physically examined by an experienced physiotherapist; in case of health problems a physician was asked if participation was acceptable.

Participants were excluded from the maximum strength test used for normalizing the EMG signal in case of 1) pregnancy, 2) high blood pressure, 3) angina pectoris, 4) use of medication for heart or lung disorders, 5) previous trauma on body parts (neck, shoulder or arms), 6) previous or planned shoulder/neck operation, or 7) severe neck/shoulder pain within the last seven days. In case of severe pain, they were also excluded from the maximum voluntary isometric contraction (MVIC) test for the upper trapezius in order to avoid pain-related incapability to carry out the test. Perceived pain within the last seven days was scored using a Likert scale from zero = “no trouble” to nine = “very very severe”- a rating scale previously used for work-related musculoskeletal disorders including among musicians (Kaergaard et al., 2000; Paarup et al., 2011).

The study protocol was approved by the Regional Scientific Ethics Committee for the Regions of Southern Denmark (S-20162000-99). All participants received written and oral information and provided a written consent in accordance with the Declaration of Helsinki.
2.2. Anthropometric measurements

The included participants had their anthropometric measures as height, weight for calculation of BMI, length of right humerus, forearm length, and left handgrip measurements (circumference from thumb to little finger or thumb to middle finger). All measurements were standardized according to a Danish report on anthropometric measures in workers (Søgaard et al., 2015) (Table 1).

2.3. The EMG test procedure

Testing was scheduled for morning hours before strenuous activity or instrument practice, and the violinists were informed not to do high load resistance training two days prior to the test day to exclude muscle fatigue or soreness. Two hours test took place in a practice room in the concert hall, but for a few in a laboratory setting, with a room temperature above 20° C. Firstly, EMG electrodes were placed, then the MVIC test was done followed by a standardized ten minutes warm-up with their instruments and finally the EMG data recording during music playing according to the protocol.

2.4. Electrode placement

The wireless sEMG (Myon 320, AG, Switzerland) was recorded bilaterally from m. trapezius, pars descendens (UT) and m. flexor digitorum superficialis (FDS), m. extensor carpi ulnaris (ECU), m. extensor digitorum communis (EDC), and m. extensor carpi radialis (ECR) with bipolar electrodes of 44.8 mm x 22 mm (Ag/AgCl, Ambu Blue Sensor, N-00-S/25, Denmark). EMG electrodes were placed parallel to the muscle fibers with an inter-electrode distance of 20 mm. To assure an interelectrode impedance <20 kΩ measured with a digital multimeter for the electrodes the placement sites were shaved, scrubbed with cleansing gel and cleaned with 70% alcohol.
Two participants had an impedance above the maximal 20 kΩ on the forearm but were included after an engineer visually had inspected the signal and noise rating (signal time and frequency domain).

For UT electrodes were placed 20% medially to the halfway point between the lateral border of the acromion and the seventh cervical vertebra (Holtermann et al., 2009).

For the forearm muscles electrode positions were in accordance with sites described in the literature (SENIAM, Perotto et al., 2011). FDS electrode placement was ¼ proximally from the wrist towards the elbow over the bulkiest part of the muscle with clutched hand. ECU was located halfway between olecranon and pisiforme. EDC was located 1/3 proximally between the lateral epicondyle of the humerus and the ulnar styloid process. ECR was located two fingers’ width distally to the lateral epicondyle of the humerus. Left ECR and right EDC was only recorded for the 13 professional violinists. The placement of the electrodes was checked through palpation and visual inspection of raw EMG signal during specific tasks (Mogk and Keir, 2003). Finally, the electrode position for the forearm muscles was checked in the typical playing position.

2.5. Maximum voluntary isometric contraction test

Before the violin playing protocol, EMG normalization were carried out. Each participant was instructed to perform three trials of resisted maximal voluntary isometric contractions (MVIC) for the forearm muscles and UT and with each contraction lasting five seconds. For normalization of the forearm extensor and flexor muscles a maximum handgrip strength test, with a Jamar grip dynamometer preset to fit the hand size was used. The participants were standing against a wall with the elbow 90° flexed and the wrist in neutral position (Essendrop et al., 2001). For normalization of UT a performance of shoulder elevation was done with the participants placed in an adjustable standardized chair with their back straight, both arms relaxed, uncrossed legs and no
floor contact; two resistance plates were placed above the shoulders one centimeter medially to the lateral edge of acromion. To ensure a maximum effort the participant was asked after each MVIC, on a Likert’s scale from 0 (nothing performed) to 10 (performed maximally) if performance was maximal and a score above 8 was accepted. The three MVIC were separated by one minute for recovery and if the third MVIC was > 5% higher than one of the previous, a fourth or even a fifth test was performed. To eliminate fatigue a five minutes rest period was held before recording the EMG signal during violin playing.

