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Follow my leader? String quartet synchronization

Alan M. Wing[1], Satoshi Endo[1], Tim Yates[2], and Adrian Bradbury[3]

[1] School of Psychology, University of Birmingham, UK
[2] Health and Safety Executive, Buxton, UK
[3] Royal Academy of Music, University of London, UK

Timing variations in individual musical performance include both intentional expressive and unintentional error components. Such timing fluctuations contribute to the liveliness of group musical performance but need to be kept under control to create a sense of ensemble. The nature of this control is the focus of this paper. We first report an experiment in which we manipulated visual cues given by violin 1 to the other players in a quartet. We then review a new model of synchronization, and finally we describe a new listening test to determine whether people can distinguish adjustments being used to maintain ensemble synchrony. Such techniques will contribute to understanding of the nature of synchronization in music ensembles.

Keywords: timing; synchronization; string quartet; feedback correction; listening test

Many areas of human endeavor involve synchronization of individual actions to produce coherent ensemble performance in the group. Examples include walking, rowing, and music performance. Individuals tend to vary in their timing, which may be intentional (as part of performance strategy) or unintentional (due to inherent variability of biological timing systems), yet, when working in a group, they keep together. How do they do this? One possible method is to adjust one's own performance on the basis of sensory information about timing discrepancies with others. Vision, hearing, and, in some cases, touch may allow detection of asynchronies so that corrective action can be taken to get more in step, pull more together on the oars, or place different players' note onsets in better temporal alignment.

In musical performance, players do not rigidly follow the scored timing, but shape note timings for the purposes of musical interpretation. This is a personal matter, but rehearsal may be expected to bring different interpretations together as players learn to predict each other's timing. Yet musical liveliness is a matter of interpretation varying from one performance to another. Thus the Guarneri Quartet revealed that in their performances they did not seek to anticipate all expressive timing variations, but instead kept themselves ready to respond to variations in timing (and dynamics) as required (Blum 1987). Responding to asynchronies between each other's playing would be one method to maintain ensemble.

This paper is presented in conjunction with the first author's keynote address at ISPS 2013. We review feedback correction in the context of music performance. Using the string quartet as a model, we first describe a study of sensory contributions. We then provide a theoretical treatment of the adjustment process, finishing with a current study in which we are using listening tests to examine the perceptibility of timing variations in music performance.

MAIN CONTRIBUTION

Sensory contributions

The sense most obviously involved in musical performance is hearing, but vision is also important. But which sound? What visual stimulus? In a music group there are multiple possible cues; many different notes and different movements, all from different players, which might be used. One way to explore the relative importance of different possible synchronization cues is to change or remove selected cues in order to determine consequent effects on performance.

In an orchestra the conductor provides a clear visual focus enabling, for example, the simultaneous entry of whole sections of the orchestra at the start of a piece, as well as providing support for sections faced with tricky entries. Making a successful entry together is also an issue in performance by small groups, such as a string quartet, and it is common practice for the leader to take the role of the conductor by making a clear signal—a silent upbeat—prior to the start. Thus, a shared glance, a postural shift, or a lift of the instrument might all serve this role. But how might the researcher determine which are the critical aspects of such movements?

We asked a professional string quartet to play an excerpt from the opening of the first movement of Haydn's Op. 77 No. 1 (see Figure 1a) while the bow motions of the players were recorded using specialized motion capture equipment. Figure 1c summarizes 16 performances and shows that violin 1's

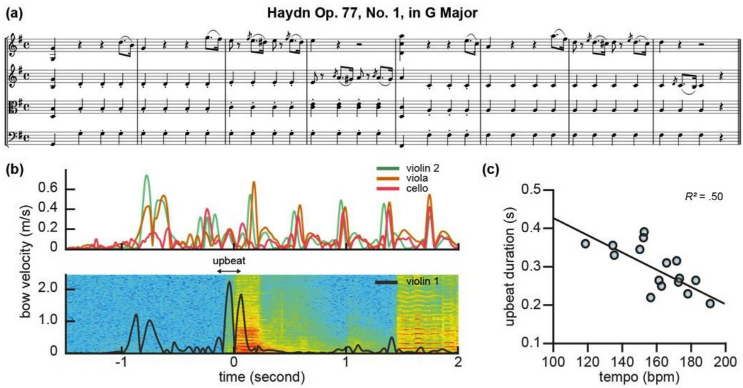

Figure 1. Silent upbeat bow velocity of violin 1 correlates with subsequent musical tempo of the quartet: (a) the excerpt: Haydn Op. 77 No. 1; (b) velocity of bow movement time-locked to the onset of the first note in the spectrogram played by violin 1; (c) scatter plot showing the negative correlation between the upbeat movement duration and the tempo of the music. (See full color version at www.performancescience.org.)

silent upbeat duration before measure 1 was negatively correlated with tempo of the following excerpt, suggesting it might have been used as a visual cue for the rest of the quartet. However, there are a number of possible visual cues associated with the upbeat movement, including not only movement of the bow arm, but also movement of the head and the violin.

