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Differences in violin fixation force and muscle activity among violinists with and without complaints of the neck shoulder region

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A B S T R A C T

Purpose: The aim of this study is to determine the relationship between complaints of the neck and shoulder region, the jaw-shoulder violin fixation force, and the activity of the neck and shoulder muscles in violinists.
Methods: In this case-control study twenty professional violinists were included, of which ten with current complaints of the neck shoulder region and ten without these complaints. A questionnaire including the DASH and NDI was used; violin fixation force and activity of the superficial neck muscles were evaluated in five playing conditions.
Results: Each group consisted of eight female and two male violists with a mean age of 29 years. Violinists with complaints had more muscle activity of all evaluated muscles compared to violinists without complaints; complaints were significantly associated with the muscle activity of all evaluated muscles. Complaints were not significantly associated with the violin fixation force. The playing condition significantly predicted the violin fixation force and the activity of all muscles except the left mTP.
Conclusions: Violinists with complaints have more muscle activity of some superficial neck and shoulder muscles. Co-contraction is thought to play a relevant role in violinists with these complaints.

1. ıntroduction

Musculoskeletal complaints are a frequent, serious and potentially career threatening problem among professional musicians (Zaza et al., 1998; Kok et al., 2016). The majority of professional musicians suffer from musculoskeletal complaints affecting their ability to play their instrument (Kok et al., 2016, 2015). In a recent systematic review, the year-prevalence of musculoskeletal complaints in professional musicians ranged between 41% and 93% (Kok et al., 2016). The neck and shoulders are among the body regions most affected, especially among the higher string instrument players, i.e. violinists (violin players) and violists (viola players) (Kok et al., 2016; Roach et al., 1994; Engquist et al., 2004; Middlestadt and Fishbein, 1989).

Violinists primarily strive for a beautiful sound, which is produced by a playing technique with efficient motion patterns and avoidance of unnecessary muscle activity (Fjellman-Wiklund et al., 2004; Philipson et al., 1990). This playing technique is by violinists often described as 'playing without tension' (Fischer, 1997; Menuhin, 1974). The muscle activity while playing the instrument is the result of many factors, among them basic posture of the violinists, and the positioning of the violin. For example, playing with minimum finger pressure possible, as excessive finger pressure necessitates counterpressure from the thumb, working in a vicious circle towards less ease of movement (Fischer, 1997). Although the left hand also supports the violin, its contribution is minimal, as this hand needs to move freely while playing (Menuhin, 1974; Tubiana et al., 1989). However, some static muscle activity in the neck and shoulder region is necessary as the violin is stabilised and fixated (both for right and left-handed individuals) between the left shoulder and jaw during active playing the instrument (Tubiana et al., 1989).

In neck pain patients in the general population altered activation of the neck muscles is observed (Lazzarini et al., 2003; Lindstrøm et al., 2011; Boudreau and Falla et al., 2014; Bech et al., 2017). Also in shoulder pain altered muscle activity is observed, including delayed activation of affected muscles, redistribution of the muscle activity within a muscle as well as redistribution to synergistic muscles (McCrary et al., 2016; Struyf et al., 2015). Therefore, in violinists playing with pain, muscle activity is likely to be altered compared to

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Table 1
Playing conditions.

Name	Playing condition	Fragment	Excerpt	Technical description
Static	1	–	Static	Left hand in first position and the bow at the tip on the E-string. The subject was asked to hold this position for five seconds. 100 bpm
Open strings	2	1	Open strings	Open strings: Four times each string, while using the whole bow. In this excerpt, the fingers of the left hand were not used other than supporting the violin. Technically low demanding. 100 bpm
First position	3	2	Ševčík etude 29	Entirely in first position of the left hand; no shifts of the left hand 100 bpm
Shifts	4	3	Ševčík etude 3	Repeated shifts of the left hand
Virtuosic	5	4	Kreisler opus 6; Recitativo and Scherzo Caprice	Virtuosic; technically demanding. Violinists were instructed to play expressive and free, like performing during a concert. No metronome

their healthy colleagues. However, contradicting results are reported in the literature on this subject (Philipson et al., 1990; McCrary et al., 2016; Berque and Gray, 2002; Park et al., 2012; Overton and Du, 2018). Berque and Gray (2002) observed more muscle activity in the trapezius muscles of pain-free violinists and violists, compared to violinists who reported pain while playing the instrument (Berque and Gray, 2002). These results are contrary to the results of the study of Philipson et al. (1990), showing more muscular activity in violinists with pain in the neck and shoulder region (Philipson et al., 1990). Also Park et al. (2012) reported more activity of the neck muscles in violinists with complaints while playing the instrument (Park et al., 2012). Overton et al concluded in a recent systematic review evaluating upper trapezius activity comparing violinists with and without pain, there is conflicting evidence for increased upper trapezius activity in symptomatic violinists (Overton and Du, 2018). However, limited evidence was reported confirming the hypothesis that musicians with musculoskeletal pain display increased EMG muscle activity.