2.6. Protocolled scale and music playing

The violin playing protocol included one static condition, two different scales (A and E major) and a music piece played in this protocolled order. The static condition was performed by holding the violin in the playing position for 20 seconds (the bow resting on the strings and the left hand holding the violin neck) without playing. This was recorded for each participant prior to the scales and music piece. Scales are standardized tasks performed with fundamental techniques where the goal when practicing scales are to improve; finger speed, rhythm, bowing techniques, muscle memory of common patterns and intonation whereas music piece combines all kinds of bow speeds and variations and finger movements in not a controlled pattern as scale playing. The A and E major scale was played in three octaves ascending and descending in pitch and with all notes played with separated bow strokes and no vibrato technique. The scales are evaluated by The Associated Board of the Royal Schools of music, violin exams 1-8, the E major being more difficult (grade 8) than the A major scale (grade 5)(ABRSM, 2019) because of the left hand position on the fingerboard. The music excerpt was the second movement from W. A. Mozart’s Violin Concerto no. 5 in A Major (supplement 1) was played right after the E major scale. This piece is often used as solo piece for violin competitions and includes different techniques for both right and left arm as well as hand.
One week prior to the test day all participants had received the music scores and information about tempo, fingering and bowing technique. All playing was performed in a tempo of crotchet = 60 beats per minute (bpm) and with a metronome set to 60 bpm and the violinists seated on a chair without armrests.

2.7. **EMG data processing**

The raw EMG data were pre-amplified with a gain of 500 and analogue band-pass filtered from 4Hz to 500Hz, 4th order. The signals were converted from analogue to digital (NI-USB 6210, 16-bit A/D converter, National Instruments Corporation, USA) with a sampling rate of 1000 Hz. Raw data was stored with laboratory interface (CED 1401mkII, spike-2 software v. 6.02 2006, Cambridge Electronic Design, UK). Signal analysis was conducted using a custom-made software (Hedera 3.0, the University of Southern Denmark, Denmark).

Prior to analyses, the digital signals of the EMG amplitude were represented as EMG root mean square (RMS) values with a window size of one second. For detection of the highest RMS amplitude during the MVIC, a window size of one second moving in 100 ms steps was used throughout the MVIC. For the playing tasks the RMS values were determined and normalized using the highest RMS found for each muscle MVIC expressing relative %MVE. The events were set for the entire period (one window) and analyzed in 1 second epochs. The playing time was 44 seconds for the scales and 76 seconds for the music piece (Figure 1).

An amplitude probability distribution function (APDF) was used to evaluate the muscle activity over the total window with muscle activity identified in the APDF as the $10^{th}$ ($P_{0.1}$), $50^{th}$ ($P_{0.5}$) and $90^{th}$ ($P_{0.9}$) percentiles of the entire recording period for the normalized RMS processed signal and summarized for each level as median (IQR) (Hagberg, 1979). The percentiles are indicators of static muscle activity ($P_{0.1}$, low level amplitude that is exceeded during 90% of the playing time), median
muscle activity (P0.5) and peak levels of muscle activity (P0.9, high level amplitude that is exceeded for 10% of the playing time).

2.9. Statistical analysis

All statistical analyses were performed using STATA (StataCorp, 2015). The level of statistical significance was set to p < 0.05. Mean value, 95% CI or SD were calculated for each continuous variable. For the APDF median and IQR were calculated.

Differences between the scales and the music piece were determined by one-way repeated measures ANOVA, and specific significant differences between the four playing conditions were determined using Turkey HSD as a post hoc test.

Differences between right and left side muscles for each playing condition in P0.1, P0.5, and P0.9 were analyzed using Wilcoxon matched pairs signed-rank test.

