Computer Methods and Programs in Biomedicine 149 (2017) 19–27

Contents lists available at ScienceDirect

Computer Methods and Programs in Biomedicine

journal homepage: www.elsevier.com/locate/cmpb

Three dimensional motion capture applied to violin playing: A study on feasibility and characterization of the motor strategy

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ARTICLE INFO

Article history:
Received 8 November 2016
Revised 27 June 2017
Accepted 18 July 2017

Keywords:
Bowing
Functional evaluation
Motion capture
Motor control
Performance evaluation
Violin playing

ABSTRACT

Background and Objective: Playing string instruments requires advanced motor skills and a long training that is often spent in uncomfortable postures that may lead to injuries or musculoskeletal disorders. Thus, it is interesting to objectively characterize the motor strategy adopted by the players. In this work, we implemented a method for the quantitative analysis of the motor performance of a violin player.
Methods: The proposed protocol takes advantage of an optoelectronic system and some infra-red reflecting markers in order to track player's motion. The method was tested on a professional violin player performing a legato bowing task. The biomechanical strategy of the upper limb and bow positioning were described by means of quantitative parameters and motion profiles. Measured quantities were: bow trajectory, angles, tracks, velocity, acceleration and jerk.
Results: A good repeatability of the bowing motion (CV $<$ 2%) and high smoothness (jerk $< 5\ m/s^3$) were observed. Motion profiles of shoulder, elbow and wrist were repeatable (CV $<$ 7%) and comparable to the curves observed in other studies. Jerk and acceleration profiles demonstrated high smoothness in the ascending and descending phases of bowing. High variability was instead observed for the neck angle (CV ~56%).
Conclusions: "Quantitative" measurements, instead of "qualitative" observation, can support the diagnosis of motor disorders and the accurate evaluation of musicians' skills. The proposed protocol is a powerful tool for the description of musician's performance, that may be useful to document improvements in playing abilities and to adjust training strategies.

Introduction

Complex motor tasks require a strong coordination between muscles and central nervous system. Acquiring such levels of coordination requires a long, sometimes lifetime, training. Examples are sportsman's gestures, high precision manufacturing, drawing/painting, and music playing. It is known from the motor control theory that the brain learns to choose those strategies that achieve the minimum energy expenditure. This is done by memory and reaching the sharpest motor strategies requires the longest training sessions [1].

Playing an instrument requires the two basic motor control mechanisms: (i) feedforward, i.e. an anticipatory mechanism that leads to high speed and sharpness of the execution; and (ii) feedback, that allows to self-adjust the sound based on the input from the auditory and tactile systems [2]. Both mechanisms are supported by memory and are refined by continuous practising [1]. Moreover, extensive musical training enables advanced interaction between auditory and motor control systems [3,4]. This helps coordinating hearing with upper and lower limbs, allowing rapid changes in dynamic, intonation and tempo [5]. Differences in bi-manual coordination occur as well. Right handed musicians demonstrated less asymmetry of hand skills than right-handed non-musicians. This was attributed to musicians' increased left-hand skills and their need of strong coordination on both sides [6,7].

From a biomechanical point of view, it is interesting to study the motor strategy, i.e. anatomical angles, force/pressure, speed, acceleration, etc. adopted by the musician to achieve a certain note. Such motor strategies often lead to postural or neuromuscular disorders, that may compromise the performance of professional

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http://dx.doi.org/10.1016/j.cmpb.2017.07.005
0169-2607/

players [8]. The most common disorders are: tendinitis, tenosynovitis, dystonia and related conditions [8]. Temporomandibular disorders are also common among violin or woodwinds players, due to the pressure on the mandible and the clenching of masticatory muscles [8]. String players are often prone to injuries occurring at the shoulder's joint, as those instruments require large and fast shoulder elevation changes, depending on the register being played [9].

Motor strategies can be studied by means of motion analysis techniques that allow the reconstruction of a detailed three-dimensional model of the human body. The gold standard method for biomechanical analysis is the Optoelectronic System (OS) that is widely used in the clinical practice to study motor disorders [10–12]. The OSs were proved accurate enough to record subtle motor tasks, such as handwriting [13,14], facial expressions [15,16] and plethysmography [17]. Several methods for handling and visualizing motion capture data are currently being developed [18].

Human motion can also be recorded by means of inertial sensors, whose use was recently validated on the upper limb [19]. With proper filtering and drift correction, inertial sensors can achieve a relatively low RMS error [20]. Inertial sensors have also the advantage of being small and cheap [21] and can be used in combination with OSs to increase accuracy [22].

