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How action adapts to social context: the movements of musicians in solo and ensemble conditions

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***Abstract*—When people perform a task as part of a joint action, their behavior is not the same as it would be if they were performing the same task alone: it is adapted to facilitate shared understanding (or sometimes to prevent it). Joint performance of music offers a test bed for ecologically valid investigations of the way non-verbal behavior facilitates joint action. Here we compare the expressive of violinists when playing solo Vs. in the string quartet music ensemble. The first and second violinists of a famous concert string quartet were asked to play the same musical fragment in a solo condition and with the quartet. Synchronized multimodal recordings have been created from the performances, using a specially developed software platform. The differences are not obvious to untrained observers but they are discriminated by musicians, and appropriate measures show that they exist. In particular, using an appropriate measure of entropy shows that head movements are more predictable in the quartet scenario. The change does not, as might be assumed, entail markedly reduced expression. The data pose provocative questions about joint action in realistically complex scenarios.**

I. Introduction

The way people carry out actions both reflects the social context and shapes it. Sometimes the adjustments are required to carry out joint activities, but adjustments also occur when they are simply sitting in the same room [2]. Research on movement has not traditionally reflected that: its approach has been described as "experimental quarantine" [14]. However, interest in the way actions are co-ordinated has been increasing. Research has studied both the behavioural adjustments that occur in social contexts, and their perceptual and cognitive underpinnings (see [16]) The range of contexts studied has been broadening, and extends from unintentional entrainment between people who are simply copresent, to deliberate and complex co-ordination in the execution of joint tasks [11]. Our interest is in studying social modulation of behavior in situations which we believe are important for a balanced overview, and which lend themselves to research that is both rigorous and ecologically valid. They involve highly skilled musical performance. A fundamental attraction of music as a scenario is that it offers contexts where action serves a strikingly wide range of social functions. A live concert is a setting where speech is marginal or non-existent, and yet people influence each other in complex, precise and profound ways. Expression is clearly part of the picture, but so is direction, opening up the prospect of exploring relationships between them. One of the questions that can be asked in that context is whether there is a necessary tradeoff between the different interpersonal functions of action. If we think of action as a limited capacity channel, then we would expect that using it to co-ordinate action would limit its ability to be used expressively. On the other hand, human action planning systems are known to be adept at multitasking, and have the ability to find ways of achieving a goal even when the resources that are usually used for the purpose are occupied with a secondary task.

We address this issue starting from the test-case of the String quartet (SQ). SQs have been identified as a particularly promising context for investigating expressive and adaptive interactions [5], [8] as all four musicians contribute equally to the performance and no explicit asymmetry as it can be observed in the orchestra case (conductor *vs.* musicians). Several studies have used observational and interview methods to explore the way musicians in a SQ interact [5]. Others, including the study reported here, model interaction by means of quantitative measures [8].

The present study makes three strategic decisions to evaluate co-ordination and expressivity interactions within the context of music ensemble. First, It adopts a comparative approach: we compare a musician's behavior while he is playing in the quartet with his or her behavior while performing the same pieces on his or her own. There are reasons to be cautious, but the naïve interpretation is that the comparison will show how execution adapts to the demands of the co-operative situation. Second, the measurement strategy records features that intuitively seem likely to capture significant information about players engagement in a joint task. This paper highlights one which has two attractions: it is not too sensitive to score details (which, for instance, is likely to be the case with movement of the bow tip); and it is sensitive to musicians' sense of their place in the ensemble. It is distance from what we call the ear of the quartet. The ear refers to a subjective center, defined by the musicians themselves, and located at nearly equal distance from each of them. Third, analysis uses particular measure of entropy called *SampEn* adapted to the specificities of human behavioral signals, i.e. their non-stationarity and non-linearity [3].

A. Summary

The paper is organized as follows: Section II introduces the experimental procedure devised to compare behavior of musicians in solo and ensemble performance; in Section II-E, we detail the obtained results and discussed them in Section IV, we conclude the paper in Section V.

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II. Experimental Procedure

We recorded performances of an internationally recognized string quartet, the Quartetto di Cremona, playing together and as individuals. Figure 3 summarizes the various steps of the experimental procedure, from data acquisition, prepocessing, extraction of expressive features and analysis of the way expressive features vary with social context.

