CONTROL AND COORDINATION OF COMPLEX BOWING PATTERNS

Erwin Schoonderwaldt

School of Computer Science and Communication
Royal Institute of Technology (KTH), Stockholm, Sweden
schoondw@kth.se

ABSTRACT

J.S. Bach's Preludium of the third Partita for solo violin contains passages with complex periodic bowing patterns, involving combinations of bow changes and string crossings across two and three strings. The recorded bow motion revealed spatial patterns in the form of circles and figure-of-eights. Closer inspection showed that string crossings consistently led changes in bowing direction in performances by advanced players. It is plausible that this behavior is necessary for the production of clean note transitions and attacks, and it can therefore be considered as a good example of optimization in human sensorimotor learning. Comparison of performances by two advanced players, one of them familiar with the piece and the other sight reading it, as well as a performance by an amateur player reveal clear differences in the stability and consistency of bowing patterns.

1. INTRODUCTION

During the execution of a musical piece on a bowed-string instrument the bow is constantly in motion. The spatial trajectories followed by the bow (bowing trajectories) are not only directly related to the control of the loudness and the quality of the tone, but also reflect past and future events as a result of co-articulation and preplanning. For example, bowing trajectories in the vicinity of string crossings often show 'rudimentary' circular patterns, as demonstrated in the 1930s by Hodgson [1]. The effects of co-articulation and preplanning were also clearly present in recent visualizations of measured bowing gestures by Schoonderwaldt [2, 3].

Repetitive bowing patterns, containing simultaneous bow changes and string crossings form a particularly interesting class of bowing gestures, in which continuous control forms an integral part with past and future events. A common type of such patterns consists of fast notes alternately played on two adjacent strings. This is often used as a compositional technique in baroque music, in which the notes on the respective strings form two intertwined voices (e.g., melody and accompaniment). Another type of repetitive bowing patterns are series of arpeggiated chords, extending over three of four strings. Many examples of these types of repetitive bowing patterns can be found in the Sonatas and Partitas for solo violin by J.S. Bach.

Earlier research on bowing gestures has mainly dealt with the analysis of isolated bow strokes, with the focus on the use of bowing parameters [4, 5] or specific bowing techniques [4, 6, 7, 8]. Furthermore, bi-manual coordination of bowing and fingering has been subject to study in simple musical sequences [9, 10]. In this paper a preliminary analysis of repetitive bowing patterns in a complex musical context will be presented, in which bow strokes cannot be considered as separate events. The focus will be on the coordination of string crossings and bow changes.

2. METHOD

Recordings were made of performances of J.S. Bach's Preludium of the third Partita for solo violin by three violinists. Two of the players were advanced students; one of them (player A) was familiar with the piece, the other (player B) was sight reading. The third player (C) was an amateur player, who was familiar with the piece. The musical fragments selected for analysis are shown in Fig. 1.

Figure 1: Selected fragments of J.S. Bach's Preludium of the third Partita for solo violin. Fragment 1 (upper staff) represents a repetitive pattern across two strings, and Fragment 2 (lower staff) is played as an arpeggio across three strings. Both fragments start on a down bow and are played détaché (a single bow stroke per note with the bow always attached to the string). The roman numbers indicate the strings; E (I), A (II), and D (III). [Score adapted from Mutopia project, http://www.mutopiaproject.org/]

The bowing gestures were recorded using an optical motion capture system (Vicon) in combination with sensors on the bow for measuring bow force and acceleration. The measurement method allowed for an accurate definition of all relevant bowing parameters, including bow velocity, bow-bridge distance and bow force, as well as the angles of the bow relative to the violin [11].

A qualitative analysis of the measured bowing patterns will be provided from two visual representations; (1) direct visualizations of the spatial trajectories followed by the frog of the bow (corresponding to the motion of the hand of the player), and (2) phase plots showing trajectories of the inclination of the bow versus bow velocity [2]. A useful property of the latter representation is that it clearly reveals the moments that the bow changes direction by the intercepts of the trajectory at zero bow velocity, making it suitable for studying the coordination between string crossings and bow changes in cyclic bowing patterns.

