The use of fine-wire EMG to investigate the kinematics of cello bowing: The results of a pilot study

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The mechanics of music making is important both in preventing injuries and in guiding how music is performed and taught. Electromyography (EMG) measures muscle activity patterns and has been shown to be a useful resource in understanding the loads involved in instrumental playing; however, only a small number of projects have been undertaken, and little is understood on the muscle activity used during string bowing. This project used a combination of fine-wire and surface EMG to evaluate the muscular load placed on the shoulder of a professional orchestral cellist playing a set of bowing exercises. The results indicated that EMG was useful in measuring shoulder load and that fine-wire electrodes did not interfere with normal playing technique. Different bowing techniques produced statistically different levels of muscle contractions, with the supraspinatus muscle in particular maintaining significantly higher levels of contraction during all bowing patterns.

Keywords: string biomechanics; electromyography; shoulder injuries; cello players; muscular load

The mechanics of muscle activity patterns and movements used during musical performance is an area of research that has the potential to have profound influences not only on the management of playing-related injuries, but also on the way music is taught and performed. Electromyography (EMG) has been used extensively to understand muscle loads and contraction patterns in elite athletes; however, EMG has only been utilized to a limited degree as a research tool in music (Visentin and Shan 2011). This is surprising considering the high-levels of musculoskeletal pain seen among musicians and that neuromuscular integration and control reaches its peak in music performance.
Surface EMG (sEMG) involving string players has produced some important contributions (Ackermann et al. 2002, Visentin and Shan 2011); however, only minimal research has attempted to understand the muscle activity around the shoulder during bowing on a string instrument. This is a significant research gap considering the high rate of right shoulder pain reported by string players (Middlestadt and Fishbein 1989). This research paper investigates the application of surface and fine-wire EMG (fwEMG) for research into the mechanics of cello bowing.

Electromyography is considered one of the most important tools in estimating the mechanical load on the human body in working life and measures the neuromuscular response to task requirements. The use of EMG to measure muscle loads during musical performance and other activities faces a number of challenges and controversy regarding the accuracy of sEMG versus fwEMG continues (Visentin and Shan 2011). Researchers argue that, while fwEMG produces more accurate results, it may interfere with the normal playing ability of the research subject (Visentin and Shan 2011). This research project aims to present a pilot study on shoulder muscle activity patterns during cello bowing using a combination of sEMG and fwEMG techniques.

String players experience high-levels of musculoskeletal pain which regularly includes dysfunction in the left and right shoulders (Middlestadt and Fishbein 1989). For cello players right shoulder pain is the one of the most common injury sites with 20% of student and 42% of professional cellists reporting pain in the right shoulder (Rickert et al. 2012). Motion-capture research has suggested that this may be related to high-levels of right shoulder abduction and flexion measured during cello playing (Turner-Stokes and Reid 1999). Such positions of abduction and flexion are likely to place high loads on the muscles of the rotator cuff, especially the supraspinatus muscle, which is required to co-contract against the superior (upward) force of the deltoids.

The aims of this project were to (1) investigate whether fwEMG could be used as a research tool during cello playing without significantly interfering with movements and sound production quality, and (2) to measure the muscular activity patterns in the right shoulder of a cellist during cello playing.

**METHOD**

**Participants**

The participant for this study was a professional orchestral cellist (first author) with no current pain in the shoulder and normal shoulder function.
Procedure

Initially the professional cellist produced a set of reductive bowing exercises that tested a range of possible bowing techniques used during cello playing. These tested the influence of variables including dynamic, string level, string changes, part of the bow, and number of bow changes per second on shoulder muscle contractions. Before electrodes were applied and during the data capture process an external expert cellist (a Professor at a major Australian tertiary school of music) observed the subject performing all musical exercises in order to determine whether fine-wire electrodes influenced normal playing ability. During the testing procedure data were acquired on a PC with a 16 bit analog to digital converter (1401, Cambridge Electronics Design, Cambridge, UK). The data were normalized, tabled, and graphed as a percentage of MVC. Data was further analyzed using two-factor repeated-measures ANOVAs. When significant (p<0.05) ANOVA results were found, a follow-up Tukey HSD post-hoc test was used to further investigate the differences. For details of electrode placement protocol and signal processing see Rickert et al. (in press).