A. Protocol

The core analysis of this paper focused on the behavior of the SQ's first and second violinists as they share similar motor repertoire related to the practice of violin instrument (the other quartet's musicians are viola and cello players). The SQs first and second violinists were asked to play a famous music piece: *Allegro* of the String Quartet No 14 in D minor by Schubert. Each musician played their part 6 times alone, and 5 times with the group. Five repetitions of the same 2 minutes length music piece without any break was considered a tradeoff between the quality of the performance and the minimum amount of quantitative data necessary to ensure significant statistical analysis. Musicians were instructed to play at best, in a concert like situation. To disentangle possible effect of group performance on solo performance, first and second violinists had to perform 3 trials before and 3 trials after the group performance. The quality of each performance was assessed by musicians through post-performance ratings (e.g., level of satisfaction and expressivity).The behavioral data were collected from two recording sessions strictly following the experimental design, the first in July 2011 and the second in September 2011.

B. Selection of the music stimuli

This piece by Schubert is a staple of the quartet repertoire. It has been further divided into 5 musical segments of about 30s each to get further control on factors that may affect musicians' behavior. Each of this music segment is actually characterized by a prevalence of a specific musical structure that organize interaction within the quartet in a specific manner: e.g., *homorhytmic* texture where musicians tends to play at unison but over which first violinist emerges progressively through a subtle original motive or *fugato* writing style which sets all musicians at the same level by replicating the musical subject over the different instruments; all parts being equal with no leading part.

C. Setup

The experiment took place in a 250-seat auditorium, an environment similar to a concert hall, suitable for experiments in ecological setups (see Figure 1). A multimodal setup was designed to capture musicians' behavior : motion capture using Qualisys system (www.qualisys.com), video camera, environmental stereo microphones and piezoelectric microphones attached to the body of the instrument. All multimodal data were synchronized through real-time applications developed within the EyesWeb XMI software platform [1].

Fig. 1. The multimodal setup for the experiment : (a) motion capture, (b) videocamera (d) environmental microphones. Each musician wears markers for motion capture. Piezoelectric microphones are in the body of the instrument. Note the position of the SQ *ear* represented by the optical reflector placed on the tripod situated in the center of the quartet, at equal distance from each musician.

D. data

This paper focuses on one particular component of the recordings, the time series data of the musicians head distance to the *ear of the SQ*. Head movement is known to play a central role in non-verbal communication in general [8] and in music in particular [4], [5]. Movements may be explicit markers, to indicate specific moments during the performance requiring synchronized start. They may also convey emotional states, either as a matter of self-expression or to communicate relevant feelings of appreciation or reassurance to others [1]. The specific measure that we extracted is distance between the head and the subjective center of the SQ, the *ear*. For a musicians movements to impact upon the ensemble, the other performers need to be able to recognize that the behavior is addressed to them. The area surrounding the ear of the SQ has a special significance for the musicians, which is bound up with their sense of the quartet as a unit. It makes sense that movements relative to that focus should have a particular significance for co-ordination. Note that before the recording, the position of the *ear* was explicitly indicated by all musicians and physically implemented using an optical reflector set on a tripod (see Figure 1). On that basis, we analyzed how the musicians head distance with respect to the ear varies over the ensemble performance. The position of each musicians head center of gravity (COG) was computed starting from the three markers placed on the musicians head, two on the front and one in the back (see Figure 2). Euclidean distance between the head COG and the String Quartets ear was then computed for each frame. Following the recommendations in [13], analysis was conducted on the increment of the head COG / Quartets ear distance time series.

E. Method

Information on head movement is used as input to the module which analyzes the regularity of head movements, based on Sample Entropy. Sample Entropy (SampEn), a non-linear technique initially developed by [15] and improved by [9] to quantify behavior regularity. The main difference between this

