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## Stringing and dynamics effects on forearm muscular activity during harp playing

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### 1. Introduction

The repetition of fast and repetitive movements as well as the effort required to set the instrument into vibration is a common source of musculoskeletal disorders for musicians (Blanco-Piñeiro et al. 2017). In the case of plucked string instruments, the plucking force is directly related to the strings' tension. Consequently, the choice of the strings has to be made based on both, the musician feel while playing (sound and tactile feedbacks), and the musculoskeletal consequences. In the case of the concert harp, the plucking action has been investigated in various musical contexts revealing plucking forces up to 30 N (Chadeaux et al. 2012). Kinematical and dynamical studies have been also conducted, underlining the specificity and repeatability of the ancillary and sound-producing gestures (Chadeaux et al. 2013). However, up to now, no study has analyzed together the plucking action and the underlying upperlimb biomechanics. The objective of the present study is to provide a more complete understanding of how the string properties and the dynamics affect the biomechanics of harp playing.

### 2. Methods

#### 2.1. Experimental procedure

Nine musicians were involved in three experimental sessions (Figure 1). At each session, a new stringing was mounted on the concert harp (CAMAC Harps, Atlantide Prestige model): gut, nylon, fluocarbon. Musicians were asked to perform an *arpeggio* sequence

at 80 bpm, under three different dynamics (*piano*, *mezzoforte*, *forte*) according to their own judgement. The sequence has been repeated five times at each dynamics in a randomized order to avoid fatigue or learning effect.

Among the sixteen strings involved in the *arpeggio*, the bidimensional movement of four strings (Table 1) has been measured using optical sensors (Le Carrou et al. 2014). Accelerometers (PCB 352C65,  $F_s = 25,600$  Hz) were fixed on the soundboard to measure its vibration. Finally, EMG signals from four forearm muscles (*flexor digitorum superficialis* (FDS), *flexor carpi radialis* (FCR), *extensor digitorum communis* (EDC), and *extensor carpi radialis* (ECR)), were collected using a wireless system (Delsys Trigno, Natick, MA, USA,  $F_s = 1925$  Hz). Electrodes were positioned, after skin preparation, on the muscles bellies. A maximum voluntary contraction (MVC) task was performed at the beginning of each session.

#### 2.2. Data analysis

The note onsets have been highlighted using a threshold detection on the optical sensors signals. First, the RMS signals of the soundboard acceleration, referred to as  $R_{str=(30, 29, 27, 24)}$ , were computed on a 500 ms window, starting at each note onset.  $R_{str}$  were finally normalized by the maximum value reached over the three sessions. Secondly, EMG signals passed through a bandpass filter and full-wave rectifier with zero phase shift ([20–400] Hz; 4th order Butterworth). The associated RMS signals were calculated using a 500 ms moving window, and divided by the MVC value.  $A_{EMG=(FDS, FCR, EDC, ECR)}$  was obtained by averaging the RMS signals over the plucking action, i.e., during the last 300 ms before the note onset (Chadeaux et al. 2012).  $\tilde{A}_{EMG}$  was finally defined by dividing  $A_{EMG}$  by  $R_{str}$ . At last, each descriptor has been averaged over all participants.

### 3. Results and discussion

$R_{str}$  averaged over the four investigated notes and the three stringings, was estimated at  $82 \pm 5\%$ ,  $49 \pm 4\%$ , and  $27 \pm 3\%$  when playing *forte*, *mezzoforte*, and *piano*, respectively. The dynamics instruction was therefore well-followed by the musicians with no obvious difference between the notes or the stringings.

$A_{EMG}$ , averaged over the three dynamics, indicated that the fingers' muscles were more activated than wrist's muscle, as well as a higher activation of FDS

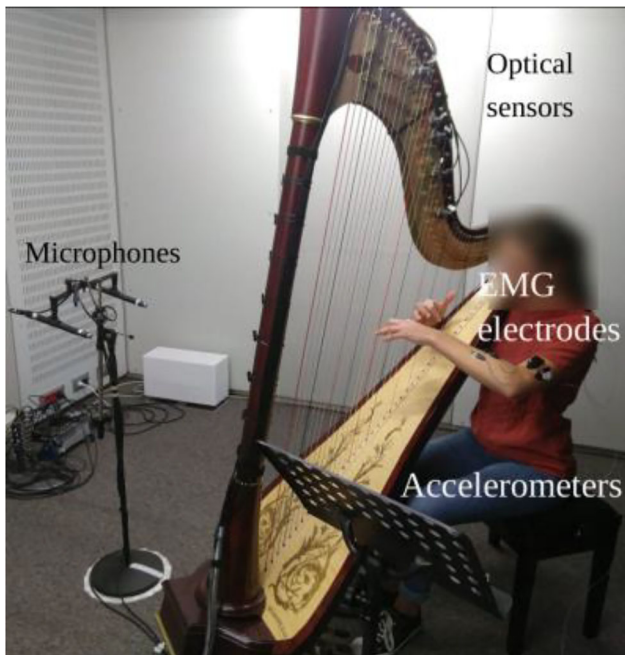


Figure 1. Experimental setup.

