KINEMATICAL STRATEGIES DURING HARPISTS’ PERFORMANCE

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For plucked strings instruments, such as the harp, the instrumentalist brings the string to a particular state defining its future free oscillations. The sound characteristics are therefore defined by the initial conditions of the string vibrations, which are driven by the finger/string interaction. To control his/her sound, the harpist owns specific plucking strategies highly dependent on his/her morphology and on the musical context. To reach this fingertip motion accuracy, the whole-body has to be recruited because of the harp constraints. Indeed, the harp is about 1.8 m high and weighs about 35 kg, which require the lower-limbs and the trunk to be responsible for the posture stability, while the upper-limbs are obviously involved in reaching and plucking the strings, using a plucking force up to 20 N. Consequently, the understanding of the harpists’ musical signature would benefit from getting insight into the harpists’ gestural strategies. To this aim, the present study investigates harpist’s individual kinematics strategies with respect to his/her plucking action in a realistic context. A specific experimental procedure was designed to measure synchronously the instrumentalist’s whole-body motion and the plucking characteristics. Eight harpists were asked to perform the same piece with imposed tempo and nuance. Kinematics was derived from nine inertial sensors, while the plucking force was estimated by a specific processing method from string displacement measurements. A set of six strings distributed across the instrument’s tessitura (from 92 Hz to 495 Hz), made of various material (wire, gut, and nylon), and of various tension (from 706 N to 127 N) was investigated. Results outlined the common and specific upper-limb strategies according to the strings properties. This contribution opens up new perspectives in musical performance analyses by underlining the significance of the whole-body biomechanical control while playing.

Keywords: Plucked strings instruments, Kinematics, Vibration, Concert harp

1. Introduction

The practice of a musical instrument requires fine dexterity, repetitive, fast, and precise movements, as well as important efforts to set the instrument into vibration, while adopting postures often unnatural for the human body [1]. As a result, musicians are often subject to pain [2] and injuries [3] from an early age [4]. As evidenced by the epidemiological study conducted by Roxane Martin in 2011, 74% of harpists surveyed revealed pain, mainly located in the upper back, neck, and shoulders [2]. This
result was also obtained for Texan harpists [5]. One hypothesis raised by Roxane Martin [2] is that the tension of harp strings is directly involved in the appearance of these musculoskeletal pain. The mechanical characteristics of the harp require the instrumentalist to provide a gesture adapted both to the production of the desired sound and to the limitation of the underlying clinical risks. In previous works, we analyzed the sound-producing gesture on the one hand (analysis of the plucking of a string in two musical contexts using a fast camera [7]), and the gestures accompanying the performance on the other hand (kinematic and dynamic analysis of the playing using an infrared camera system [7]). Thus, during chord or arpeggio playing, the initial conditions of string vibration are characteristic of the musician, particularly repeatable and dependent on the playing technique [7, 8]. The posture of the instrumentalist is found to be stable during the playing, the movements of the hand participating in the musical performance of the played score, and the moments at the joints increasing from the wrist to the shoulders [5, 9]. However, as these studies are decoupled and focused on a limited number of playing conditions, they need to be implemented simultaneously over a wider range of musical contexts. The objective of this study is therefore to extend these results to a more realistic playing context for several strings of different tension and material. In particular, we will focus here on the influence of string properties on the instrumentalist’s playing on upper limb kinematics and plucking. The experimental setup and the data analysis procedures are first described in section 2. Then, Section 3 describes the experimental results and the paper conclusions are finally drawn in section 4.

2. Method

2.1 Experimental procedure

Eight harpists without noteworthy pathology were involved in the experiments. The harpists were asked to perform the Gimblette of B. Andrès on a concert harp (CAMAC Harps, Atlantide Prestige model). The tempo was fixed and set at 110 bpm. The instruction given to the harpists was

The general context of the performance is the recording in studio of some variations of the Gimblette of B. Andrès. This sound recording is the essential element of the experiment, leading thereby your performance.

The experimental setup (presented in Fig. 1) used a system composed of twelve optical sensors (two per string) fixed close to the string’s end and properly calibrated beforehand [8] to measure the
Table 1: Characteristics of the studied strings: Frequency ($f_0$), Tension (T), Diameter (D), and material (W: Wire, G: Gut, N: Nylon).