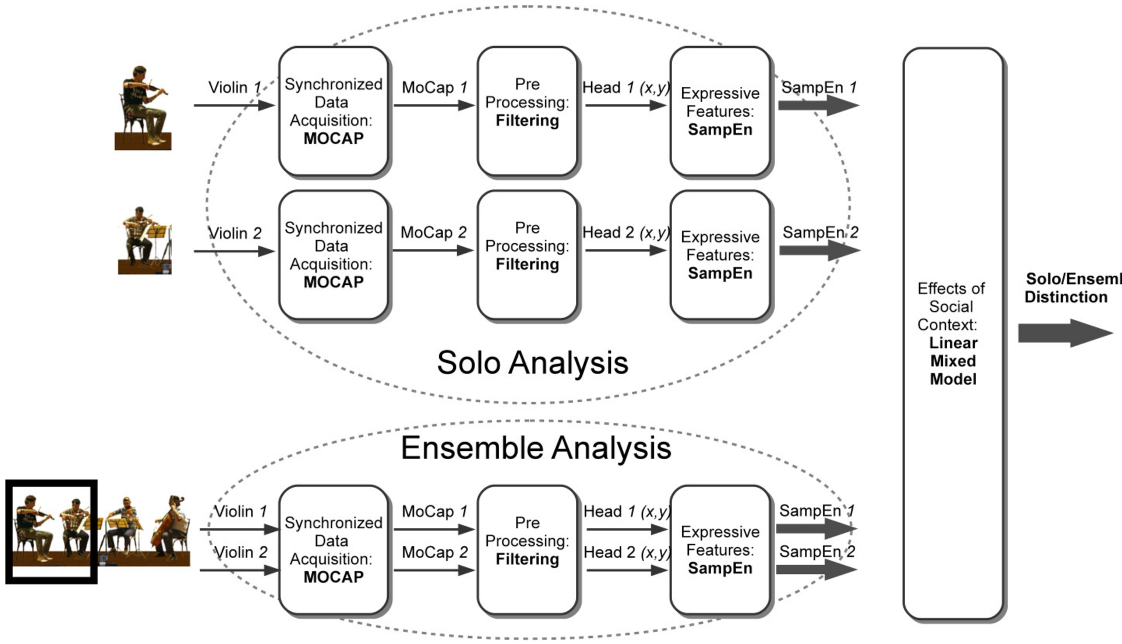

Fig. 3. Visualization of the data processing and analysis steps to evaluate the difference between behavior in solo Vs. ensemble performance. Research on complex patterns of behavior requires attention to data acquisition, preprocessing, extraction of expressive features, and analysis of the way expressive features vary with social context. In the present study, we extracted expressive features of two violin players playing in a solo and in a string quartet, respectively. Violinists head movements were obtained by the Qualisys motion capture system, and we analyzed the regularity of head movements using a measure of entropy (SampEn).

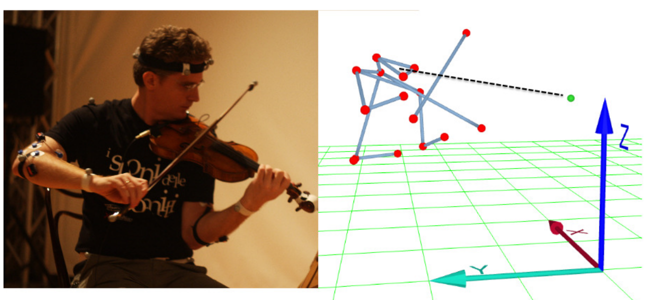

Fig. 2. Picture and Motion Capture (MoCap) data of the first violinist, with particular detail of the musicians head center of gravity (COG) with respect to the ear, the subjective center of the string quartet (see the dashed line representing the distance between these two points)

measure and traditional time and frequency domain techniques (e.g., spectral analysis) is that SampEn considers the recent movement history. For example, suppose that one swings her head forward/backward in a periodic way to support a rhythmic pulse, and then she suddenly increases her head excursion at the beginning of a more animated musical phrase.The corresponding SampEn distinguishes this sudden change in motion. A traditional entropy approach would consider each frame as a separate event and compute an average value of these events entropy, ignoring the history of the input signal. High values of SampEn indicate disorder, smaller values indicate greater regularity. SampEn has been applied to a variety of physiological data (heart rate, EMG, see [17] for a review). Most recent applications deal with behavioral data (e.g., investigating postural control mechanisms [13]) and some specifically address affective and social dynamics [7].

1) SampEn Algorithm: Given a standardized one-dimensional discrete time series of length N, $X = \{x_1, ..., x_i..., x_N\}$:

1) construct vectors of length m (similarly to the time delay embedding procedure) [18],
$$u_i(m) = \{x_i, ..., x_{i+m-1}\}, 1 \le i \le N - m \quad (1)$$
2) compute the correlation sum $U_i^m(r)$ to estimate similar subsequences (or *template vectors*) of length m within the time series:
$$U_i^m(r) = \frac{1}{(N-m-1)} \sum_{i=1, i \neq j}^{N-m} \Theta(r - \parallel u_i(m) - u_j(m) \parallel_\infty) \quad (2)$$
where $u_i(m)$ and $u_j(m)$ are the template vectors of length m formed from the standardized time series, at time i and j respectively, N is the number of samples in the time series, r is the tolerance (or *radius*), Θ is the Heaviside function, and $\|\|_\infty$ is the maximum norm defined by $\parallel u_i(m) - u_j(m) \parallel_\infty) = max_{0 \le k \le m-1} \mid x_{j+k} - x_{i+k} \mid$.
3) calculate the average of U_i^m, i.e., the probability that two vectors will match in the m-dimensional reconstructed state space
$$U^m(r) = \frac{1}{(N-m)} \sum_{i=1}^{N-m} U_i^m(r) \quad (3)$$
4) set $m = m + 1$ and repeat steps 1-4

