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Focus of Attention Affects Togetherness Experiences and Body Interactivity in Piano Duos

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Group music-making is a socially rewarding activity that strengthens social bonds and leads to feelings of musical togetherness, that is, feelings of musical alignment and social connection. For skilled ensemble musicians, social rewards are closely tied to the aesthetic rewards that come from achieving a high-quality performance. What playing conditions encourage or discourage togetherness experiences? The purpose of this study was to show how joint and mutual attention contribute to experiences of togetherness, and how togetherness relates to communicative body motion in classical piano duo playing. The study tests two hypotheses: (a) that attention focus affects pianists' togetherness experiences and communicative body motion; and (b) that pianists' body motion can index the strength of their togetherness experiences. Piano duos performed two pieces under conditions that manipulated their attention focus to encourage or discourage joint or mutual attention. Body motion data were collected using optical motion capture, and pianists rated the quality of their playing experience on a number of scales via self-report questionnaire. Results show that joint and mutual attention improved togetherness ratings, while self-directed attention decreased enjoyment. Pianists moved their bodies less when the focus was self-directed and more at the end of the session than during a baseline performance. Coupling of motion periodicities, contrary to expectations, was lower in conditions that promoted joint attention than in the baseline. The main conclusion of the study is that joint and mutual attention strengthen togetherness experiences and affect communicative body motion, but that measures of body motion provide unreliable indicators of togetherness. The study leads to a more nuanced understanding of the construct of togetherness and how it can be measured.

Keywords: musical interaction, musical togetherness, expressivity, body motion, attention

Many forms of joint action, including collective dance, sports, and music-making, involve interpersonal synchronization of rhythmic actions. Interpersonal synchronization is associated with a range of social benefits, including increased affiliation (Hove & Risen, 2009; Stupacher et al., 2017), feelings of closeness (Tarr et al., 2015), memory for synchronization partners (Miles et al., 2010), and more cooperative behavior (Kirschner & Tomasello, 2010; Reddish et al., 2013). These social benefits have been linked to activity in the endogenous opioid system (Tarr, 2014) and may be moderated by trait empathy (Stupacher et al., 2021).

It has been theorized that musicality (i.e., the abilities that enable understanding and production of music; Fitch, 2015) may have evolved in humans, at least in part, because music participation facilitated social bonding in large groups (Savage et al., 2020) and allowed groups to communicate their strength and cohesion to other groups (Lee et al., 2020; Mehr et al., 2021). In today's world, most music is experienced socially. We share listening experiences with others (e.g., at concerts or social gatherings) and we share playing experiences with others (e.g., music teachers and classmates, coperformers in casual or professional ensembles, community members at worship services or other events).

For skilled music performers, the social and aesthetic rewards of ensemble playing are tightly linked. Playing music with others can be enjoyable and socially rewarding, but it can also be frustrating and strain the relationships between performers if they do not agree on how to play or do not perform to each other's expectations. Some recent studies have investigated the conditions that encourage positive social experiences during ensemble playing. These conditions include a balance in the magnitude of contributions from different ensemble members and a consensus on what the rules of the performance will be (Seddon & Biasutti, 2009; Saint-Germier et al., 2021). The positive social experiences that emerge during real-time musical interaction could be described in terms of *togetherness*.

What is Togetherness?

The term togetherness has appeared increasingly in the music psychology literature, where it may refer to feelings of being part of an accepting group or "we" (Bilalovic Kulset & Halle, 2020), feelings of unity or solidarity (Granot et al., 2021), or feelings of belonging and being able to work together or collaborate (Kos, 2018). Hart et al. (2014) described togetherness as an emergent quality of musical

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(or other artistic) interaction characterized by an absence of clear leading–following relationships. The current study defines musical togetherness as a spectrum of experiences that arise during expressive musical interaction and are characterized by feelings of social presence, closeness, and joint agency. These three concepts are summarized below.

Social presence has been discussed at length in the literature examining social interaction in online environments, especially online learning platforms (Kim et al., 2011), and more recently, virtual concerts (Onderdijk et al., 2021; Swarbrick et al., 2021). According to the Networked Flow model, social presence is felt when one perceives enacting others (i.e., others with intentions) in a shared (real or virtual) environment (Gaggioli et al., 2013). The model posits that recognizing others' motor intentions allows one to imitate the intended actions, while recognizing motor and proximal intentions (situated in the present) allows for interaction, and recognizing motor, proximal, and distal intentions (situated in the future) allows for empathizing.

People or agents in a shared environment need to be able to express themselves behaviorally to demonstrate their intentionality, so social presence is reduced in environments that do not allow for adequate self-expression or perception of others' self-expression. The degree of social presence that is experienced by audiences during prerecorded concerts, for example, differs depending on the quality of audio and visual signals (Shin et al., 2019). The social presence among ensemble musicians has been positively associated with the frequency of glances between coperformers and negatively associated with the exchange of orders, which reflect an imbalance in coperformers' contributions (Gaggioli et al., 2017). In a study of human–robot conversational interaction, people gave higher social presence scores and showed more expressiveness when the robot behaved expressively (e.g., making eye contact, nodding, and using facial expressions) than when the robot behaved inexpressively (Heerink et al., 2010). This finding suggests that expressivity may be promoted in interactive groups where members are attuned to their partners' expressive behavior.