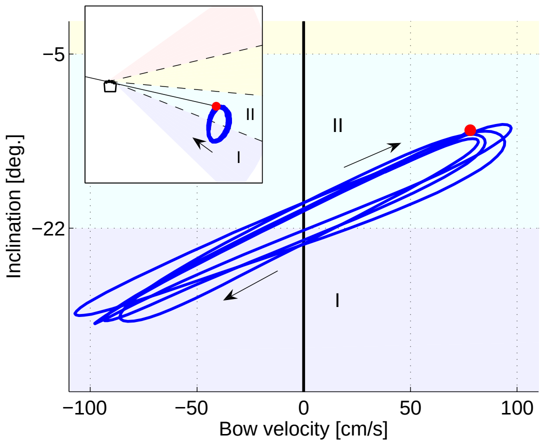

Figure 2: Performance of Fragment 1 by player A. The phase plot shows bow inclination versus bow velocity. The trajectory shows a couple of cycles of the repetitive bowing patterns, the directions are indicated by the arrows. The angles corresponding to string crossings (measured for the open strings) are labeled at the y-axis. Bow changes occur where the trajectory intersects with the thick vertical line corresponding to zero bow velocity. The small plot on top provides a more intuitive spatial representation of the bowing pattern, more or less as seen from the player's point of view. The dashed lines show the borders of the fan-shaped string zones on the violin, and correspond to the labeled inclination angles in the phase plot. The strings are indicated by roman numbers.

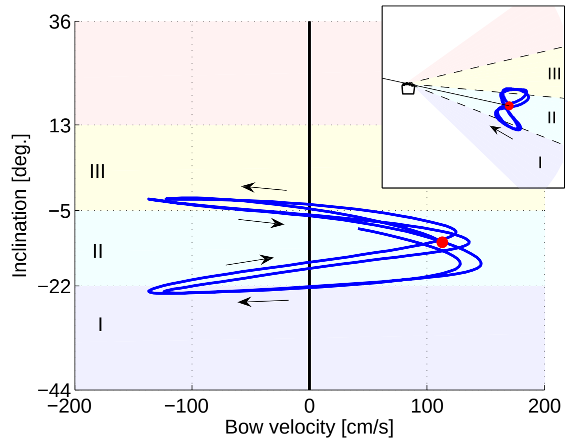

Figure 3: Performance of Fragment 2 by player A (see Fig. 2 for an explanation of the graphs).

3. RESULTS

3.1. Circular bowing patterns

Figure 2 shows the performance of Fragment 1 by player A. The spatial bowing trajectory (small panel on the left side) shows a clear circular pattern, which can be explained as follows. The bow motion can be decomposed into a radial and a tangential component, where the string forms the axis. The radial component corresponds to the displacement of the bow, which is directly related to sound production, or more precisely, the excitation of transverse vibrations on the string. The tangential component (inclination of the bow) corresponds to the motion used for selecting the string. In the tempo the piece was played (about 7 notes per second) both components can be characterized as simple sine-like time series, and as their periods are equal (2 notes) they add up to a circular spatial trajectory.

The phase representation (main panel of Fig. 2) of the bow motion is derived from the spatial trajectory by taking the polar representation of the tangential component (bow inclination) versus the time derivative of the radial component (bow velocity). The trajectory in the phase plot shows a narrow elliptical shape. This might be surprising at first consideration, as this indicates that string crossings and bow changes are not perfectly synchronized. In case of perfect synchrony one would expect that the two movement components would be exactly in phase, which would yield a diagonal trajectory. The hysteresis in the phase plot indicates that the bow changes lag behind the string crossings in the performed bowing pattern.

This behavior was highly consistent in the performance of player A. Given the high quality of the performance it is unlikely that this behavior is erratic or that it reveals a lack of control. On the contrary, there might be good acoustical reasons for the observed behavior.

A possible explanation can be provided by closer consideration of the mechanics of tone production during string crossings. Firstly, it should be realized that the string crossings do not occur instantly, but that they take place during a finite amount of time due to the bending of the strings and the bow hair at the contact point. During the transition, the bow force is transferred from one string to the other. It is then plausible that the optimal moment for bow reversal is at the end of this transition, rather then the beginning or the middle, for two reasons; (1) the bow force acting upon the old string is released before bow reversal, preventing the vibration from being 'choked' [12, 13], and (2) the bow force is built up on the new string, providing the necessary conditions for a good attack [14].

From these considerations, it follows that the observed lag of bow changes might in fact reflect an optimal strategy for producing clean note transitions. At the speed of the performance this timing profile is achieved by the player by maintaining a roughly constant phase difference between the two movement components. Given that this strategy has developed by practicing under influence of auditory feedback, it is a convincing demonstration of the level of sophistication of performance skills internalized by sensorimotor learning.

3.2. Figure-of-eight patterns

The bowing pattern of Fragment 2 is more complex as there are three strings involved, and it is therefore considerable more difficult to play. Again, it is helpful to decompose the bow motion in a radial and a tangential component. However, in this case the periods of the two components are not equal; the tangential component has a period of four notes corresponding to the sequence of strings (II-I-II-III), which is twice the period of the to-and-fro motion (down-bow, up-bow) for playing the notes. Thus, the total bow motion forms a spatial pattern with a figure-of-eight shape, as shown in Fig. 3 (small panel on the right side).