5) calculate the sample entropy of X_n

$$SampEn(X_n, m, r) = -ln\frac{U^{m+1}(r)}{U^m(r)} \quad (4)$$

SampEn computes the negative natural logarithm of the conditional probability that subsequences similar for m points in the time series remain similar (as defined by Eq. 3) when one more point $(m+1)$ is added to those sequences. Small values of SampEn indicate regularity. Following [13], parameters of SampEn were set to $m = 3$ and r (tolerance) $=$ .20.

F. Analysis of the score

It could be argued that the behavior irregularity observed during the experiment might be a product of the complexity of the musical task faced by each musician (e.g., more notes with higher intervals to play may result in more complex movement to execute). To disentangle the effects of structural features of the music as distinct from the interpersonal dynamics within the group, an analysis of the complexity of the musical score was carried out. For each of the five musical segments played in the experiment, the individual musicians parts were evaluated using the expectancy-based model of melodic complexity [6]. That results in a unique index for each musician's part, based on the variety of intervals, the rhythmic and melodic densities encountered in each musicians part, a unique index is given. Friedman's nonparametric repeated measures analysis of variance was conducted to compare the melodic complexity index between musicians, over the five extracts.

G. Perceptual study

20 samples were selected for perceptual analysis from the full set of audio-video recordings of the first violin's performance. The selection of the recordings was based on the annotations made by the first violinist after each of his performances. We ensured that a broad range of expressive performance qualities could be represented in our sample recordings by considering the annotation given by the musician himself (e.g., worst and best interpretations). Recordings were displayed via a flat screen (17") and headphones (Sennheiser). After each audio-video sequence, the participants had to report whether they thought that the performance was solo or en ensemble. Two groups of participants were selected: non expert and music expert (with a minimum of 6 years of music practice in music school). Fourty participants, twenty for each group (16 females, 22 males) took part to the experiment (Mean age 29.16 years, range 18-60).

III. Evaluation

A. Perceptual and score-based analysis

The key comparisons were between ratings of performances solo and with the quartet. There were significant differences in ratings of the two stimulus types only for the expert group of musicians (result from a Fisher' s exact test showing significant association of Condition - *Solo* vs *Ensemble*, with the Perceived Condition - *Perceived Solo* vs *Perceived Ensemble*, $p < .05$). There are two main implications. The first is that the samples subjected to SampEn analysis were not grossly different. If the measure detects differences, then they are, from the point of view of a human observer, relatively subtle, especially for untrained participants. The second is that if musicians' behavior changes in the quartet context, it involves a complex trade-off between social and expressive qualities. As for the level of melodic complexity, no significant effects were found (Exact p=.630) so complexity of music-score can be considered similar for each musician. Thus, it is reasonable to assume that score-based properties did not have a major effect on differences in expressive and social behavior

Source	Numerator df	Denominator df	F	p
Intercept	1	190	6594.195	$< .001$
Musician	1	190	145.963	$< .001$
Condition	1	190	137.945	$< .001$
Music Segment	4	190	18.006	$< .001$
Condition * Musician	1	190	39.092	$< .001$
Musician * Music Segment	4	190	46.812	$< .001$
Condition * Music Condition	4	190	4.367	.002

TABLE I. Tests of Fixed Effects with SampEn (Sample Entropy) as Dependent Variable. This Table shows significant main effects and interactions