Social closeness is sometimes used as a measure of affiliation in studies of interpersonal synchronization (Pearce et al., 2015; Rabinowitch & Knafo-Noam, 2015; Stupacher et al., 2017; Tarr et al., 2016; Wolf et al., 2016), and is commonly quantified with some version of the pictorial Inclusion of Other in Self scale (Aron et al., 1992). Some research has also investigated changes in musicians' perception or use of physical space during and after ensemble playing. Dell'Anna, Rosso, et al. (2020) observed a suppression of individual musicians' peripersonal space (the space within reach of the body) following improvisation with an uncooperative partner, suggesting a cognitive withdrawal from the uncooperative partner that affected even the musicians' use of physical space. In contrast, string quartet musicians have been shown to move toward each other more in perturbed conditions (where the first violinist introduces unexpected expressive nuances into the performance) than in concert-like conditions with rehearsed expression (Glowinski, Gnecco, et al., 2013).

Agency refers to the sense that one is in control of their actions and the consequences of those actions. Joint agency can be defined as the sense that one's contributions to a group product are similar in magnitude and symmetrical to the contributions of others (Pacherie, 2012; see Loehr, 2022, for an extensive review). Joint agency is more likely to arise in egalitarian groups than in hierarchical groups where the contributions of some individuals dominate, and it is positively linked with partner predictability (Bolt & Loehr, 2017), mutual rather than one-way coordination (Bolt et al., 2016), and coordination success (Bolt et al., 2016; Dell'Anna, Buhmann, et al., 2020). In collective free improvisation, joint agency has been negatively linked with interdependence in sonic activities between coperformers, suggesting that high degrees of interdependence might reduce the musicians' sense that they are contributing to the joint outcome (Saint-Germier et al., 2021). The construct of joint agency may be subdivided into shared agency, the sense that agency is distributed among group members, and united agency, the sense that group members are acting as a single unit (Pacherie, 2012).

Are Shared Intentions Needed for Togetherness?

Some of the findings described above—for example, the positive relationship between joint agency and partner predictability—suggest that shared intentions may be important for creating experiences of togetherness. On the other hand, togetherness can emerge in free improvisation, where players may have few shared intentions beyond producing an artistic output together (Hart et al., 2014; Noy et al., 2015; Saint-Germier et al., 2021).

It is clear that shared intentions can exist at different levels: high-level intentions might broadly involve creating music together, while low-level intentions might involve playing specific notes and synchronizing specific chords. Some intentions are preplanned, while others emerge during the performance as the ensemble renegotiates their ideas and expectations in real-time (Schiavio et al., 2021). The level of shared intention that is needed for togetherness to emerge likely depends on the rules and expectations associated with the musical style, and therefore how precisely group members must align their actions to feel that they are playing well.

In the Western classical ensemble tradition, which is the focus of the current study, it is conventional to perform pitches and rhythms as they are notated in a score (this is the modern convention, though in previous eras, performances commonly included improvisation, see Gooley, 2018). Ensembles construct a shared interpretation of the music while rehearsing, using a combination of online collaboration (experimenting while playing) and offline collaboration techniques (demonstrating ideas and verbal discussion; Biasutti, 2013; Davidson & Good, 2002; Ginsborg & King, 2012; King & Ginsborg, 2011). Eventually, they establish some shared interpretive and expressive intentions relating to how timing, intonation, sound intensity, and sound quality should be shaped, although high-level performers should be flexible enough to adapt if a performance unfolds differently than expected (Glowinski et al., 2016). In sum, a combination of high- and low-level shared intentions is important for high-quality classical ensemble playing.

Is Joint Attention Needed for Togetherness?

Joint attention toward intended musical features might be similarly important. It should be noted that music performance is very attention-demanding, and the ability to distribute attention effectively while performing is something that is learned over time. Keller (2008) describes an attention strategy that skilled musicians use during ensemble playing: prioritized integrative attending, a form of divided attention where one stimulus receives a higher priority (e.g., one's own playing) and another stimulus receives a lower priority (e.g., the combined group sound). This is an effortful form of attention that requires continuous and simultaneous segregation and integration of signals from different sources. Intermittency in the distribution of cognitive resources, resulting in fluctuations in attention in line with the metrical structure of the music, can help performers to maintain divided attention in this way (Bishop, Jensenius, et al., 2021; Hurley et al., 2018; Jones & Boltz, 1989; Keller et al., 2014).

A distinction can be made between joint attention toward a stimulus (e.g., the music) or some specific aspect of the stimulus (e.g., a crescendo), and mutual attention, where two or more people simultaneously attend to each other. The ability to follow social cues to others' attention (e.g., gaze cues) develops early in life (Mundy et al., 2007; Phillips-Silver & Keller, 2012). In musical and nonmusical joint action tasks, joint attention can contribute to interpersonal coordination by making coordination partners more predictable to each other (Fiebich & Gallagher, 2013).