In several occupational groups, prolonged static loading of the neck musculature is associated with pain (Larsson et al., 2007). We hypothesize the same association is present in professional violinists. The aim of this study is therefore to determine the relationship between complaints of the neck shoulder region in violinists and the violin fixation force and muscle activity. We hypothesize that the violin fixation force is higher among violinists with complaints of the neck shoulder region compared to violinists without these complaints. Furthermore, we hypothesize more muscle activity of the sternocleidomastoid muscles (mSCM), upper trapezius muscles (mTP) and left anterior part of the deltoid muscle (mDTA) among violinists with complaints of the neck shoulder region compared to violinists without these complaints. Finally, we hypothesize a difference in the adjustment of the violinists' own shoulder-rest between the two groups of violinists.

2. Methods

2.1. Participants

We asked professional violinists to participate in this observational case-control study, aiming to balance violinists with and without current complaints of the neck shoulder region. Professional violinists were defined as either currently attending a music academy or a finished music academy degree, with the violin as main subject. Inclusion criteria included playing the violin on a professional level and age 18 years or older. Exclusion criteria included recent fractures or operations of the spine and upper extremities (< 1 year) and systemic diseases influencing the musculoskeletal system. Violinists were approached at music institutions, social media, and by word of mouth. The study protocol was reviewed by the local ethical who decided the Medical Research Act did not apply. All participants provided written informed consent.

2.2. Questionnaire

All participants were asked to complete a questionnaire, consisting of baseline demographic questions, questions on and playing habits and complaints. Baseline characteristics (age, sex, length, weight, hand dominance, smoking, sports), profession (professional mainly teaching/professional mainly performing/student/other), playing habits (average playing hours in a week during last 4 weeks, age of start playing the violin) and the presence of current complaints of the neck and/or shoulder(s) were questioned. Subjects who answered at least one of the following questions with 'yes' were included in the 'complaints' group: 'Do you currently have complaints of your neck?'; 'Do you currently have complaints of your shoulder(s)?'. The questionnaire also included the Neck Disability Index (NDI) and Disabilities of the Arm, Shoulder and Hand (DASH) (Hudak et al., 1996; Vernon and Mior, 1991). Both the regular DASH the optional 4-item music module were

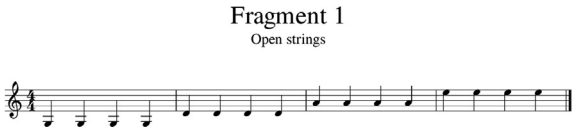

Fig. 1. Fragment 1/Playing condition 2: 'Open strings'

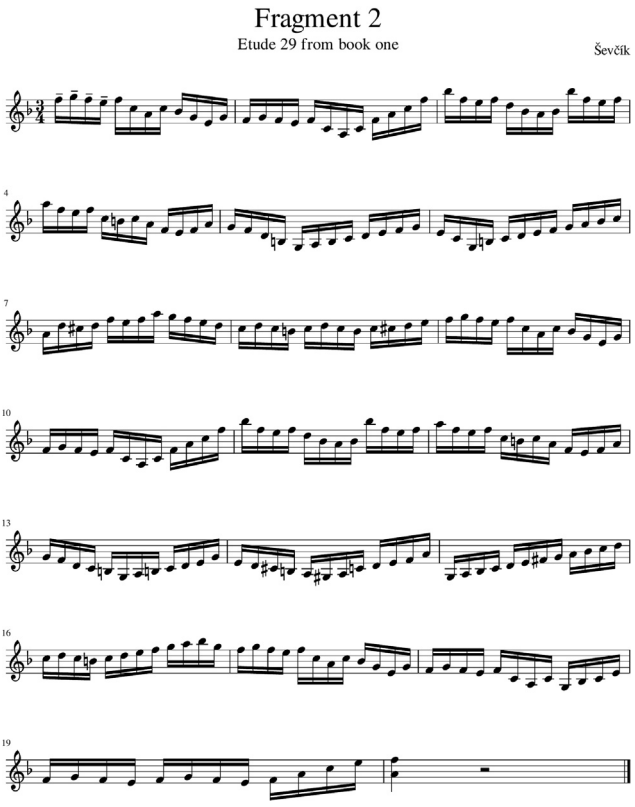

Fig. 2. Fragment 2/Playing condition 3: 'First position', Ševčík etude 29.

used in the current study.

2.3. Measurement procedures

This study was performed between April and August 2017. All violinists played on the provided violin with instrumented chin-rest but used their own shoulder rest. The excerpts were made available to the participants prior to data collection; participants were asked to prepare the excerpts. Five different measurements ('playing conditions') were performed by each violinist, a static position and four playing conditions: 'open strings', 'first position', 'shifts', and 'virtuosic' (Table 1, Figs. 1–5). Fatigue is supposed to play no role in our measurements (Chan et al., 2000; Yeung et al., 2000), therefore no resting interval was established in between the different playing conditions. The first fragment consisted of open strings and therefore is considered as technically low-demanding. The second fragment consisted of Ševčík etude 29 from book one (Ševčík and Schirmer, 1905); The third fragment was derived from Ševčík etude 3 from book 3 (Ševčík and Schirmer, 1905), compared to fragment two it is of increasing difficulty. The last fragment consisted of the first nine bars from Kreisler opus 6, Recitativo and Scherzo Caprice (Kreisler, 1911).