An explorative analysis was done including a Spearman correlation between %MVE and humerus, forearm length or circumference from thumb to little or middle finger.
3. Results

In total 21 violinists were examined, of those one was excluded due to acute emerged illness not related to this study, one rejected the skin preparation procedure for sEMG, and one failed to play the repertoire, leaving 18 violinists in the study of which 11 were females aged 21-60 years and seven males aged 28-64 years. Fourteen were symphony orchestra violinists, three conservatory students, and one semi-professional violinist (Table 1). Only one participant was excluded from the maximum strength test due to medical reasons and also from the maximum voluntary isometric contraction (MVIC) test.

3.1. Muscle activity

Table 2 shows the muscle activity level for each muscle during the different playing conditions (static, scales and the music piece). Both left and right forearm showed a significant difference in muscle activity between the four playing conditions (p<0.001). For the left forearm muscles: FDS (F3,46=23.55), EDC (F3,46=26.56), ECR (F3,36=24.08) and ECU (F3,46=86.76), and for the right forearm muscles: FDS (F3,46=14.54), EDC (F3,46=39.62), ECR (F3,46=58.07) and ECU (F3,46=63.66). The post-hoc analysis revealed higher muscle activity for playing the music compared to the static condition (p=0.001) for all muscles in both forearms. Only left ECU (p=0.03) and left FDS (p=0.001) showed a statistically significant higher muscle activity when the music piece was played compared to the A major scale. No significant differences in muscle activity were found for UT bilaterally compared to the playing conditions.

The APDF demonstrated an overall significant difference between right and left forearm muscles in both P0.1, P0.5 and P0.9 (Figure 2) with a higher activity for the left forearm muscles. During the music piece left ECU presented the highest peak load (P0.9) (median 30.6 %MVE) of all muscles. The P0.1 static level for right UT showed no side difference across all playing conditions,
indicating that the muscles on both sides exceeded this level for 90% of the playing time. However, the high level P0.9, was for right UT found to be 41.7% higher compared to left UT across all playing conditions. The outliers were all identified as measures related to professional violinists, respectively three men and five women and the age in both groups from 22 to 64.

3.3. Anthropometric measurements

The relationship between muscle activity (% MVE) for right and left side and the anthropometric measurements (humerus, forearm length or circumference from thumb to little or middle finger) was assessed by correlation (Figure 3). A strong negative correlation was demonstrated between %MVE of right ECR and all the anthropometric measurements, likewise between %MVE of left EDC and the circumference from thumb to middle finger. Generally, men had longer anthropometric measurements and lower %MVE.
4. Discussion

To our knowledge the current study is the first to compare and quantify the relative activity levels for playing standardized scales and a music piece. Previous research has utilized various measurement conditions to quantify muscle activity during violin playing either scale playing (Shan et al., 2004) or music pieces in different levels of difficulty (Berque and Gray, 2002) or a combination (Möller et al., 2018) but with different focus; the differences in playing conditions may lead to difficulties in comparing the results (Rensing et al., 2018). The results of the current study found no overall differences between playing scales or the chosen music piece. However, the more challenging E major scale was more comparable to the muscle activity produced while playing the music piece than the easier A major scale looking at activity across all muscles. This is probably due to the difficulty in playing the E scale, that has a higher positioning on the fingerboard (ABRSM, 2019). Generally, the EMG levels show that playing the violin is a low-force activity for both the right and left upper extremity muscles that overall show static levels (P0.1) of roughly 5-13 %MVE across all muscles indicating a muscle activity of this level for 90% of the playing time. Generally, left forearm muscles had higher static EMG levels than the right, which is in accordance with the different complex movement pattern for the two sides during violin playing, the left hand fingers moving on the finger board, the right hand holding the bow. The UT performed static and constant muscle activity across all playing conditions with no side difference which is probably related to a muscle coactivation where left UT are holding the instrument clenched between the left shoulder and the jaw without much freedom to change position. An earlier study showed that the right arm deltoid muscle is responsible for lifting the bow over the strings (Shan et al., 2004) and that in the high muscle activity levels (P0.9) higher muscle activity is found in right UT than in the left, which can be explained by the kinematic movements.
Despite higher muscle activity in the left forearm, this study found generally low muscle activity levels for both sides which supports that both sides are equally prevalent to injuries and pain with no side difference (Kok et al., 2016). In this study the musicians only played for a few minutes whereas the playing time for full-time professional musicians in symphony orchestras is between 23 and 33 hours per week (Paarup et al., 2011; Schmidt et al., 2014). The mechanism behind the association of injuries, pain and low contraction is not yet fully understood (Sjogaard et al., 1986) and establishing a safe threshold to avoid the risk of pain and muscle fatigue is currently not possible. However, previous research has shown that repetitive work as low as only 5% MVE still involves an increased risk for muscle fatigue. This is compatible with the so-called Cinderella hypothesis explaining how continuous work of low threshold motor units can lead to fatigue, pain and strain injuries even during low force contractions (Hagg, 1991). A recent study (Möller et al., 2018) among violinists with and without pain in their upper arm found that the right arm muscles tended to fatigue more amongst violinist with pain and with no sign of fatigue in the left arm than in pain-free violinists. This could be related to the findings in this study with low static activity in the right arm compared to a more dynamic contractions with muscle activity as high as 30.6 %MVE.