Yet joint attention may not always be needed for successful coordination. Action observation can also facilitate prediction, as can task-sharing, or knowledge about the conditions of a partner's task (Sebanz et al., 2006). According to ecological theory, people who share a task environment perceive affordances, or opportunities for action, that are relevant to each other's tasks in addition to those that are relevant to their own task (Clarke et al., 2018; Gibson, 1979; Vesper et al., 2017). For example, imagine that two pianists are playing a duet. The primo player may adjust the position of their hands, anticipating that the secondo player is about to shift into the same range of the keyboard, and not wanting their fingers to be in the way. Central to the concept of affordances is the relationship between the individual and the environment, which can lead different individuals in the same environment to perceive different affordances. A person's own abilities may also mediate their perception of their partner(s)' affordances. Partners on a joint action task may perceive joint affordances: actions that are only relevant at the level of the group and must be carried out jointly.

In ensemble performance, joint attention to specific musical features is likely important for maintaining coordination at certain key moments (e.g., when a tempo change must be negotiated or a chord carefully synchronized) and less important at other times. The effects of joint attention may extend beyond coordination of actions, however. Relevant to the current study is the question of whether joint attention contributes to togetherness beyond facilitation of coordination; for example, by promoting joint agency. Both mutual attention and joint attention toward a specific aspect of the music might contribute to togetherness in this way.

Mutual attention has been studied in the context of communicative musicality—the aspects of human musical communication that allow "coordinated companionship" to emerge—as demonstrated in parent–infant musical (e.g., vocal) interactions (Malloch, 1999; Trevarthen, 2012). These interactions are notable partly because of how participatory they are: the parent is the one capable of producing clearly defined music, but the infant's responses shape the parent's singing in real-time. Also notable are the clear social rewards that arise in the form of parent–infant bonding.

Mutual attention in ensemble playing can be tracked, to some extent, through musicians' eye gaze patterns. Gaze direction is partially subject to cognitive control, but rapid gaze shifts can also reflect an orienting response to something that has grabbed a person's attention (Dalmaso et al., 2020). Gaze also carries social weight, and if directed toward the face of another person, communicates an intention to interact (Hamilton, 2016).

In ensemble playing, glances from one musician to another prompt redirection in the attention of the audience (Kawase & Obata, 2016). Classical ensemble musicians look toward their coperformers, especially at the starts and ends of pieces or piece sections and when musical timing is irregular (Bishop et al., 2019a). Musicians' roles in the ensemble can affect who looks at whom (Vandemoortele et al., 2018). For example, analysis of gaze patterns in a student string quartet showed that the musicians' visual attention was most often on the first violinist (conventionally, the musical leader of the group); meanwhile, the first violinist rarely looked at any of their coperformers (Bishop, González Sánchez, et al., 2021). A study of rehearsal in piano duos and clarinet duos showed that musicians spent more time watching each other after rehearsing a new piece than before (Bishop et al., 2019a). Visual attention between partners was therefore positively linked with the duos' familiarity with the music and each other.

Mutual gaze strongly suggests mutual attention. Joint attention to specific musical features is more subtly suggested by the way musicians relate to each other through their sound and body motion; noting, however, that attention is only sometimes focused on specific features, and often directed to a more abstract idea or image of what the musician(s) want to express. Still, ensemble musicians are likely somewhat sensitive to where their coperformers' attention is focused, particularly in situations where there is an established shared intention to play a certain way, and the coperformers either play as expected or play something unexpected.

Does Body Motion Reflect Togetherness?

Coordinated patterns of expressive motion are suggestive, though not necessarily confirmation, of joint attention to some aspect of the music. A large body of research has documented the patterns and relationships that emerge in musicians' expressive body motion during ensemble performances. Musicians have been shown to move more predictably when playing with others than when playing solo (Glowinski, Mancini, et al., 2013). They tend to move more when they can see their coperformers than when they are visually isolated (Bishop et al., 2019b; Bishop, González Sánchez, et al., 2021), and move more following joint rehearsal of new music than before (Bishop et al., 2019b; D'Amario et al., submitted).

Coordination between ensemble members in periodic head motion or body sway is common (Eerola et al., 2018; Glowinski, Gnecco, et al., 2013; Goebl & Palmer, 2009; Keller & Appel, 2010). The strength of coupling in body sway has been positively linked to the emotional intensity of playing by musical trios (Chang et al., 2019) and reflects leader/follower relationships in string quartets (Chang et al., 2017). Changes in body sway coupling were also observed between the first violin section, second violin section, and conductor when a seating reconfiguration placed the first violins facing the second violins instead of the conductor (Hilt et al., 2019). Leading and following in periodic head motion was found to relate to empathic perspective-taking ability in singing-piano duos (D'Amario et al., submitted).