2.4. Violin fixation force

The violin fixation force was measured by using an instrumented chin-rest (height: 2.6 cm); an ATI-mini40 6D force-sensor (ATI Industrial Automation) was used and build within a 3D printed chinrest

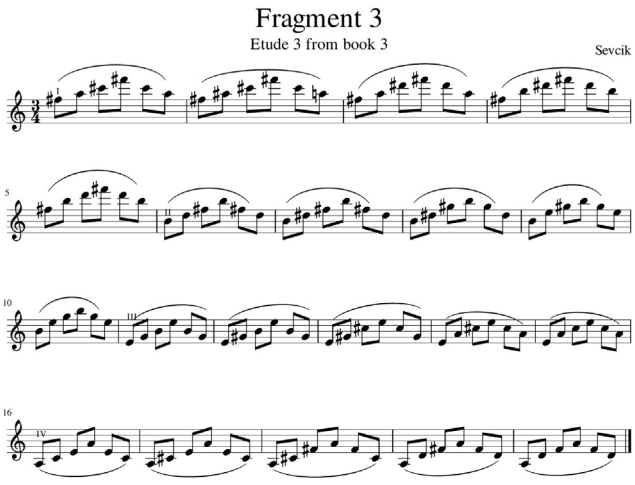

Fig. 3. Fragment 3/Playing condition 4: 'Shifts', Ševčík etude 3.

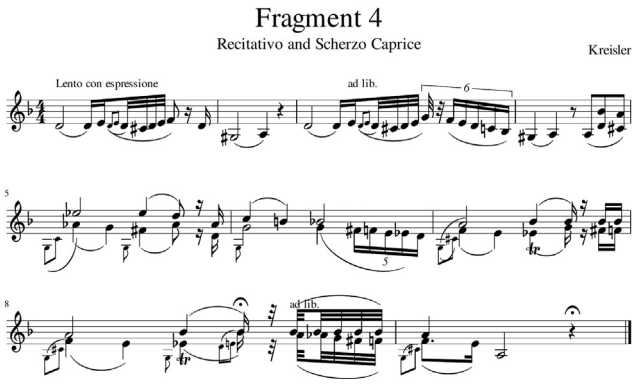

Fig. 4. Fragment 4/Playing condition 5: 'Virtuosic', Kreisler opus 6, Recitativo and Scherzo Caprice.

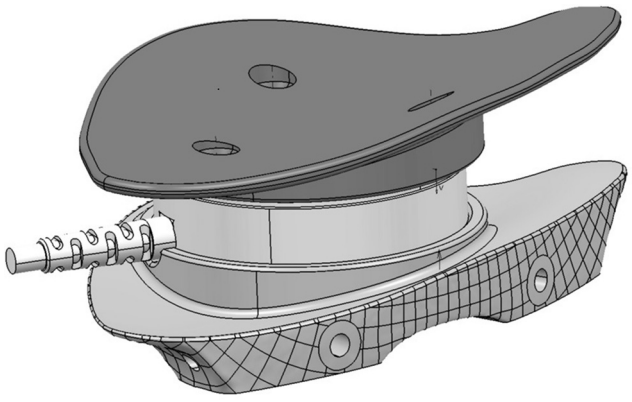

Fig. 5. The custom-made 3D printed violin chin-rest with built-in force sensor.

(Fig. 2). The three orthogonal components of the force were sampled at 1000 Hz using Vicon Nexus acquisition software. Prior to the measurements of each subject the offset of the unloaded force sensor was measured during a calibration measurement.

2.5. Muscle activity

The activity of the following muscles was measured using a surface-EMG (electromyogram): The left and right sternocleidomastoid muscles (mSCM, the left and right upper trapezius muscles (mTP) and the anterior part of the left deltoid muscle (mDTA). Recordings were made using self-adhesive Ag/AgCl disposable electrodes (Kendall H124SG;