RESULTS

The expert cellist observer noted no noticeable difference between the performance of the bowing exercises before the electrodes were inserted and the performance during the testing procedure.

Based on average EMG across the entire testing process, a significant difference in muscle activation was found between muscles ($F_{9,117}=148$, p<0.001) with the supraspinatus maintaining levels of contraction more than twice that of all other muscles (p<0.01; see Table 1).

The percentage of time each muscle spent above or below Björkstén and Jonsson’s (1977) muscle fatigue threshold of 14% of MVC is summarized in Table 2.

For the supraspinatus muscle, differences in individual bowing patterns produced statistically different levels of contraction with dynamic ($F_{8,1040}=17$, p<0.001), string level ($F_{8,1320}=1411$, p<0.001), and string changes ($F_{8,1496}=12$, p<0.001) producing significant interaction effects (Figure 1).

Table 1. Mean (±SD) EMG level (% MVC) for each muscle across all exercises.

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<tr>
<td>20.61(3.8)</td>
<td>6.4(0.8)</td>
<td>2.6(1.4)</td>
<td>9.2(1.6)</td>
<td>3.7(32.2)</td>
<td>5.6(2.3)</td>
<td>6.4(2.8)</td>
<td>2.9(0.9)</td>
<td>4.4(0.9)</td>
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Table 2. Percentage of time spent above or below an established fatigue threshold.

<table>
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<tr>
<th>%MVC</th>
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<td>&lt;14%</td>
<td>13%</td>
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<td>&gt;14%</td>
<td>87%</td>
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<td>5%</td>
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<td>2%</td>
<td>7%</td>
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Figure 1. The influence of different bowing techniques on supraspinatus contractions. X-axis=bowing techniques, y-axis=muscular response (% MVC), * denotes p<0.05.

Figure 2 demonstrates right shoulder muscle recruitment while playing demisemiquavers on the A-string.

DISCUSSION

This study provides an introductory investigation into the use of fwEMG as a research tool during bowing on string instruments. Contrary to arguments in the literature (Visentin and Shan 2011), fwEMG was not observed to interfere with normal musical performance during the testing procedure. The results also present preliminary information about the relative loads and contraction patterns of the right shoulder during cello bowing. Of particular interest is the finding that the supraspinatus maintains relatively high levels of contraction during all bowing techniques. The sustained supraspinatus loading seen during this study, based on the work of (Björkstén and Jonsson 1977) may lead to fatigue and a disruption of normal shoulder kinematics. This could in part explain the right shoulder pain profiles and physical testing results seen in Rickert et al. (2012). This research has important implications for musi-
The examination of right shoulder muscle contraction patterns during cello playing shows that muscle recruitment matches expected biomechanical function. For example, at the beginning of a down-bow peak contractions are seen in the middle deltoid muscle which would be consistent with the contraction force required to begin the elevation of the arm required during a down-bow. The supraspinatus and infraspinatus muscles contract with the middle deltoid offering stabilization against the superior (upward) force of the deltoid muscle and may contribute to external rotation at the shoulder during commencement of the down-bow. For the up-bow movement, peak contractions are seen in the pectoralis major, upper trapezius, and subscapularis muscles. The pectoralis major contraction would be consistent with the beginning of the up-bow movement which requires the abduction of the arm. The upper trapezius contractions align with the increased scapular abduction required during the position the arm assumes at the tip of the bow. The subscapularis contractions are likely to result from the increased internal rotation required to articulate the beginning of an up-bow at the tip of the bow.

This research project has established that EMG using both surface and indwelling electrodes can be a useful research tool in understanding the muscle activity patterns of the shoulder during bowing on a string instrument. Pre-
liminary data on the influence of cello bowing on muscular load in the right shoulder of a cellist have been presented. This pilot study protocol provides a working methodology for future research in string biomechanics.

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**References**