Physical load is only one of the external factors that may be involved in development of injuries in violinists, others as seating posture (Spahn et al., 2014) and playing technique (Visentin et al., 2015) should also be considered together with internal factors as gender-related anatomical variability and physiology and the individual susceptibility. In this study a correlation was found between shorter anthropometric measurements and higher muscle activity, respectively, for two different forearm muscles (right ECR and left EDC). Furthermore, women with shorter arms and finger circumference had higher muscle activity levels than men, which supports that anthropometric measures may be the underlying factor for the difference in the playing-related pain between men and women. Several studies have confirmed that females in general report more
musculoskeletal pain than males (Cimas et al., 2018; De Zwart et al., 2000; Paarup et al., 2011). An explorative study observing six violinists found that a smaller stature and shorter humerus measurement were associated with a greater elbow and shoulder work in the higher positions on the fingerboard, hence anthropometry may be a factor to an alteration of both kinematic movement and muscle activity (Visentin et al., 2015). The anthropometric measurements are representative and comparable to other occupational groups using this protocol (Søgaard et al., 2015), although the violinists in this study had a longer circumference from thumb to little finger which may be related to their training with stretching out to reach the different notes while playing, not longer fingers.

A recent literature review describing the musculoskeletal demands for violinists highlighted that violin playing is complex for both left and right side but in different ways (Rensing et al., 2018). This may be one of the reasons for why many studies have solely described one of the sides and why studies of the activity in different muscles limit the possibility for comparison of study results. In this study the playing protocol and its design allow well-structured sEMG-based investigations among violinists, which is a strength just as the wireless equipment minimizing constrains of movements and interaction with normal movement patterns and the measurement of many muscles bilaterally is. Nevertheless, the many muscles in the forearm are close to each other and with a small surface area on the overlying skin and due to stretch of the skin and other deeper or nearer muscles influencing the signal crosstalk cannot be ruled out. Furthermore, a limitation in the use of sEMG is that with rotation of the forearm during playing the geometrical relationship may change as target muscles may move away from the electrodes on the skin. The position of the electrodes was checked in the playing position, but the results should be interpreted as a rough representation for the entire flexor and extensor muscle groups in general.

Other limitations were the small population and the mixing of professional and semi-professional violinists, which may have increased variation in the EMG measures, providing less
statistical power and raising the risk of type 2 error. However, age, gender and level of music experience cannot explain the outliers found in this study and should be further investigated.
5. Conclusions

This study demonstrated that scales played as standardized tasks can be used to estimate the average muscle activity during violin playing. It confirmed that violinists have higher EMG levels from the left than from the right forearm muscles, and that higher muscle activity can be found among women, the latter probably due to their relatively shorter arms and hand circumference. Overall, violin playing is a constant, low force activity <20 %MVE and these results are decisive for future investigation of preventive initiatives to minimize development of musculoskeletal problems in violinists.

Acknowledgments

M.Sc. Henrik Baare Olsen has assisted with advice and technical support.