foam discs with solid gel, diameter 24 mm), with an interelectrode distance of 25 mm. For the mSCM the electrodes were placed along the sternal portion of the muscle, with the electrode centre 1/3 of the distance between the mastoid process and the sternal notch (Falla et al., 2002). For the mTP the medial electrode was placed 2 cm lateral to the midpoint of the C4-C45 interspinous distance and oriented along the palpated anterior border of the trapezius in line with the muscle fibres (Burnett et al., 2007). For the mDTA the cranial electrode was placed three cm under the tip of the anterior part of the acromion, the second electrode was placed following the direction of the muscle fibres. The EMG signal was recorded and wirelessly transmitted (WAVE by CometaSystems) The EMG was synchronously sampled with the forces at 1000 Hz. Normalisation of the EMG was based on maximum voluntary isometric contractions (MVIC); during three seconds. For each of the procedures the participant maintains a given position isometrically to the maximum of their muscular ability against the external force applied by the examiner. After training of the procedures, with verbal feedback of the researcher concerning maintaining the adequate positioning of the joints and adequate (maximum) force, a normalisation procedure was carried out: a set consisted of three times three seconds maximal isometric force, alternated with maximal relaxation in between, also for three seconds. All tests were performed seated, with full back support. The following normalisation procedures were followed, all of them performed both left and right; 1. 'Shoulder flexion'; Shoulder flexion in 125 degrees as resistance applied above elbow and at inferior angle of scapula attempting to de-rotate scapula; (normalisation of the mTP and mDTA) (Boettcher et al., 2008) 2. 'Empty can'; Shoulder abducted 90 degrees in the plane of the scapula, internally rotated and the elbow extended. The arm was abducted as resistance was applied at wrist by the researcher (normalisation of the mTP and mDTA) (Boettcher et al., 2008). 3. 'Anterolateral neck flexion'; anterolateral neck flexion while resistance was applied to both shoulder and head (normalisation of the mSCM) (Kendall and Kendall, 2005). None of the violinists reported pain or discomfort during the MVIC testing).

2.6. Shoulder rest, chin rest, neck length

The brand of the participants' own shoulder rest was noted, as was the height of the left and right wing of the shoulder rest. The height of the wings was measured, ranging between the part of the wing resting on the shoulder and the part of the wing supporting the violin. Also, the height of the participants' own chin rest was measured at the point halfway between the two clamps fixating the chin rest to the violin. The neck length of all participants was measured twice; at the beginning and at the end of the study protocol. The neck length in this study was the distance between the angle of the mandibula and the middle of the ipsilateral clavicula, evaluated with the subject in neutral position (no violin).

2.7. Data processing

The force signals along the three axes were low pass filtered using a 3 Hz cut-off frequency after being corrected for offset in the unloaded calibration measurement. The violin fixation force was calculated as the average magnitude of the force vector applied during each excerpt. All EMG signals were high pass filtered (second order Butterworth filter with a cut-off frequency of 20 Hz) to remove motion artefacts. Then the signal was rectified, after which a two-directional low pass filter was applied (second order, Butterworth 3 Hz cut-off frequency) to obtain the envelope. The MVIC was determined by calculating the mean activity of the middle second of all relevant normalisation procedures for the relevant muscle. (Shoulder flexion and empty can for both the mTP and mDTA; anterolateral neck flexion for the mSCM). EMG normalisation was then achieved by dividing each envelope value by its MVIC. The mean of the EMG envelope and its standard deviation were calculated over the total playing period for each muscle for each playing condition. A custom designed Matlab script was used for all signal processing.

2.8. Data analysis

Subject variables are presented as mean and SD, except for the DASH and NDI which are presented as median with an interquartile range. Categorical variables are presented as a percentage. Comparisons between patient characteristics of the two groups were performed with chi-squared tests (for categorical variables: gender, hand dominance, smoking, profession), independent samples t-tests (for normally distributed continuous variables: age, BMI, sports, playing load, starting age) or Mann Whitney U-tests (for continuous variables, not normally distributed: NDI, DASH and music module of the DASH). Multivariable linear regression analysis were performed, with the activity of the five muscles and jaw-shoulder violin fixation force as dependent variable and complaints of the neck shoulder region and playing condition as independent variables. Also, the same analysis with the DASH outcome measure instead of complaints (yes/no) was performed. Correlation between the activity of the left and right mSCM ('co-contraction') was calculated using Pearson's correlation coefficient. The level of statistical significance was set at $p \leq 0.05$ for all analyses. Statistical analyses were performed in SPSS (IBM, version 23).

3. Results

3.1. Subject characteristics

Twenty violinists were included in this study, of which ten with current complaints of the neck shoulder region and ten without these complaints. Among the violinists with current complaints of the neck shoulder region, 2 violinists reported solely neck complaints, 4 violinists reported complaints of the neck and both shoulders, 2 violinists reported complaints of the neck and right shoulder, 1 violinist reported complaints of both shoulders, and 1 violinist reported solely pain of the left shoulder. Baseline variables for the two groups are presented in Table 2. The groups were comparable for all evaluated baseline variables except for BMI. Each group consisted of eight female and two male violinists; the mean age of the participants in both groups was 29 years. All violinists were able to play the four musical excerpts, including the virtuous excerpt. The scores of the outcome measures NDI, DASH and the music module of the DASH were significantly different between the two groups (Table 2), thereby validating our stratification. The median score of the NDI was 13.0 (IQR 10.0–21.0) and 4.0 (IQR 0.5–6.0) in the group with and without complaints respectively. The median score of the regular DASH was 7.5 (IQR 6.0–21.8) compared to 0.9 (IQR 0.0–2.3) in the control group. The median score of the music module of the DASH was 3.2 (IQR 0.0–11.6) in the control group. None of the participants had to call in sick or missed earnings due to complaints of the neck shoulder region.