A first attempt to record the motion of bowing arm of string playing musicians was made by Turner-Stokes and Reid [9] that developed a protocol based on two cameras able to identify the motion patterns potentially leading to injuries. They also proposed a standardized bowing task, easy to perform and reproduce, where the subject was asked to play a "legato bowing" guided by a metronome at 100 bpm [9]. In another work, Baader et al. [23] focussed the attention on finger movements of violin players. They studied the motor coordination between fingers in terms of synchronization, timing and anticipation. The coordination between bowing and finger movements was also studied by Kazennikov and Wiesendanger [2] finding out that rapid string changes affect the coordination between limbs in both amateurs and professional players. Schoonderwaldt and Demoucron [24] developed a method for the measurement of player's performance and comparison of the bowing strategies among players. They used an OS with six cameras in conjunction with an accelerometer and a load cell placed on the bow. Such setup measured: (i) bow tilt, inclination and skewness; (ii) bow velocity; (iii) distance of the bow from the bridge; (iv) bow force; (v) bow acceleration. Another finding was that the sound level and the spectral centroid were correlated to the bowing parameters. The subjects adjusted the motor strategy according to the physical properties of the instruments and to the spatial limits [25].

The previously discussed works were focussed on some aspects of playing, such as finger coordination. To the authors' best knowledge, it is advantageous to develop a method for the overall characterization of player's ability.

Aim

The aim of this work was the implementation of a modern and simple motion capture protocol to quantify the motor performance of a violin player. The repeatability of the measured biomechanical parameters was assumed as an index of player's performance. The protocol was designed to be as simple as possible and to work with any optoelectronic motion capture system with sufficiently small calibrated volume. A feasibility analysis was conducted and the most relevant biomechanical parameters were identified.

Materials and methods

Equipment

Motion was recorded by means of a SMART-D Optoelectronic System (BTS, Italy), composed of six infra-red cameras. The OS markers were spheres and hemispheres, diameter 3 mm, placed on the subject and on the violin, in order to reconstruct a biomechanical model of the subject and his motion over time (landmarks for markers are described in the following section). The cameras were placed along the perimeter of the acquisition volume and viewpoints were optimized in order to make each marker visible by at least two cameras at the same time. The acquisition volume was about 2 m^3 and it was designed according to the following criteria: (i) it had to include the whole motion and (ii) it had to be as small as possible, in order to achieve the highest accuracy. The system was calibrated according to manufacturer's instructions before each recording session. Accuracy was 0.1 mm and sampling frequency was 200 Hz.

The violin used was a *Cannone Guarnerius*, opportunely tuned. A standard mechanical metronome helped the musician to keep the tempo.

Measurement method

A motion capture protocol was designed *ad hoc*. The design criteria were: (i) keep the protocol as simple as possible in order to speed up preparation, recording and processing; (ii) allow a biomechanical modelling of the upper limb, spine and head; (iii) allow to study bowing motion.

The protocol required a calibration (static) trial to identify the landmarks on the violin and on the bow. The same landmarks were reconstructed in the dynamic trials by means of a three-points localization procedure, as implemented in a previous work [13]. In calibration trials, the violin and the bow were kept still in the calibrated volume with their respective marker sets. Static marker coordinates were recorded for about five seconds. Seven landmarks were identified on the violin (Fig. 1): one marker on the scroll, two markers on the waist (left and right), one marker on the tailpiece, two markers on the fingerboard (top and bottom), one marker on the bridge. The latter three markers were removed during the playing trials. Four markers were placed on the bow (Fig. 2): two markers on the stick near midpoint, one marker on the screw, one marker on the tip. The latter two markers were removed during the dynamic trials. The subject did not take part in the calibration trials but he was involved in playing (dynamic) trials. The subject wore 20 markers (Fig. 3): three markers on the head, left and right acromioclavicular joint, right sternoclavicular joint, C7, t8, l1 and sacrum vertebrae, right elbow, right wrist, right hand, left elbow, left wrist, left hand and left four fingers (excluding thumb). Not all the markers were used in the present study, but they were kept for future uses.

Dynamic trials required the subject to be sitting on a chair within the calibrated volume, while holding the violin and the bow in the natural playing position. The subject was an Academy Maestro and professional player (male, age 30 years, weight 81 kg, height 182 cm). He performed a legato bowing task, that consisted in keeping a sustained note playing on the second string. The metronome was set at 100 bpm and each bowing covered 4 beats. The subject kept playing until at least 10 complete bowings were acquired.

The overall data recording procedure is depicted as a flowchart in Fig. 4.