Conflict of interest

None to be declared.
References


Hagberg, M., 1979. The amplitude distribution of surface EMG in static and intermittent static


Table 1
Descriptive characteristics of the participants. Continuous variables are presented as mean ± standard deviation and nominal as number (%).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Women</th>
<th>Men</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of participants</td>
<td>11</td>
<td>7</td>
<td>18</td>
</tr>
<tr>
<td>Professional musicians (%)</td>
<td>73</td>
<td>86</td>
<td>78</td>
</tr>
<tr>
<td>Age (years)</td>
<td>39.2 ± 16.0</td>
<td>46.6 ± 13.2</td>
<td>42.2 ± 15.0</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.7 ± 0.1</td>
<td>1.7 ± 0.1</td>
<td>1.7 ± 0.1</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>67.5 ± 16.5</td>
<td>73.6 ± 11.9</td>
<td>69.9 ± 14.8</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.7 ± 5.6</td>
<td>24.9 ± 3.4</td>
<td>24.5 ± 4.7</td>
</tr>
<tr>
<td>Daily practice the last 12 months (hours)</td>
<td>3.6 ± 1.4</td>
<td>4.3 ± 1.0</td>
<td>3.9 ± 1.3</td>
</tr>
<tr>
<td>Age for starting with main instrument (years)</td>
<td>6.5 ± 1.2</td>
<td>8.9 ± 3.1</td>
<td>7.3 ± 2.0</td>
</tr>
<tr>
<td>Age for starting playing music (years)</td>
<td>5.1 ± 1.5</td>
<td>7.0 ± 2.3</td>
<td>5.8 ± 2.0</td>
</tr>
</tbody>
</table>

**Anthropometry**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Women</th>
<th>Men</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circumference from thumb to little finger (cm)</td>
<td>6.2 ± 3.3</td>
<td>10.29 ± 1.8</td>
<td>7.8 ± 3.4</td>
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<tr>
<td>Circumference from thumb to middle finger (cm)</td>
<td>10.6 ± 2.8</td>
<td>15.14 ± 1.1</td>
<td>12.3 ± 3.2</td>
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<tr>
<td>Humerus length (cm)</td>
<td>32.4 ± 2.4</td>
<td>35.6 ± 1.4</td>
<td>33.6 ± 2.6</td>
</tr>
<tr>
<td>Forearm length (cm)</td>
<td>43.6 ± 3.0</td>
<td>47.8 ± 2.5</td>
<td>45.2 ± 3.5</td>
</tr>
</tbody>
</table>

**Tension or soreness within the last 12 months**

<table>
<thead>
<tr>
<th>Source</th>
<th>Women</th>
<th>Men</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck, N (%)</td>
<td>9 (81.8)</td>
<td>5 (71.4)</td>
<td>14 (77.8)</td>
</tr>
<tr>
<td>Upper back, N (%)</td>
<td>6 (54.6)</td>
<td>3 (42.9)</td>
<td>9 (50.0)</td>
</tr>
<tr>
<td>Right shoulder, N (%)</td>
<td>4 (36.4)</td>
<td>3 (42.9)</td>
<td>7 (39.9)</td>
</tr>
<tr>
<td>Left shoulder, N (%)</td>
<td>5 (45.5)</td>
<td>3 (42.9)</td>
<td>8 (44.4)</td>
</tr>
</tbody>
</table>
The scales and music piece from the article entitled “Surface electromyography of forearm and shoulder muscles during violin playing”.

First playing task in the playing protocol: The A major scale

A major scale

Second playing task in the playing protocol: The E major scale

E major scale
Third playing task in the playing protocol: The music piece

Mozart Violin Concerto No. 5 in A major, 2nd movement

Fingering Frieder Hermann:
Fig. 3. Correlations (Spearman’s rank correlation coefficient, r).
A-D: Correlation between %MVE of right ECR and the different anthropometric measurements.
E: Correlation between %MVE of left EDC and the circumference from thumb to middle finger.
Table 2
95% CI for the mean RMS level (%MVE) examined for each muscle while holding the instrument, playing scales and the music piece. A total score for the average of the mean %MVE was calculated from all measured right side and left side muscles. \( P \leq 0.05 \) indicates a statistically significant difference between the four playing tasks.