3.2. Violin fixation force & muscle activity

The mean jaw-shoulder violin fixation force as measured by the force sensor in the chin rest during playing of the five playing conditions is shown in Table 3. The muscle activity of the mSCM (left and right), mTP (left and right) and mDTA in violinists with and without complaints are displayed in Table 4. Violinists with complaints have higher activity of all evaluated muscles compared to violinists without complaints (left mSCM + 48.5%; right mSCM + 43.6%; left mTP + 75.2%; right mTP + 43.3%; left mDTA + 24.2%). In Fig. 6 a sample of the saw EMG signals from each group is presented.

To investigate the effect of complaints of the neck shoulder region and the playing condition (fragment) linear regression models with fixation force and muscle activity of the five muscles as outcome variable were estimated; results are displayed in Table 5a. Complaints had a

Table 2
Subject characteristics of the included violinists with and without neck complaints.

		Violinists with complaints (n = 10)	Violinists without complaints (n = 10)	Significance (p)
Age (years)		29.4 (3.7)	29.3 (3.9)	0.954*
Gender	Male:	2 (20%)	2 (20%)	1.000~
	Female:	8 (80%)	8 (80%)	
BMI (kg/m^2)		23.2 (1.8)	20.6 (1.9)	0.006*
Hand dominance	Right:	10 (100%)	9 (90%)	0.305~
	Left:	0	1 (10%)	
Smoking	Yes:	2 (20%)	0	0.136~
	No:	8 (80%)	10 (100%)	
Sports (hours/week)		2.2 (2.1)	1.5 (1.0)	0.274*
Profession	Mainly performing:	8 (80%)	8 (80%)	0.513~
	Music academy student:	1 (10%)	2 (20%)	
	Other:	1 (10%)	0	
Playing load (hours/week)		23.0 (10.0)	33.2 (15.2)	0.094*
Starting age		5.9 (1.6)	6.3 (1.5)	0.529*
NDI*		13.0 (10.0–21.0)	4.0 (0.5–6.0)	0.009^
DASH*		7.5 (6.0–21.8)	0.9 (0.0–2.3)	< 0.001^
music module DASH*		28.2 (14.1–42.2)	3.2 (0.0–11.6)	0.009^

Nominal values: number (%), continue variables: mean (SD), *median and IQR.
* independent-samples *t*-test.
~ Chi-squared test.
^ Mann-Whitney *U* test.

Table 3
Mean violin fixation force in violinists with and without complaints of the neck shoulder region for the different playing conditions.

	Violinists with complaints (N) (n = 10)	Violinists without complaints (N) (n = 10)
Static	1.44 (1.18)	1.03 (0.62)
Open strings	1.88 (1.32)	1.98 (1.51)
First position	2.59 (1.98)	2.00 (1.30)
Shifts	5.27 (2.93)	5.47 (2.47)
Virtuosic	5.29 (3.22)	4.72 (2.38)

Results displayed as mean violin fixation force in Newton (SD).

significant effect on the activity of the five muscles, but did not significantly predict the violin fixation force. Playing condition (the musical fragment) was significant in all models except for the left mTP. When the variable complaints is replaced for the DASH score in the linear regression models (Table 5b), a significant association was found with the activity of the left mSCM, both the mTP as well as the violin fixation force.

Simultaneous contraction of both the mSCM is different between the two groups; in violinists with complaints there was a strong positive correlation between the activity of the left and right mSCM (0.771, $p < 0.001$), while in violinists without complaints there was a moderate positive correlation (0.425, $p = 0.002$) Co-contraction of both the mSCM for each playing condition and group is displayed in Table 6.

Table 4
Muscle activity in violinists with and without complaints of the neck shoulder region.