B. Movement Data analysis

Considering the unbalanced repeated measures design (6 observations for solo condition and 5 for the quartet condition), the *sphericity* assumption could not be assumed. Corrections due to Greenhouse-Geisser and Hyunh-Feldt, could be envisaged but they are not optimal solutions to handle correlated data and unequal variance. The linear mixed model has been chosen to compare musicians SampEn values across conditions [12]. To control the inflation of type I error probability due to multiple comparisons, the Bonferroni correction was applied to P-values (the levels of statistical significance). Applied on the full set of 420 samples (210 for each musician), The linear mixed model identified significant main effects of Condition (Solo vs Ensemble, $p < .001$), Musician (Violinist 1 vs Violinist 2, $p < .001$), and Music Segment ($p < .001$). A number of significant interaction effects have also been identified: Condition x Musician interaction ($p = .017$), Condition x Segment interaction ($p = .001$), Condition x Musician x Segment ($p = .009$) and Musician x Segment interaction ($p < .001$), see Table I. Bonferroni-corrected post-hoc analyses were performed to assess specific difference among the Conditions, Segments, and the Musician x Condition, Musician x Condition x Segment interaction effects. We review in the following the main effect of *Condition* and two related interaction effects: *Condition* x *Musician* and *Condition* x *Music Segment*.

Main effect of Condition.
Results showed that the experimental condition had a significant main effect on SampEn values: considering the two musicians altogether, for all segments, SampEn values in the Solo Condition were significantly higher than in Ensemble Condition ($F_{1,190}$= 137.945, $p < .001$), see Table I and Figure 4.

Condition x *Musician* interactions. Post-Hoc analysis of the Condition x Musician interaction revealed that the effect of condition was significant specifically for Musician 2 ($F_{1,190}$= 156.347, $p < .001$), see Figure 5. It showed that he tended to move his head toward the center of the quartet with significant lower entropy (lower SampEn values) when playing within an ensemble. By contrast, the SampEn values of Musician 1 remained less affected by the condition change ($F_{1,190}$= 15.646, $p < .001$), see Figure 6.

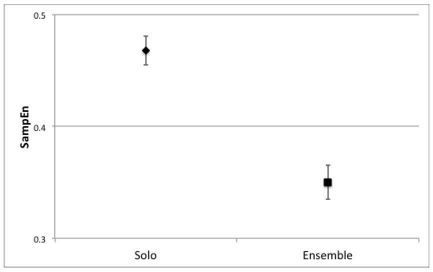

Fig. 4. Main effect of Condition *Solo* Vs *Ensemble*

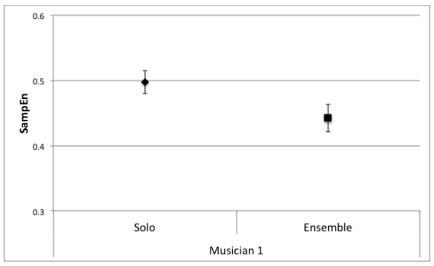

Fig. 5. Plot of Condition x Musician interaction effect (Musician 1)

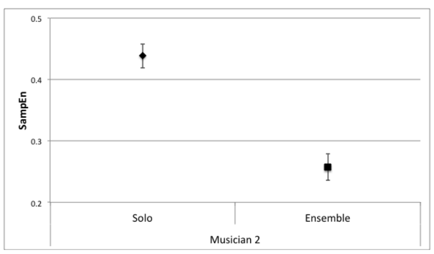

Fig. 6. Plot of Condition x Musician interaction effect (Musician 2)

Condition x *Music Segment* interactions. Despite the difference writing styles of the five music segments (see section above), Post-Hoc analysis of the Condition x Music Segment interaction revealed SampEn values of both musicians are significantly higher in Solo Condition Vs Ensemble one in all music segment except segment 1 as reported in Table II and Figure 7.

IV. Discussion

The most general aim of this paper was to highlight the potential of the SQ scenario as a setting for research on meaningful, ecologically valid joint action. The experimental findings establish a combination of facts which is intriguing.

On the surface, playing a piece with three other musicians appears to be a very different task from playing it solo. The

Segment	(I) Condition	(J) Condition	Mean Difference (I-J)	df	*p*
1	Solo	Ensemble	.054	190	.017
2	Solo	Ensemble	.158	190	.000
3	Solo	Ensemble	.152	190	.000
4	Solo	Ensemble	.082	190	.000
5	Solo	Ensemble	.145	190	.000

TABLE II. Post-Hoc tests of Condition x Segment effect (pairwise comparisons)