<table>
<thead>
<tr>
<th>Note</th>
<th>G2</th>
<th>D3</th>
<th>E3</th>
<th>G3</th>
<th>C4</th>
<th>C5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_0$ (Hz)</td>
<td>92</td>
<td>138</td>
<td>155</td>
<td>185</td>
<td>247</td>
<td>494</td>
</tr>
<tr>
<td>T (N)</td>
<td>706</td>
<td>294</td>
<td>303</td>
<td>238</td>
<td>173</td>
<td>127</td>
</tr>
<tr>
<td>D (cm)</td>
<td>1.6</td>
<td>1.96</td>
<td>1.9</td>
<td>1.68</td>
<td>1.4</td>
<td>1.06</td>
</tr>
<tr>
<td>Material</td>
<td>W</td>
<td>G</td>
<td>G</td>
<td>G</td>
<td>G</td>
<td>N</td>
</tr>
</tbody>
</table>

The bi-dimensional trajectory of six string. Simultaneously, nine inertial sensor modules (T-sens Captiv Motion, 64 Hz) were used to capture the range of motion of the harpist and the harp. Note that the inertial sensor modules were only used for six harpists. The physical characteristics of the studied strings are given in the Tab. [1]. Finally, the produced sound was recorded using microphones (Shoeps CMC6 + MK6).

2.2 Data analysis

Although the entire piece was performed by the musician, only the sixth variation was investigated in the present paper.

The bi-dimensional strings’ trajectories were processed in order to estimate the string motion at the plucking position. For this purpose, the method described in [10, 11] was used. Consequently, the instants of interest for the harp plucking analysis ($t_c$ and $t_r$: instants where the finger touches and releases the string [7]) were highlighted on each investigated string during the performance. As the initial conditions of the string’s free oscillations were previously reported related to both the produced sound features and the plucking technique [9], the string’s displacement and velocity at $t_r$, referred to as $D_{tr}$ and $V_{tr}$, were extracted from its estimated motion.

The inertial sensor modules were used to obtain joint motion during the harp performance. Based on the firstly highlighted instants $t_c$ and $t_r$, the kinematics database was segmented around each plucking action. In particular, the amplitude of motion in the sagittal plane was investigated at the wrist, the elbow, the shoulder, and the trunk. As the right and the left upper-limbs are involved in the harp playing, both were investigated here.

3. Results

Figure [2] presents the initial conditions of the string’s free oscillations in the plane ($D_{tr}$ ; $V_{tr}$) estimated for the eight harpists. As already reported in the literature, the initial conditions of the string’s free oscillation is a complex mix of displacement and velocity highly dependent on the harpist [7, 11]. Additionally, results indicate that ($D_{tr}$ ; $V_{tr}$) are also specific to the string. The lower the frequency, the higher the displacement, and the lower is the velocity provided to the string. This result is more likely related to the string properties such as its tension. Considering that a combination of displacement and velocity is required to pluck a harp string, the proportion of each value may vary. The straightforward solution when plucking a string of high tension would be to provide it with more displacement than velocity while the...
opposite solution may be considered for strings with lower tension.

Figure 3 presents the amplitude of motion in the sagittal plane for the wrist, the elbow and the shoulder with respect to the six investigated strings. Regarding first the wrist, the flexion order of magnitude during the plucking action was estimated at about 20°. A more important amplitude in flexion was observed while playing the note D♭3 (about 25°). Further, the wrist flexion during the plucking action tended to vary less when the note frequency increased. Considering further the elbow, the amplitude of flexion rize regularly from about 10° to 20° for the strings G♭2, D♭3, E♭3, and G♭3. On the contrary, almost no variation was observed for the strings C♭4 and C♭5. These results are likely to be explained by the strings’ position with respect to the harpist. The highest the frequency, the closest the string to the harpist. Consequently, the admissible range of motion in flexion is reduced for strings particularly close or far from the harpist. On the contrary, a higher range of motion reflecting the musical interpretation can be expected in the intermediate comfort zone.

Moreover, no obvious trend appeared considering the amplitude of flexion of the shoulder. This observation can be related to the trunk amplitude of flexion which has been estimated between 1° and 3°. It conveys that the harpist keep their body posture whatever the string’s position in order to develop enough force to pluck the strings. This result is also consistent with previous work revealing that harpists develop more energy at the shoulder joint than at the more distal joints [5].

4. Conclusion

This paper investigated the kinematical strategies set up by harpists when playing the Gimblette written by B. Andrès. A specific experimental procedure was designed to measure synchronously the harpist’s whole-body motion and the initial condition of the string’s free oscillations.

Accordingly to our previous studies, the properties of the string’s free oscillations and therefore of the produced sound, consist into a combination of displacement and velocity specific to the harpist, where an important displacement implies a low velocity, and vice versa. Interestingly, the present study
indicated further that the displacement and velocity provided to the string are also highly dependent on the string. Our hypothesis is that the string’s tension govern the ratio between the provided displacement and velocity. Considering further the harpist’s body kinematics, almost no motion of the trunk and the shoulder were observed in the sagittal plane, revealing that this two anatomical pieces of high masses are responsible for the posture and the force production. On the contrary, the amplitude of flexion estimated at the elbow and the wrist were related to the plucking action and constrained by the string’s distance from the harpist.

Based on this framework, future work will consist into investigating how harpists deal with musical nuance and various tempi at their gesture and plucking action level.

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REFERENCES