Again, the phase plot (main panel in Fig. 3) revealed a small phase difference between the two movement components, in such a way that bow changes lagged behind string crossings. This indicates that the player used a similar strategy to achieve clean note transitions. Even though some local deviations could be observed within the whole 12 measures arpeggio passage, player A was able to maintain this strategy, which is indicative

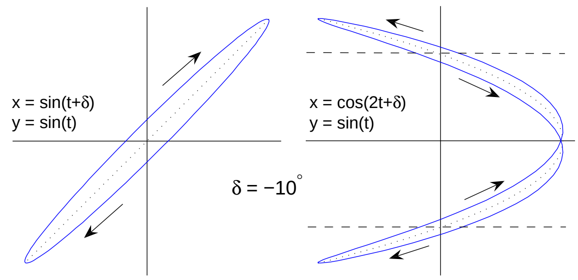

Figure 4: Lissajous patterns. A high degree of similarity to the observed bowing patterns is obtained by introducing a phase lag of about 10 deg to the x-component. The dotted lines indicate the Lissajous patterns without phase shift. In the right panel the dashed lines indicate the positions of the string crossings.

for a high level of control.

Figure 4 shows how the phase plots of both bowing patterns can be reconstructed by introducing a phase lag of about 10 deg to the x-component of the shown Lissajous patterns. However, it is possible that the optimal amount of phase delay depends on performance variables such as bow force.

3.3. Inferior performances

Figures 5 and 6 show performances of the two fragments by two other players. Player B – an advanced student – was sight reading the piece at the time of the recording. Player C – an amateur player – was familiar with the piece.

The phase plots in Fig. 5 reveal that there was a high degree of similarity between the performances of Fragment 1 by all three players (cf. Fig. 2). All performances exhibit hysteresis in the phase plot, indicating that bow changes lagged behind string crossings. However, there were also some discrepancies. The pattern of player B was slightly irregular, which might be due to unfamiliarity with the piece. Furthermore, the phase plots show sharp cusps at the down-left end of the patterns, most notably in the performance of player C. Inspection of the separate movement components showed a variable phase lag throughout the cycle. At the cusp the minima of the time series were in phase, whereas there was a clear phase difference between the maxima. This implies that the movement components deviated somewhat from a perfect sine shape, and it is tempting to speculate that the variable phase behavior reveals a less efficient movement strategy. However, no definitive conclusions can be drawn based on these examples.

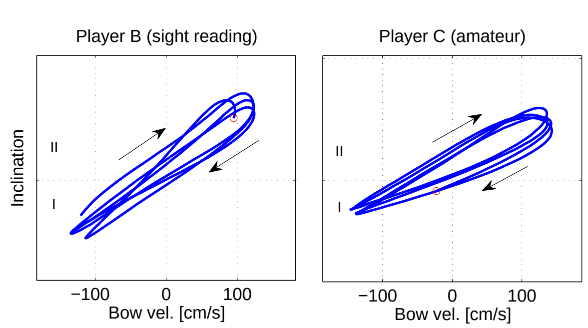

Figure 5: Phase plots of performances of Fragment 1 by players B and C.

The performances of Fragment 2 shown in Fig. 6 reveal greater discrepancies between the players' performances. Player B made many mistakes and did not manage to develop a stable coordination pattern. Player C did develop a somewhat stable coordination pattern. However, the shape of the spatial trajectory is clearly different from the performance of player A (cf. Fig. 3). Player C made larger excursions on the outer strings (I and III), which is indicative of a less efficient movement strategy. Furthermore, it was found that the phase lag between the movement components was inverted in the performance of player C, i.e., bow changes were *leading* string crossings. By listening to the audio recording it could indeed be noted that the quality of the note transitions was inferior compared to the performance by player A, confirming the significance of the observed phase behavior for the control of note transitions.

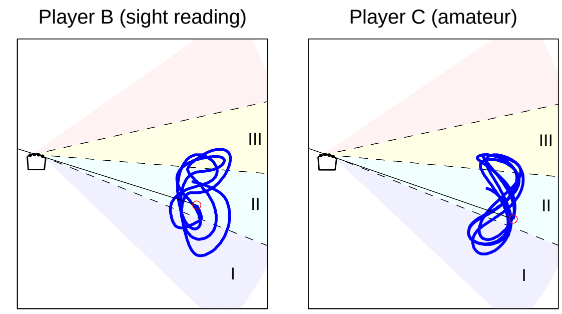

Figure 6: Spatial trajectories of the bow motion of performances of Fragment 2 by players B and C.