From an audience perspective, the way that ensemble musicians move communicates something about the quality of their relationships and the cohesiveness of the group. Viewers perceive higher synchronicity or togetherness when musicians carry out periodic motion at similar frequencies (D'Amario et al., 2022; Eerola et al., 2018; Jakubowski et al., 2020). Similarly, viewers have been found to rate dancing ensembles as more formidable and closely bonded when the synchronicity of their body motion increases (Lee et al., 2020).

This research shows that the dynamics of expressive body motion is a rich source of information about ensemble musicians' relationships with the music and their coperformers. The quality of musicians' playing experiences, both socially and aesthetically, is reflected in the way they move. It remains an open question, however, how expressive body motion can be used to index experiences of togetherness as they emerge and fluctuate during ensemble performances.

The Current Study

This study addresses two main research questions: (a) How do joint and mutual attention contribute to togetherness in classical piano duos? (b) How does togetherness relate to communicative body motion? Semiprofessional pianists performed duets on separate pianos while their focus of attention was manipulated through instructions. Motion capture data were collected and piano audio was recorded. Following each performance, the pianists rated the quality of their playing experience on a number of scales. The rating scales included an item evaluating togetherness, and items evaluating aspects of experience that were expected to contribute to togetherness, based on the literature (individual and group performance quality, partner responsivity, perceived control or agency over the sound, and enjoyment; see Bolt et al., 2016; Gaggioli et al., 2017; Hart et al., 2014). These potentially contributing factors were included in the questionnaire to give a more comprehensive picture of how pianists' experiences varied across conditions.

Four hypotheses were defined. H1–H2 were motivated by the literature demonstrating the importance of joint attention for coordination, especially on tasks that involve shared intentions (e.g., MacRitchie et al., 2018), and associating mutual attention with social rewards (e.g., Bishop et al., 2019a; Malloch, 1999). H3 was motivated by prior studies suggesting that body motion becomes more communicative and musicians watch each other more after a period of free rehearsal than before (Bishop et al., 2019a, 2019b). H4 was motivated by the extensive literature on body coordination in music ensembles, which shows that the dynamics of coordination at the level of expressive and communicative body motion are highly sensitive to changes in performance demands and constraints (e.g., Bishop, González Sánchez, et al., 2021), representative of the relationships between ensemble members (e.g., Chang et al., 2017), and convey togetherness to observers (D'Amario et al., 2022).

The following hypotheses were tested:

> *Hypothesis 1:* Stronger togetherness and more communicative body motion would occur in conditions promoting mutual attention, that is, when pianists' attention was focused on the group, compared to a starting baseline. Weaker togetherness and less communicative body motion would occur in conditions discouraging mutual attention, that is, when pianists' attention was focused on their own part.

> *Hypothesis 2:* Stronger togetherness and more communicative body motion would occur in conditions promoting joint attention, that is, when pianists jointly focused their attention on the same musical feature (e.g., both focused on dynamics), compared to a starting baseline. Weaker togetherness and less communicative body motion would occur in conditions discouraging joint attention, that is, when pianists focused on different features (e.g., one focused on achieving a certain tempo while the other focused on balancing the loudness of melody and harmony.)

> *Hypothesis 3:* Stronger togetherness and more communicative body motion would occur at the end of the experiment than at the beginning.

> *Hypothesis 4:* Stronger togetherness, measured in terms of pianists' ratings of their playing experiences, would be positively linked with communicative body motion, measured in terms of (a) the strength of coupling between coperformers in head and arm motion, (b) quantity of head and arm motion, and (c) predictability of head and arm motion. These measures were selected to reflect different aspects of communicative interactive body motion that are commonly evaluated in the literature, including the degree of coordination in periodic body motion, the magnitude or intensity of body motion (which affects how visible the motion is to coperformers), and motion smoothness and predictability.

The experiment included a total of seven conditions, which were meant to either encourage or discourage joint or mutual attention. The conditions are listed by name in Table 1. The table includes the instructions that were given in each condition to the pianists and the intended effects of the instructions on attention. Two conditions encouraged/discouraged mutual attention between partners, and three conditions encouraged/discouraged joint attention toward a common musical feature. The first and last conditions had no attention manipulation. It should be noted that the study was not intended to measure either joint or mutual attention, but to evaluate the effects that different attention strategies had on body motion and togetherness experiences.

Methods

Participants

Twenty-four semiprofessional pianists (15 women, 9 men; age $M = 26$, $SD = 5.2$) participated in the study, all current piano students at [the Norwegian Academy of Music]. They reported 16.3 years of formal training, on average ($SD = 4.2$). Pianists were grouped into pairs for the experiment. Two pairs had played duets together before, three pairs knew each other but had never played piano together, and the remaining seven pairs had not met before. All pianists provided written informed consent before participating in the study.