		Violinists with complaints (% MVIC) (n = 10)	Violinists without complaints (% MVIC) (n = 10)	Difference	Effect size
Static	mSCM left	7.5% (4.7%)	5.1% (3.8%)	47.0%	
	mSCM right	7.0% (3.8%)	4.2% (2.1%)	66.7%	
	mTP left	15.6% (18.4%)	8.0% (4.9%)	95.0%	
	mTP right	5.3% (4.5%)	3.6% (3.4%)	47.2%	
	mDTA	25.2% (14.4%)	20.1% (7.7%)	25.4%	
Open strings	mSCM left	10.6% (6.4%)	6.2% (3.2%)	71.0%	
	mSCM right	12.0% (6.5%)	7.5% (6.0%)	60.0%	
	mTP left	18.2% (17.6%)	9.9% (5.9%)	83.8%	
	mTP right	22.9% (13.6%)	14.3% (5.2%)	60.1%	
	mDTA	21.7% (10.8%)	18.1% (6.6%)	19.9%	
First position	mSCM left	14.6% (9.6%)	9.1% (4.9%)	60.4%	
	mSCM right	13.3% (7.1%)	10.2% (10.3%)	30.4%	
	mTP left	18.8% (17.6%)	10.8% (4.8%)	74.1%	
	mTP right	19.7% (8.2%)	9.9% (4.1%)	99.0%	
	mDTA	20.6% (13.6%)	16.3% (4.6%)	26.4%	
Shifts	mSCM left	19.6% (11.1%)	15.3% (10.1%)	28.1%	
	mSCM right	15.3% (8.8%)	10.3% (8.3%)	51.4%	
	mTP left	16.8% (14.3%)	10.9% (6.3%)	54.1%	
	mTP right	19.6% (9.7%)	15.2% (4.3%)	28.9%	
	mDTA	16.5% (12.2%)	13.3% (4.6%)	24.1%	
Virtuosic	mSCM left	22.6% (11.6%)	14.6% (8.6%)	54.8%	
	mSCM right	20.0% (8.3%)	14.9% (14.1%)	34.2%	
	mTP left	21.8% (13.5%)	12.9% (7.2%)	69.0%	
	mTP right	32.4% (18.2%)	24.1% (6.1%)	34.4%	
	mDTA	16.2% (14.8%)	12.8% (4.2%)	26.6%	

Results displayed as mean (SD).

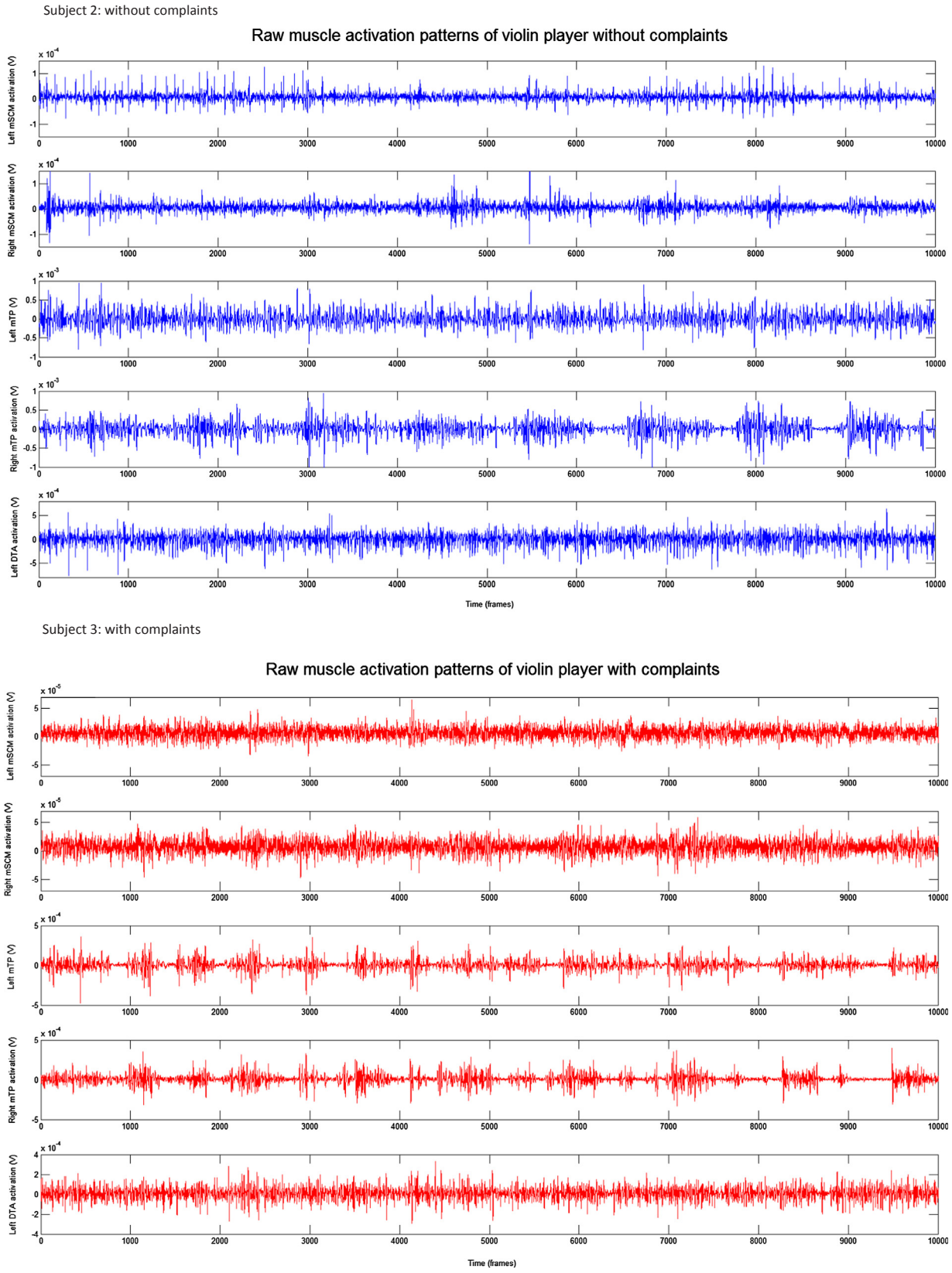

Fig. 6. Raw muscle activation patterns of violin players with and without complaints.