Table 1. Propert of the studied strings: number (#), frequency ( $F_0$ ), and tension (T) for the three stringings.

Note	Db2	Eb2	Gb1	Cb1
#	30	29	27	24
$F_0$ (Hz)	138.6	155.6	185	246.9
$T_{gut}$ (N)	282	283	228	169
$T_{nylon}$ (N)	248	242	196	151
$T_{fluocarbon}$ (N)	373	365	292	234

than EDC ( $A_{FDS} = 19 \pm 11\%$ ,  $A_{FCR} = 6 \pm 3\%$ ,  $A_{EDC} = 12 \pm 2\%$ , and  $A_{ECR} = 8 \pm 3\%$ ).

Figure 2 presents the evolution of  $\tilde{A}_{EMG}$  with respect to the dynamics and the stringing for each investigated note. As expected, no important effect of the playing dynamics was observed, conveying that the muscular activation increased with the dynamics.  $\tilde{A}_{EDC}$  and  $\tilde{A}_{ECR}$  showed a slight increase while the dynamics decreases. This observation is likely to be related to the joint stabilization during playing. Regarding finally the stringing properties, Figure 2 indicated that  $\tilde{A}_{FDS}$  is greatly affected by the stringing. The activation was estimated at  $0.13 \pm 0.03$ ,  $0.67 \pm 0.22$ , and  $0.38 \pm 0.09$  for the gut, the nylon, and the fluocarbon stringings, respectively. It suggests that muscular activation increases when playing less stretched stringing. An explanation could be that a higher control is required when plucking a low stretched than high stretched string to provide it the desired motion.

4. Conclusions

This study has investigated how the harp stringing affect the forearm muscle activation. The main contribution is that FDS is highly related to the stringing properties and the playing control, while the extensor muscles are most likely to be related to the joints stabilization. Future work will include co-contraction to get insight into the playing control, especially regarding joint stabilization.

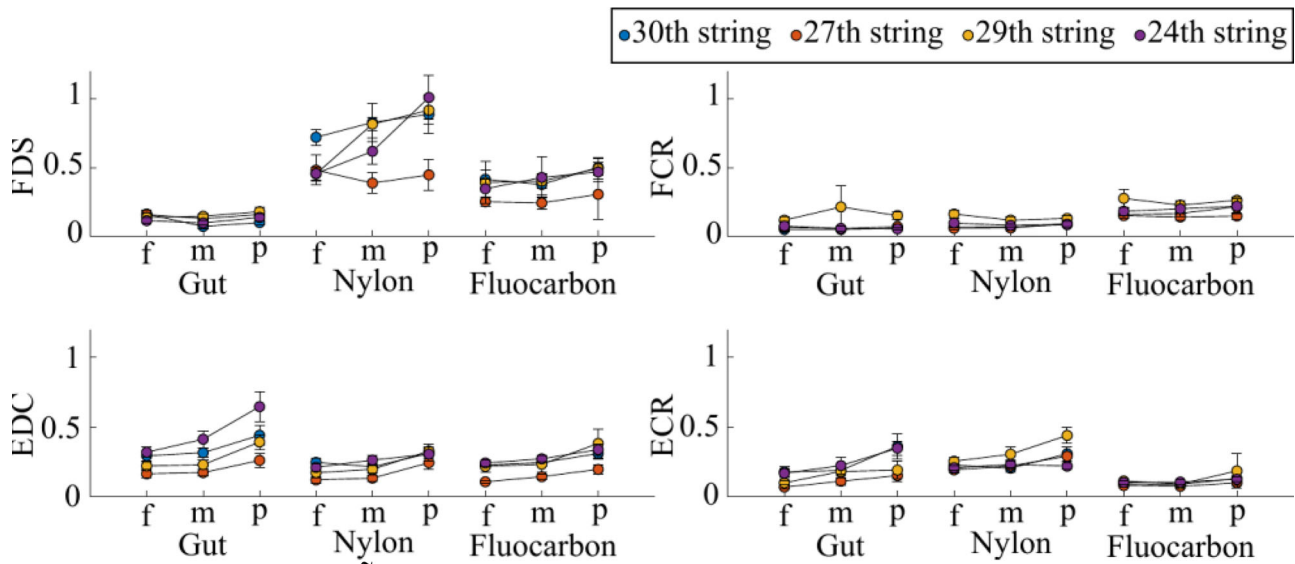


Figure 2. EMG indices  $\tilde{A}_{EMG}$  during the plucking of four notes played under three dynamics and three stringings. Error bars represent a 95% confidence interval.

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