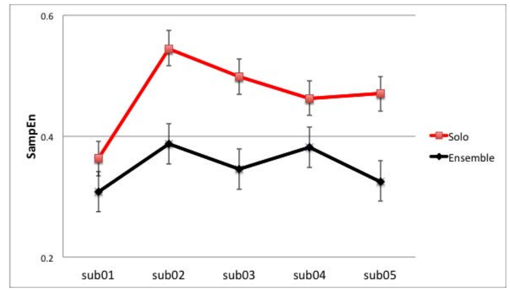

Fig. 7. Plot of Condition x Segment interaction effect

joint performance absolutely requires players to synchronize. That means they have to carry out a perceptual task which is not present in the solo situation, and to adapt their behavior accordingly. The adaptation has to be anticipatory: professional musicians do not wait to change a note until they have heard somebody else doing so. These are heavy demands. The natural inference from that kind of reasoning is that there should be quite substantial behavioral differences between a musician playing solo and one playing in a quartet. The first intriguing finding, from the perceptual study, is that the differences are not obvious for untrained perceivers but they are for expert musicians. One might expect that players would have to sacrifice some freedom to express themselves emotionally for the sake of co-ordination. One might expect that players would show telltale signs of the requirement to communicate with others, turning their heads to look, or signals in the form of nods or smiles. Again, although the measure used here is crude in some respects, it indicates that any effects of that kind are subtle: only trained observers were able to distinguish between solo and quartet performances.

The instrumental analysis based shows that there are differences, and they make theoretical sense. The SampEn measure shows that musicians do adapt to the quartet scenario in at least one way that would appear to be relevant to communication. Essentially, their upper body sway becomes more regular. It makes functional sense that that should happen: it that means that other members of the quartet have a rhythmic signal that they can detect without needing focal attention, because the spatial and temporal frequencies involved are low. From a theoretical standpoint, that is reassuring. However, there are still other pieces of evidence to account for. One reading of that finding is that the changes in SampEn noted here have no functional significance. They could be like the effects noted by [14], a mere tendency to move together, with neither communicative nor expressive significance. However, two other readings are at least equally plausible. The first option is suggested by the findings of [20]. They found that when people were required to perform a tapping task, they made their behavior more regular, presumably because increased regularity makes it easier to co-ordinate. It may be that the SampEn finding reflects that kind of generalized shift towards regularity. From that perspective, the observed change in head movement should simply be understood as part of a general regularization The difficulty with that proposal is that rhythmic regularity or irregularity is known to be expressively significant [10]. Hence if our measure were a symptom of a general regularization, we would expect it to affect perceived expression. Given that any such effects are weak, either there is no general regularization, or the musicians adopt a different way of achieving expression. The second option is suggested by a question about the artistic significance of the findings by [19]. Increased precision of timing does not always improve performance artistically (otherwise musical boxes would be star performers). The point is rather to find the right level of elasticity. Reading the findings of [19] in that context, the point may be that the low temporal frequency information provided by vision allows musicians to achieve a kind of synchrony that is artistically satisfying: broadly aligned, but not metronomic. An ongoing study including the analysis of student quartet confirms the results observed so far.

V. Future work and conclusion

The work that we have reported here establishes a few key conclusions, and points to a great many more questions. It can be established whether the observed regularization of head movement is a symptom of a more general regularization. The question can be pursued using both movement and audio recordings. If there is regularization in some aspects but not others, it raises intriguing questions about intra- as well as inter-personal co-ordination. Associated with that is the question of whether players alter the way that they achieve expression to suit different settings, for example by varying stress or timbre [10]. All of these involve substantial amounts of analysis, but they can be done using the available data. Behind all of these lie questions about the role of learning. The performances that were studied here are overlearned. In that context, it seems quite plausible that the solo performances are not solo in the usual sense of the word, but decontextualised instances of behavior that has been massively rehearsed in the quartet setting. If so, the fact that head movement changes remains to be explained. Whatever the outcome, though, it is important for research on joint action to recognize that intensive joint learning is a feature of skilled joint action just as much as intensive individual learning is a feature of skilled individual action. From that viewpoint, comparing performances in a professional quartet with performances in isolation is simply one of a natural grid of comparisons, looking at different levels of skill and familiarity.

The findings of this study indicate that each of these lines of inquiry raises real scientific challenges. Extracting satisfying answers is likely to be an intricate task. The question that remains, though, is what, if anything, science stands to gain by achieving a deep understanding of such a specialized kind of performance. The obvious answer is that the string quartet scenario is not as unique as it might seem. It is an extreme case of skilled collaborative activity. Recreationally, executing skilled activities together seems to be something that humans find satisfying, whether in structured dances or choirs or bands; and watching other people achieve it (as musicians or dancers or acrobats) seems to exert a peculiar fascination. The raw abilities to achieve that kind of joint activity, and the motivation to try, would seem to be widely distributed. Correspondingly, failing to study that kind of phenomenon would seem to leave a real gap in our picture of human social and expressive behavior.

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