3.3. Shoulder rest adjustment & neck length

No significant differences in neck length or height of the shoulder or chin rest were present between participants with and without complaints. In Table 7 the measurements of neck length, shoulder rest and chin rest are displayed, as well as for the shoulder rest height corrected neck lengths. Also, after exclusion of the participants playing without a shoulder rest (n = 3), no significant differences were found in

Table 5a
Results of the linear regression modelling.

	Complaints		Playing condition (fragment)	
	B (SE)	p-value	B (SE)	p-value
mSCM left	0.049 (0.016)	0.002	0.034 (0.006)	< 0.001
mSCM right	0.041 (0.016)	0.011	0.027 (0.006)	< 0.001
mTP left	0.079 (0.024)	0.001	0.011 (0.008)	0.201
mTP right	0.058 (0.019)	0.003	0.046 (0.007)	< 0.001
mDTA left	0.039 (0.020)	0.050	−0.021 (0.007)	0.003
Violin fixation force	0.256 (0.185)	0.167	1.097 (0.065)	< 0.001

Estimated effect (B) along with the standard error (SE) from a multivariable linear regression model.

Table 5b
Results of the linear regression modelling.

	Dash		Playing condition (fragment)	
	B (SE)	p-value	B (SE)	p-value
mSCM left	0.003 (0.001)	0.003	0.034 (0.006)	< 0.001
mSCM right	0.002 (0.001)	0.088	0.027 (0.006)	< 0.001
mTP left	0.008 (0.001)	< 0.001	0.011 (0.008)	0.201
mTP right	0.005 (0.001)	< 0.001	0.046 (0.007)	< 0.001
mDTA left	0.002 (0.001)	0.182	−0.021 (0.007)	0.003
Violin fixation force	0.080 (0.023)	0.001	1.097 (0.065)	< 0.001

Estimated effect (B) along with the standard error (SE) from a multivariable linear regression model.

Table 6
Simultaneous contraction of both the mSCM.

	Violinists with complaints (n = 10)	Violinists without complaints (n = 10)
Static	0.761	0.345
Open strings	0.794	0.692
First position	0.712	0.534
Shifts	0.676	0.537
Virtuosic	0.661	0.097

The displayed values are correlation coefficients.

these variables between the two groups.

4. Discussion

The results of this study show that professional violinists with complaints of the neck shoulder region have increased muscle activity of the sternocleidomastoid muscles, trapezius muscles and left deltoid muscle while playing their instrument. Despite this increased muscle activity, complaints did not significantly predict the jaw-shoulder violin fixation force.

Conflicting results are presented concerning the effect of the complaints on the activity of the several neck and shoulders muscles (Philipson et al., 1990; McCrary et al., 2016; Berque and Gray, 2002; Park et al., 2012; Overton and Du, 2018). Recently, muscle activity of the trapezius in violinists with and without complaints was evaluated in a meta-analysis (Overton and Du, 2018). In this meta-analysis the studies of McCrary, Park and Philipson were included (Philipson et al., 1990; Park et al., 2012; McCrary et al., 2016); pooling of the data indicated no statistical differences in muscle activity in both the right and left upper trapezius muscles between the two groups of violinists (Overton and Du, 2018). However, Philipson et al. and Park et al. reported more and McCrary et al. less activity of the left and right trapezius muscles in violinists playing with pain (Philipson et al., 1990; Park et al., 2012; McCrary et al., 2016). Also in a study among bassists no difference in activity of the trapezius muscle was found between the symptomatic and asymptomatic group (Woldendorp, 2013). However, the study of Berque et al was not included in this meta-analysis; in this study violinists with pain showed more trapezius activity in rest, and less trapezius activity while playing, compared to asymptomatic violinists (Berque and Gray, 2002). Heterogeneity of the study populations and study methods may account for the reported differences between the several studies.

The above reported differences in studies examining muscle activity in violinists with and without complaints could be explained by differences in study protocols, for example the played excerpts, measuring techniques, heterogeneity of the study groups, different inclusion criteria and the small number of participants in the afore-mentioned studies. Also, the severity of and disability due to the complaints is a relevant factor, which was not fully addressed in the above-mentioned studies. In the current study we aimed to increase scientific quality; therefore we evaluated a homogenous group of violinists, thereby excluding violists as the viola is a bigger instrument and therefore has different biomechanical playing properties. Within the current study baseline variables, except for BMI, were evenly distributed between the two groups of violinists. Above, the severity and disability due to the complaints were evaluated using validated outcome measures.