Equipment

The experiment took place in a lecture/performance room at [the University of Oslo]. The pianists played on separate grand pianos that were arranged end-to-end (Figure 1). Body motion was recorded using an OptiTrack motion capture system with eight Flex 13 cameras, which sampled at 120 Hz. Reflective markers were placed on each pianist's head, shoulders, back, elbows, wrists, and hands (10 markers total). Pianists also wore Pupil Labs Core headsets, which

Table 1
Attention Conditions

Condition	Instructions to participants	Intended manipulation
Pre	Please play through the pieces.	None (baseline)
Group	Focus on your partner, and try to synchronize well.	Encouraged mutual attention between players
Self	Focus on pitch accuracy and try to play all of the notes correctly.	Discouraged mutual attention, as players focused on their own parts
Matched	Focus on bringing out the dynamics in the music.	Encouraged joint attention to the dynamics
Mismatched-timing	(Player 1) Focus on balance and voicing. (Player 2) Play the music slightly faster this time.	Discouraged joint attention, as players focused on different features
Mismatched-articulation	(Player 1) Focus on emphasizing articulation. (Player 2) Focus on balance and voicing.	Discouraged joint attention, as players focused on different features
Post	Please play through the pieces.	Effects of practice (no attention manipulation)

Note. The names of the conditions are listed, along with the instructions that were given to the pianists and the intended manipulations of attention.

recorded gaze and pupil size at 200 Hz. Pupil Core headsets were attached by cable to separate MacBook Pros, which ran Pupil Capture software to collect the data. Audio from the pianos was captured using two Shure SM57 microphones and a Tascam DR-680 MKII.

A clapboard fitted with a reflective marker was stuck at the start of each trial, providing a visual signal that was recorded by the motion capture system, and an audio signal that was recorded by the Shure microphones and the microphones of the two MacBook Pros, within the Pupil Capture software. All recordings were retrospectively cropped to the timestamp of this audiovisual signal. The current study reports on data from the motion capture recordings.

Musical Material

The pianists played Nos. 1 and 11 from the piano duet version of 16 Waltzes, Op. 39, by Brahms. Both Waltzes take a binary form and have a similar distribution of roles, with the primo carrying the melody and the second providing a blocked chord accompaniment. The Waltzes are engaging and dynamic, with articulation and dynamics (ranging from *piano* to *forte* in both pieces) notated in the score. They are also short (24 and 40 bars without repeats) and not very demanding to read, so most advanced students would be able to learn them quickly. Almost none of the pianists had played the Waltzes before (only one, who had played them many years earlier).

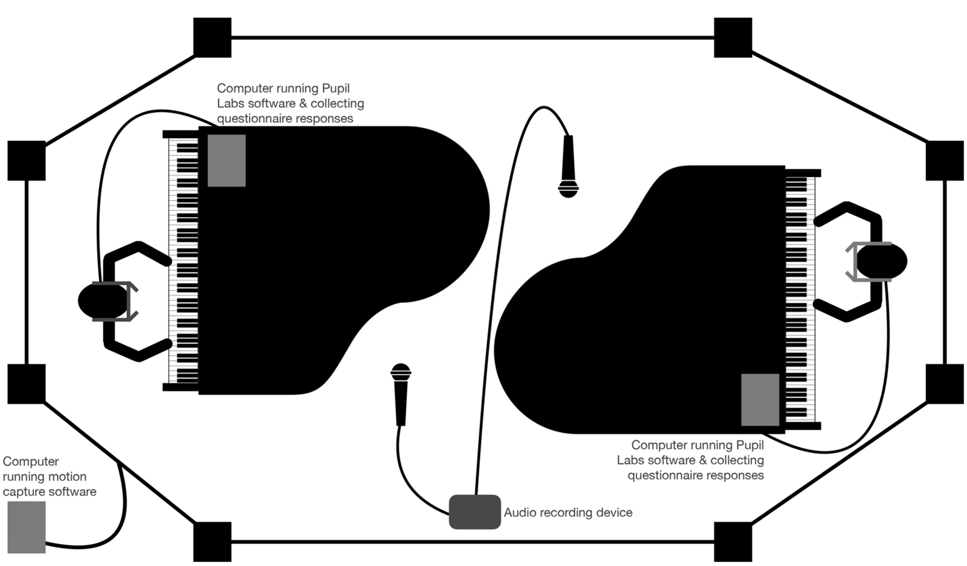
Design

The experiment comprised seven conditions. Within each condition, one performance of each of the two pieces was recorded. The Pre and Post conditions were always completed first and last, respectively. Four different random orders were set for the other five conditions, and duos were assigned to one of the order groups (three duos per order). Within duos, each pianist played the primo part of one piece and the secondo part of the other piece.

Procedure

At the start of each session, the pianists completed written consent forms and were fitted with a jacket, hat, markers for motion capture,

Figure 1
Diagram Showing the Experiment Setup



and Pupil Core headsets. They were then given hard copies of the scores for the pieces. They were allowed up to 30 min to practice the pieces together. We then recorded one performance of each piece under seven different conditions. The instructions are summarized in Table 1. Pianists received their instructions individually and were not told that they and their partner would sometimes receive different instructions. Note that no specific instructions were given for the Pre and Post conditions; the pianists were allowed to play freely.