In order to provide an indication as to which of these is more important, we ran another study in which the players attempted to synchronize with a video (without sound) in which their leader's playing movements (without violin) were shown in skeletal form with either left arm, right arm, or head removed (see Figures 2a and 2b). The note-by-note asynchrony variability between the three players reveals increases in variability at the start, midpoint, and end of the excerpt. Figure 2c summarizes how the average absolute asynchrony between the three players over the 5 repetitions is greater when the right arm or head is missing, consistent with their roles as visual cues for synchronization at the unison entry points. In further research it will be important to extend this analysis of entry cues to more realistic situations where, for instance, sound cues are also available.

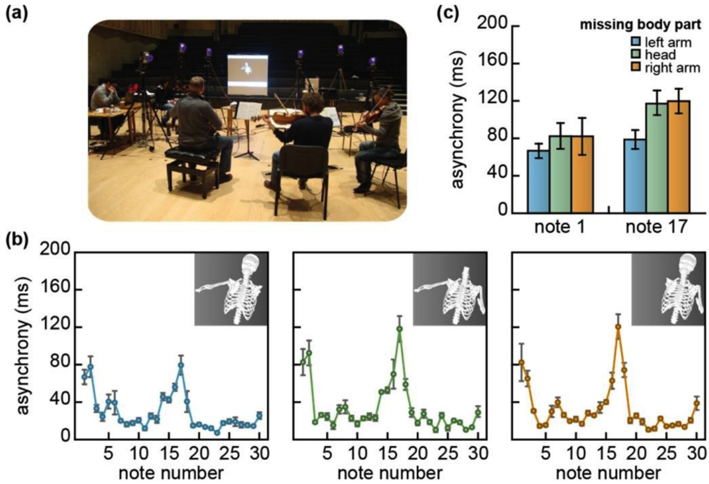

Figure 2. (a) Recording setup. The participants faced a projector screen where the avatar was displayed and the cameras tracked the bow and instrument movements; (b, c) the averaged absolute asynchrony between violin 2, viola, and cello at measure 1 and measure 5 unison entries depends on the availability of visual cues of the leader's movements at entry. (See full color version at www.performancescience.org.)

Feedback adjustment

The previous section focused on visual cues for synchronization at entry points. During the intervening periods of relatively continuous playing by all members of the quartet, it seems likely that auditory cues to synchronization would be more important. A linear feedback model describing the maintenance of synchrony by a quartet was proposed by Wing *et al.* (2013). Each player was assumed to adjust the timing of her next note in proportion to the asynchrony between her current note and the other players' current notes (see Figure 3). In such a model there are 12 proportional correction factors (gains) between all pairs of players.

Consider the musical excerpt from the fourth movement of Haydn's Op. 74 No. 1 shown in Figure 4a. Each player has a long series of eighth notes to be played simultaneously with the others. The homophony affords an interesting opportunity to explore feedback correction effects on synchrony. Simulations of a quartet playing this piece were run using the feedback model for

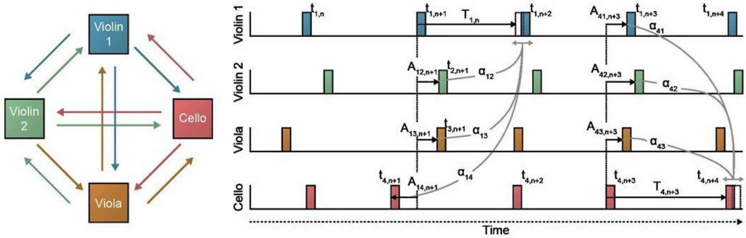

Figure 3. Asynchrony feedback correction model of quartet synchronization. The next event time, T_n, is derived from the current asynchrony against each other player, A_n, and the correction gain (α) shown for violin 1 and cello. Random timing noise (σ) is assumed to affect the intervals, T_n.

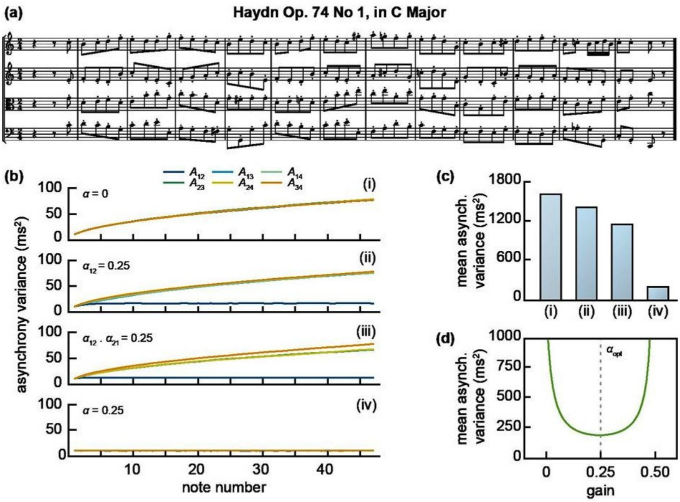

Figure 4. (a) Excerpt from Haydn Op. 74 No. 1; (b, c) asynchrony variances and their means for the 6 pair-wise combinations in a simulated quartet; (d) effects of gain on mean asynchrony variance. (See full color versions at www.performancescience.org.)