4. DISCUSSION AND CONCLUSIONS

This paper presented preliminary analyses of coordination of complex bowing patterns in musical performances by three violin players. The bow motion was decomposed into two components; a radial component related to sound production, and a tangential component related to selection of the string played. It was demonstrated that the two motion components showed a systematic phase relation, in such a way that the timing of bow changes lagged behind string crossings. It was hypothesized by considering the mechanics of the bowed string that this most likely reflects an optimal strategy to obtain clean note transitions. This needs to be further investigated by analysis of the synchronously recorded sound, possibly complemented by bowed-string simulations.

The study focussed on two typical bowing patterns. Both patterns reflect expert behavior, internalized as a result of long-term sensorimotor learning. The circular pattern associated with Fragment 1 (see Fig. 1) represents a relatively basic skill, and is encountered in a wide range of musical repertoire. The figure-of-eight pattern associated with Fragment 2 is considerably more difficult to master, and requires deliberate practice even by advanced players. The analyses presented in this paper showed indeed that the circular bowing pattern was mastered by all three players, whereas the figure-of-eight pattern was only performed well by the advanced player who was prepared.

The measurement method in combination with the visualizations allowed to differentiate between subtle aspects of the movements of the three players, and some inferences could be made about the effectiveness of the strategies. However, further studies are needed to shed more light on this largely unexplored area. In any case, the presented analyses demonstrated that the used methods offer the possibility to analyse performance skills at a high level of detail, and as such possess promising pedagogical potential.

On a more general level, it can be stated that there still exists a wide gap between scientific performance studies and musical practice and pedagogy. Bridging this gap will require efforts from both sides. Some of the main challenges for scientists will be to account for the complexity encountered in music performance, to focus on topics relevant to music practice, and to present the results in an intuitive way understandable to musicians and music teachers. Challenges for the latter will be to break through the barriers of traditional teaching, to have an open mind to scientific results and possibilities offered by technology, and to be willing to put popular beliefs and "idées fixes" to the test.

Acknowledgments

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5. REFERENCES

[1] P. Hodgson, *Motion study and violin bowing*, American String Teachers Association, Urbana, Illinois, June 1958, First published 1934 by J. H. Lavender & Co., London.

[2] E. Schoonderwaldt, *Mechanics and acoustics of violin bowing: Freedom, constraints and control in performance*, Ph.D. thesis, KTH – School of Computer Science and Communication, Stockholm, Sweden, 2009.

[3] E. Schoonderwaldt, "Bowing gestures," Youtube channel, `http://www.youtube.com/schoondw`.

[4] A. Askenfelt, "Measurement of the bowing parameters in violin playing. II: Bow-bridge distance, dynamic range, and limits of bow force," *J. Acoust. Soc. Am.*, vol. 86, no. 2, pp. 503–516, August 1989.

[5] E. Schoonderwaldt, "The player and the bowed string: Coordination and control of bowing parameters in violin and viola performance," *J. Acoust. Soc. Am.*, vol. 126, no. 5, pp. 2709–2720, 2009.

[6] N. Rasamimanana, E. Fléty, and F. Bevilacqua, *Gesture in Human-Computer Interaction and Simulation: 6th International Gesture Workshop, Revised Selected Papers*, chapter Gesture analysis of violin bow strokes, pp. 145–155, Springer Berlin / Heidelberg, 2006.

[7] M. Demoucron, *On the control of virtual violins: Physical modelling and control of bowed string instruments*, Ph.D. thesis, Université Pierre et Marie Curie (UPMC), Paris & Royal Institute of Technology (KTH), Stockholm, 2008.

[8] D. Young, *A methodology for investigation of bowed string performance through measurement of violin bowing technique*, Ph.D. thesis, Massachusetts Institute of Technology, 2007.

[9] A.P. Baader, O. Kazennikov, and M. Wiesendanger, "Coordination of bowing and fingering in violin playing," *Cognitive Brain Research*, vol. 23, no. 2-3, pp. 436–443, 2005.

[10] O. Kazennikov and M. Wiesendanger, "Bimanual coordination of bowing and fingering in violinists-Effects of position changes and string changes," *Motor Control*, vol. 13, pp. 297–309, 2009.

[11] E. Schoonderwaldt and M. Demoucron, "Extraction of bowing parameters from violin performance combining motion capture and sensors," *J. Acoust. Soc. Am.*, vol. 126, no. 5, pp. 2695–2708, 2009.

[12] J.C. Schelleng, "The bowed string and the player," *J. Acoust. Soc. Am.*, vol. 53, no. 1, pp. 26–41, 1973.

[13] E. Schoonderwaldt, K. Guettler, and A. Askenfelt, "An empirical investigation of bow-force limits in the Schelleng diagram," *Acta Acustica united with Acustica*, vol. 94, no. 4, pp. 604–622, 2008.

[14] K. Guettler, "On the creation of the Helmholtz motion in bowed strings," *Acta Acustica united with Acustica*, vol. 88, no. 6, pp. 970–985, 2002.