At the end of each condition, after playing through both pieces, the pianists completed a questionnaire, which was presented using the web-based PsyToolkit. On a scale of 1 to 5, pianists were to rate the following (the direction of the scale as presented in the questionnaire is indicated in parentheses):

- The quality of their own performance (low–high).
- The quality of the group performance (low–high).
- How responsive their partner was to their playing (low–high).
- How much control they felt that they had over the overall duet sound (high–low).
- How together they and their partner were overall (high–low).
- How much they enjoyed the performance (low–high).

At the end of the experiment session, pianists completed a musical background questionnaire, which included questions about how long they had been playing piano, whether they play professionally, how often they perform, whether they have (completed or in progress) a university music degree, and whether they teach piano.

Analysis

Preprocessing of Head and Arm Motion

Small gaps (under 200 ms) in body motion data were filled using a spline interpolation. Data were then smoothed and velocity was derived using a Savitzky–Golay filter (polynomial order = 3, window size = 41; "prospectr" package in R; Stevens & Ramirez-Lopez, 2022), and the Euclidian norm was taken of the smoothed 3D velocity data. Extreme outliers with z-scores outside the range −6 to 6 were then removed from the data. Velocity data were highly positively skewed, so a log+ .1 transformation was applied.

Once motion and audio were aligned (see the "Equipment" section), data for individual performances were extracted. Performance onsets and ends were identified manually in audio recordings. Performances were cropped to begin 1 s before the first note onset and end at the acoustic end of the piece (i.e., when sound was no longer audible on the audio recording).

Measures of Motion

Three measures were calculated using head and arm velocity data: power of cross-wavelet transformation (CWT power), quantity of motion (QoM), and Surprisal. CWT power indexed the strength of coupling between players and Surprisal indexed predictability. QoM and Surprisal were computed per pianist and CWT power was computed per duo.

Cross-Wavelet Transformation

For the CWT analysis, gaps larger than 200 ms were filled using a linear interpolation. This was a necessary step as the function that was used to calculate CWT could not handle missing values. The first stage of analysis involved identifying the range of frequencies that would be considered for the analysis. Musicologically, we would expect body motion to relate to the metrical and bar structure of the music (Clayton et al., 2019; D'Amario et al., submitted). The total duration of each performance was divided by the number of beats in the piece to obtain an average interbeat interval (IBI). These IBIs were relatively short ($M = .43$ s, $SD = .08$ for Waltz No. 1 and $M = .47$ s, $SD = .07$ for Waltz No. 11), making it likely that periodicity in expressive motion would unfold more meaningfully at the level of bars and phrases than at the level of beats. A broad range of frequencies (.5–16 s) was therefore included in the CWT analysis. This range corresponded to between one bar (in a fast performance) to eight bars (in a slow performance).

CWTs were computed per duo and performance, separately for velocity trajectories of the head, left arm, and right arm. This was done using the R package "WaveletComp" (Roesch & Schmidbauer, 2018). Power spectrums were extracted for the periods corresponding to < 1 bar duration (up to 2 IBIs), 1 bar (± 1 IBI), 2 bars (± 1 IBI), 4 bars (± 2 IBIs), and 8 bars (± 2 IBIs). The range of periods that corresponded to each bar level was calculated per performance, since each performance had a slightly different average IBI. Power data were then averaged across periods at each time index to obtain an average power series per bar level. Average power data were positively skewed, so a log+ .1 transformation was applied.

Power spectrums for two performances are shown in Figure 2. The distributions of CWT power across bar levels for the head and arms are shown in Figure 3. To determine which bar level corresponded to the strongest CWT power across the dataset of performances, two tests were carried out. The first test examined the effect of bar level on power using linear mixed-effects modeling (LMM). A model was run for each of head data, left arm data, and right arm data that included duo crossed with piece and condition as random effects to account for repeated measures. All models yielded a significant main effect of bar level ($p < .001$), so Tukey honestly significant difference tests were run and tested against a Bonferroni-corrected $\alpha = .005$. For the head, power was higher at the < 1-bar, 1-bar, 2-bar, and 4-bar levels than at the 8-bar level (all $p < .005$). For the left and right arms, power was higher at the < 1-bar and 1-bar levels than at the 2-bar, 4-bar, and 8-bar levels (all $p < .005$).