<table>
<thead>
<tr>
<th>Muscles</th>
<th>Rest with instrument</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean %MVE</td>
<td>95% CI</td>
<td>Mean %MVE</td>
<td>95% CI</td>
<td>Mean %MVE</td>
<td>95% CI</td>
<td>Mean %MVE</td>
<td>95% CI</td>
</tr>
<tr>
<td><strong>Right side</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UT</td>
<td>7.1</td>
<td>4.4 - 11.4</td>
<td>12.8</td>
<td>9.4 - 16.3</td>
<td>13.0</td>
<td>9.6 - 16.4</td>
<td>11.5</td>
<td>8.2 - 14.9</td>
</tr>
<tr>
<td>FDS</td>
<td>3.3</td>
<td>2.3 - 4.3</td>
<td>8.6</td>
<td>5.7 - 11.6</td>
<td>8.9</td>
<td>6.5 - 14.2</td>
<td>10.3</td>
<td>6.5 - 14.2</td>
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<tr>
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<td>3.7 - 6.9</td>
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<td>9.8 - 14.5</td>
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<td>9.7 - 14.6</td>
<td>11.9</td>
<td>9.4 - 14.3</td>
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<td>8.7</td>
<td>6.0 - 11.4</td>
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Fig. 1. A sample showing the raw EMG from ECU during the first part of the music piece and with its RMS envelope.
Fig. 2. EMG activity is presented as median (IQR) for the 10th percentile (P0.1), 50th percentiles (P0.5) and 90th percentiles (P0.9) for all muscles during the playing conditions including mean (x) and outliers. * Significant difference between left and right side muscles for either A-major, E-major or music piece.
Author Biography

**Stephanie Mann** is currently enrolled as a PhD student in the research unit for Physical Activity and Health in working life from the Department of Sports Science and Clinical Biomechanics, University of Southern Denmark and is a research member in the Center for Performing Arts Medicine. She received her MSc. in physiotherapy in 2017 from University of Southern Denmark. Stephanie has played the viola for several years as an amateur with different high amateur orchestras in Denmark as KYS (Copenhagen Young Strings). She developed an interest in musicians’ health after developing her own difficulties with playing her instrument. Her research is focusing on quantifying violinists work exposure and to use this knowledge to find preventive initiatives as ergonomic and training for preventing of musculoskeletal problems related to playing.

**Mads Panduro** completed his BSc. in physiotherapy in 2014 and received the MSc. in physiotherapy in 2019 from the department of Sports Science and Clinical Biomechanics, Faculty of Health Sciences at the University of Southern Denmark (SDU), and in the period from 2015 to 2019, he has been working as a research assistant at the Center for Performing Arts Medicine at the Clinic of Occupational and Environmental Medicine at Odense University Hospital (OUH) and is currently working as a project manager targeting quality development and evidence-based practice in the private sector. His main area of research is focused on quantifying work exposures and the use of physical exercise interventions in rehabilitation and prevention of work-related musculoskeletal disorders.
Lars Brandt, Specialist in Occupational Medicine, Ph.D. Head of Department of Occupational and Environmental Medicine and Clinic of Performing Arts Medicine, Odense University Hospital, Denmark. Ass. Professor and Research Leader Section of Occupational Medicine, Department of Clinical Research, Faculty of Health Science University of Southern Denmark.

Helene M. Paarup has a PhD in occupational medicine and has 15 years of research experience within medical epidemiological studies including in musicians’ health. She is the initiator of the Clinic for Performing Arts Medicine at Odense University Hospital and since 2005 she has been part of the Center of Performing Arts Medicine, a cooperation between the University of Southern Denmark and Odense University Hospital. She is a trained physician and holder of diploma in specialized business studies in innovation. She is currently fulfilling a position as post.doc. at the Research Unit of Occupational & Environmental Medicine, the Department of Clinical Research, University of Southern Denmark.

Professor Karen Sogaard, received her M.Sc. in Physical Education from the August Krogh Institute, University of Copenhagen in 1986 and at the same institution pursued a Ph.D. in Human
Physiology in 1994. Currently, she is head of the research unit, Physical Activity and Health in Working Life, professor at Center for Performing Arts Medicine as well as Center for Muscle and Joint Health, University of Southern Denmark. Main field of competence is human exercise physiology with focus on muscle activity, mechanics, and fatigue. Her recent main focus is randomized controlled trial interventions focused on physical activity as prevention and rehabilitation. Karen Søgaard has contributed to 240 original papers in international peer reviewed scientific journals. She has been member of the ISEK council since 2010 and president from 2018-2020.