We hypothesize that co-contraction is likely to be a relevant factor in violinists with complaints as there is a high correlation between activity of the left and right mSCM is present in violinists with complaints compared to a low correlation in violinists without complaints. This finding is consistent with the literature evaluating the general population, in which patients with neck pain show increased antagonistic activity of their superficial neck muscles (Lindstrøm et al., 2011; Falla et al., 2004; Graven-Nielsen et al., 1997). Altered behaviour of the superficial neck flexors in violinists with complaints was also observed by Steinmetz et al. (2015). Also, comparable to our study, Steinmetz et al. reported more activity of the mSCM in violinists with complaints compared to violinists without (Steinmetz et al., 2015).

Additionally of note in the current study is the difference between the regular DASH score and the score of the optional performing arts module in the group of violinists with complaints. The DASH and NDI scores in this group are near-normal, however the score on the performing arts module of the DASH indicates an incapacitating influence of the complaints on professional functioning as a musician. The same discrepancy between the regular DASH and performing arts module of the DASH is found in other studies evaluating musicians (Kochem and Silva, 2017; Rodriguez-Romero et al., 2016). A recent study evaluated the psychometric properties of the music module of the DASH, which

Table 7
Shoulder rest adjustment & neck length.

	Violinists with complaints (n = 10)	Violinists without complaints (n = 10)	p-value
Neck length (cm)	13.34 (1.62)	12.35 (1.21)	0.148
Chin rest height (cm)	2.18 (0.38)	2.15 (0.41)	0.868
Left shoulder rest height (cm)	3.62 (1.73)	3.14 (1.92)	0.565
Right shoulder rest height (cm)	3.25 (1.61)	3.69 (2.22)	0.619
neck length – length left shoulder rest (cm)	9.72 (2.75)	9.21 (2.46)	0.671
neck length – length right shoulder rest (cm)	10.09 (2.82)	8.66 (3.00)	0.288

Results displayed as mean (SD); independent samples *t*-test.

showed a good internal consistency and good discriminative validity, but moderate construct validity (Baadjou et al., 2017). Future research should evaluate norm scores for the music module of the DASH in musicians, which will aid interpreting the outcome scores in this specific group. For the current study, our DASH data confirm that the complaints of the violinists evaluated in our study were playing-related.

A major strength of this study is the homogeneous distribution of the two groups of violinists in this study. Age and gender are evenly distributed among the two groups of violinists, reducing the risk of bias. Above, contrary to all comparable studies in the literature evaluating biomechanical aspects of violin playing, the complaints and the impact of functioning on the participants were quantified by validated questionnaires (DASH and NDI). Another strength of this study is the sample size of twenty violinists, which is considerably larger than previous studies.

A possible limitation of this study concerns the use of the instrumented chin-rest, as it was generally somewhat higher compared to the participants' own chin rest due to the insertion of the force-sensor. Therefore, despite using their own shoulder rest, the study situation was not completely comparable to the usual adjustment of the violinist. However, as this mean difference in height of the shoulder rest was only 4 mm, we consider this difference, and therefore the risk of bias, minimal.

Another limitation could be our choice to use a MVIC as normalisation procedure. Hypothetically, violinists with complaints could deliver due to their complaints lower maximal muscle activities compared to violinists without complaints. This could theoretically explain the increased EMG activity in violinists with complaints. However, in the current study none of the violinists reported pain or discomfort during the normalisation procedure. Therefore, we consider the influence of complaints on the normalisation procedure small.

Potentially there are many variables affecting both complaints, as well as muscle activity in violinists. For example, posture of the violinist (e.g. anteposition of the head, abduction of the arm, arm length), as well as the positioning of the violin (e.g. tilt, drop). The current study does not evaluate an analysis of posture or position of the performer. Also, as we do not know the exact origin of the complaints in the violinists, the exact pathophysiological mechanism and relationship between complaints and evaluated muscle activity in this study is potentially biased by these variables.

Most violinists experience neck and shoulder complaints during their career, the consequences of these complaints are potentially severe (Kok et al., 2016, 2015; Paarup et al., 2011). The exact relationship between pain and muscle activity is still unclear, as it is unknown if the changes in muscle activity are the consequence of pain, or contributing to the development or maintenance of pain. In the latter, preventive and therapeutic strategies could be explored aiming to reduce muscle activity. For example, biofeedback training could be a suitable modality; a pilot study using biofeedback training of the left hand of nine violinists showed promising results (LeVine and Irvine, 1984).

Future research in this field should aim at increasing knowledge on muscle activity during violin playing. The use and adjustment of the shoulder rest could be evaluated in an experimental setting in order to evaluate its influence of playing kinematics. Also, biofeedback training based on EMG activity could be evaluated, especially co-contraction of mSCM, as this study showed this co-contraction is associated with complaints of the neck and shoulder region. Finally, in all studies evaluating participants with complaints, the severity and impact of these complaints should be evaluated, preferably by using validated outcome measures.

Concluding, this study shows that the presence of complaints is significantly associated with the activity of some superficial neck and shoulder muscles. Among violinists with complaints there is a more simultaneous contraction of both the mSCM, which is hypothesized to be the result of co-contraction.

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Conflicts of interest

None.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jelekin.2018.11.002.

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