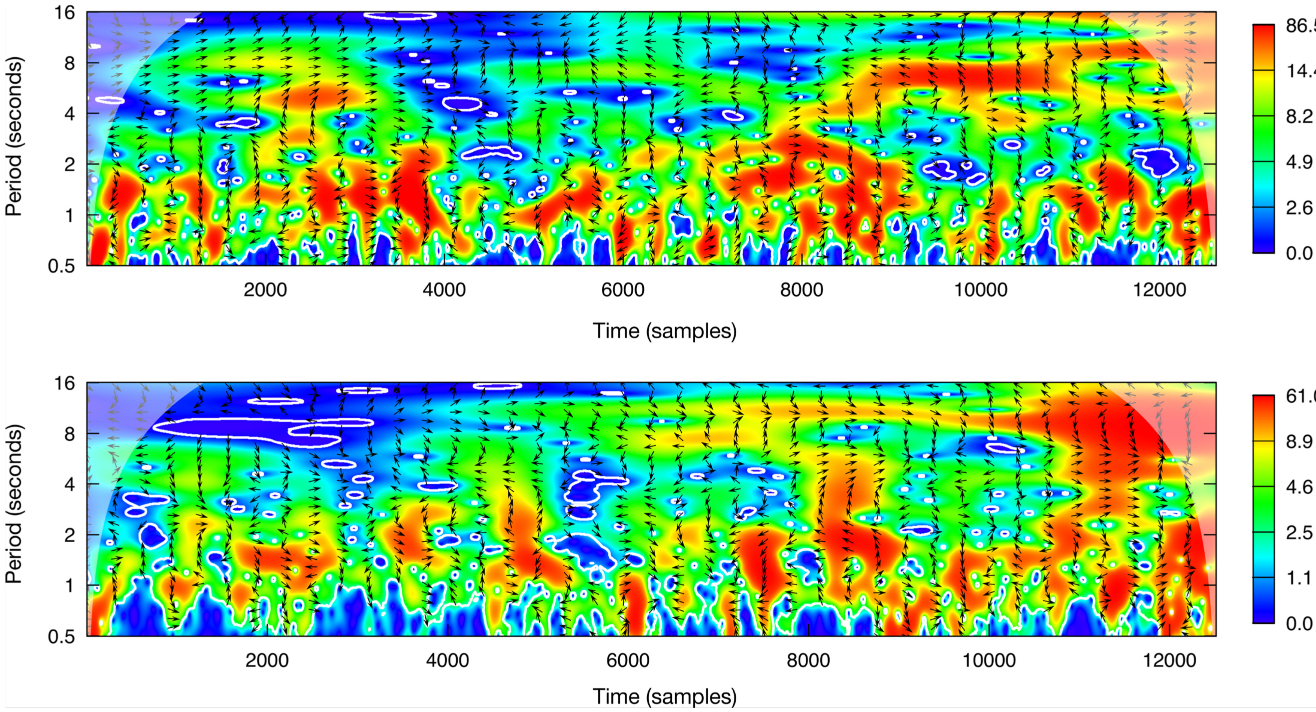
The second test extracted the single strongest period for each performance (i.e., the period with the greatest average power) and examined how often these strongest periods fell into each of the bar-level bands. These results are shown in Table 2. Proportion tests evaluated at $\alpha = .005$ showed lower occurrences at the 8-bar level than at all other levels for the head, and lower occurrences at the 2-bar and 4-bar levels than at the < 1-bar and 1-bar levels for the right and left arms (and no occurrences at 8-bars).

In sum, no bar level stood out as significantly stronger in power than the others. The < 1-bar and 1-bar levels, however, tended to be stronger than the others and were associated with the highest occurrence of strongest periods. Therefore, in the interest of brevity, these bands were combined for the next stage of analysis.

QoM. To obtain QoM, log-transformed velocity data for each marker (head, left elbow, right elbow) were summed per second. QoM was then averaged between the left and right elbows for each pianist.

Figure 2

Power Spectrums for the Performances of One Duo That Were Strongest (Top) and Weakest (Bottom) in Power of Cross-Wavelet Transformation (CWT Power) for Head Velocity in the < 1-Bar and 1-Bar Bands



Note. The color scale indicates the strength of CWT power. Arrow direction indicates leading and following (which was not analyzed here). See the online article for the color version of this figure.

Surprisal. A linear interpolation was used to fill gaps larger than 200 ms, which had been left empty during preprocessing. Just as for CWT, this was needed because the functions that were used to calculate Surprisal could not handle missing values. A Kalman filter was used to calculate the Shannon information content (negative log-likelihood) for each series of marker velocities (head and average of left and right arms). The filter took parameters from a first-order autoregressive integrated moving average (ARIMA) model, computed for each performance using maximum likelihood estimation. Lower Surprisal values indicate higher predictability.

Effects of Condition on Head/Arm Motion and Ratings of Playing Experience

The effects of condition on pianists' ratings of playing experience were evaluated using LMM. There were two parts to this analysis. First, a separate model was run for each individual scale. Control and togetherness ratings were reversed so that all scales ranged from low to high. Pianist and condition were included as crossed random effects. (Note that ratings were collected per condition, not per piece, so the piece was not included here as a random effect.) Second, a model was run to test the effects of condition on summed ratings. This model included the sum of ratings across all scales as the response variable and performer crossed with a condition as random effects. Again, control and togetherness ratings were reversed, so all scales ranged from low to high. For all models, Pre was set as the base condition against which all other conditions were compared, and significance was evaluated at $\alpha = .008$ following Bonferroni's correction.

The effects of the condition on the head and arm motion were evaluated separately for each measure using LMM. Each model included condition as a fixed effect, and performer (QoM and Surprisal) or duo (CWT power) crossed with piece and condition as random effects. Again, Pre was set as the base condition against which all other conditions were compared. Significance was evaluated at $\alpha = .008$.