48 notes, repeated and averaged over 10000 runs. The simulation included timing variability (σ=10ms) in the intervals T_n. Four conditions, where the correction gains were varied were run to study the effects on asynchrony variances (Figure 4b). When all gains were set to zero, all pairwise asynchrony

variances asymptotically increased with note number (i). When a single gain was set to 0.25 (e.g. α_{12}) but the rest remained zero, the asynchrony variance was stable only for this pair (ii). With the reciprocal gain (α_{21}) set to 0.25, this yielded a further decrease of asynchrony variance, and the asynchrony for those paired with player 1 or 2 was also slightly reduced (iii). When all gains were set to 0.25, stability was observed across the quartet (iv). Figure 4c summarizes the average asynchrony variance for all the conditions. The gain of 0.25 was used for the simulation since the average asynchrony variance is at a minimum when the gain is 0.25 in this model (Figure 4d).

In summary, the simulation showed effects on synchronization of the correction gains between players in a quartet. In two case studies of professional quartets playing the excerpt in Figure 4a we have observed gain estimates approximating the value of 0.25, which is optimal in the sense of minimizing asynchrony variance (Wing *et al.* 2013). Elsewhere in this volume we ask if players are aware of the feedback corrections they apply (Timmers *et al.* 2013). In the next section we propose a new approach to determine whether listeners can hear the corrections.

Listening tests

Individual variability in inter-note intervals (timing noise) results in asynchrony variance. Correction restores ensemble, reducing asynchrony variance. If the correction gains of a quartet vary, what difference does it make to the listener? Figure 5a shows changes in the asynchrony variance of a virtual quartet with two levels of timing noise and across correction gains, which were set to be equal over all player pairs. Figure 5b shows that the level of the asynchrony variance can be equivalent for a low-correction, lower timing noise quartet and for an optimally adaptive, higher timing noise quartet (e.g. α=0.03, σ=5ms versus α=0.25, σ=10ms). In the current research we are asking listeners to discriminate between the playing of two musical excerpts in which (1) gains are equal but the timing noise varies and (2) the gains vary but the timing noise levels are matched. This allows us to investigate the listener's sensitivity to the amount and form of variance in note asynchrony.

Two pilot experiments were conducted, both using the same task: three participants listened to two instances of the virtual quartet playing the 48-note excerpt shown in Figure 4a, and then reported which had the larger asynchrony (i.e. which was the target quartet). In the first experiment gain was fixed at 0.25, and the timing noise level of the target, ε, was varied by a staircase algorithm. Participants' timing noise detection thresholds were measured and the asynchrony variance at threshold, σ^2 [ε=thresh, α=0.25],

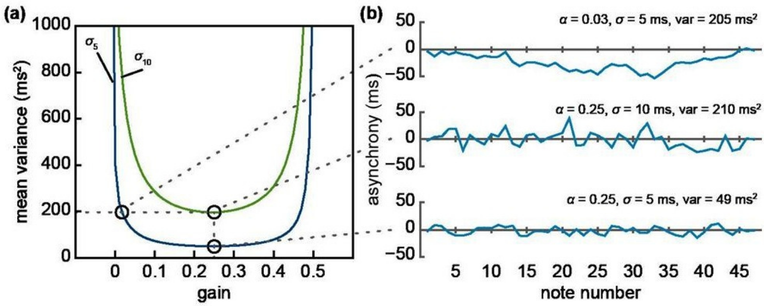

Figure 5. (a) Effects of correction gain and timing noise on asynchrony variance; (b) single trial examples of asynchrony time series when gain is optimal but timing noise is higher (middle) and when the timing noise is smaller but lower than optimal gain (top); the bottom trace shows optimal gain with lower noise. (See full color version at www.performancesciece.org.)

was computed using curves such as those in Figure 5a. In a second experiment, the timing noise in the target interval was fixed at half the participant's detection threshold and the gain was varied. Asynchrony variance at threshold in the second experiment, σ^2 [ε=thresh/2, α<0.25], was found to be significantly lower than σ^2 [ε=thresh, α=0.25] indicating that people do not discriminate asynchrony using variance amplitude alone: the structure of the asynchrony caused by the lower gain was influencing evaluation of quartet performance.

CONCLUSIONS

In this paper we reviewed synchronization in string quartets, describing a new empirical study of the use of visual cues in timing of entry points, presenting simulation results for a feedback correction model of timing, and reporting on a new listening test to determine effects of timing variability and feedback correction on the listener's perception of ensemble. The development of these techniques is helping us understand the nature of ensemble synchronizations.

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Address for correspondence

Alan Wing, School of Psychology, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK; *Email:* a.m.wing@bham.ac.uk

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