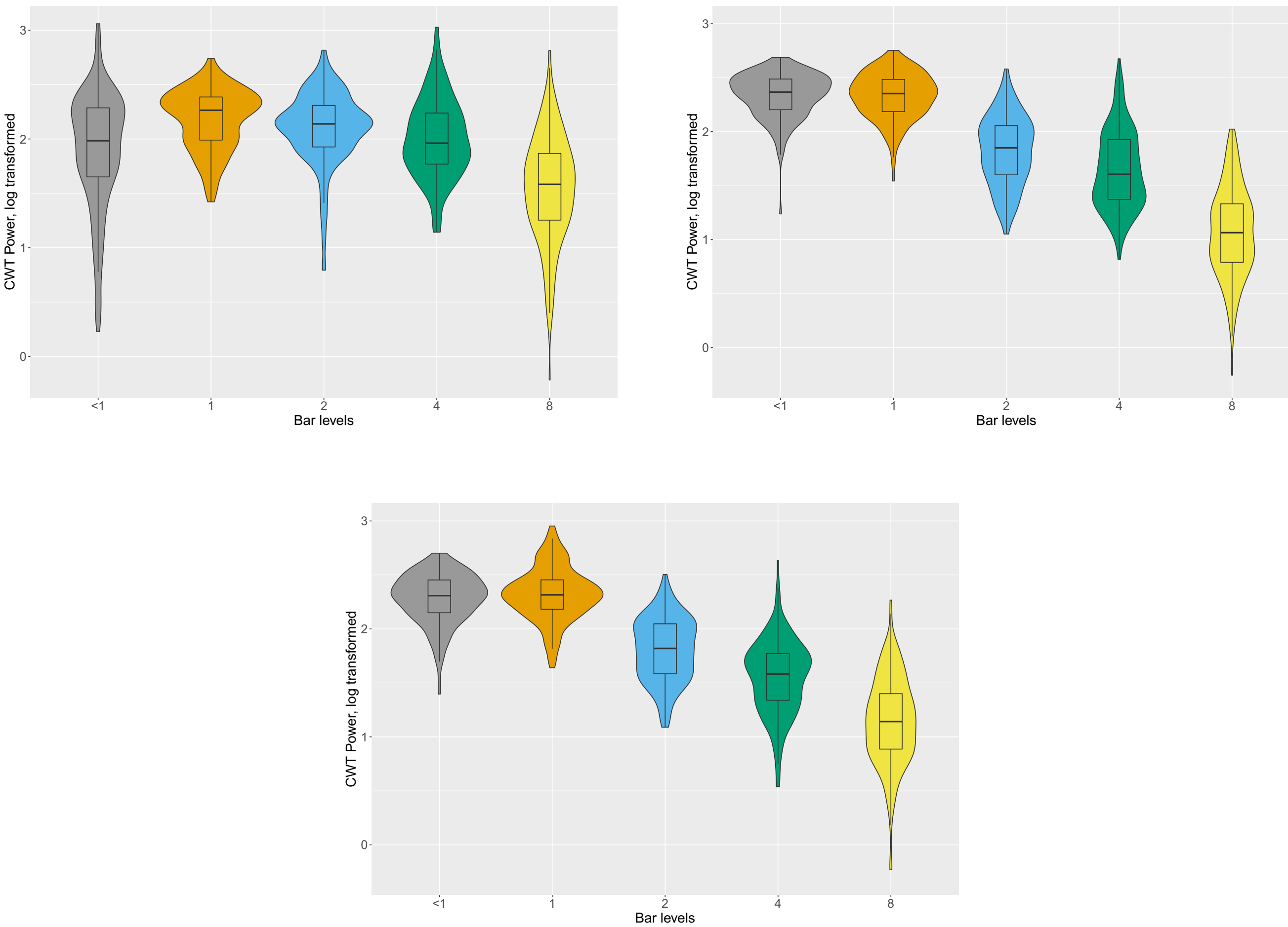
LMM was then used to test how strongly the combination of motion measures predicted ratings of playing experience. Separate models were run for head motion and arm motion. These models included the sum of ratings across all scales as the response variable and tested the interactions between CWT power, QoM, and Surprisal as fixed effects. Pianist and condition were included as crossed random effects. The "performance" package in R (Lüdecke et al., 2021) was used to evaluate multicollinearity for the models, and in both cases confirmed that variance inflation factors were all below 5, indicating acceptably low correlations between predictors. Significance for these models was evaluated at $\alpha = .05$.

Results

It was predicted that ratings of playing experience, QoM, and CWT power would be higher in Group (H1), Matched (H2), and Post than in Pre (H3), and lower in Self (H1), Mismatched–articulation, and Mismatched–timing than in Pre (H2). Surprisal in head and arm motion was predicted to follow the opposite pattern, being higher in Self (H1), Mismatched–articulation, and Mismatched–

Figure 3

Violin Plots Showing Cross-Wavelet Transformation (CWT) Power Per Bar Level for the Head (Top Left), Right Arm (Top Right), and Left Arm (Bottom)



Note. See the online article for the color version of this figure.

timing than in Pre (H2), and lower (indicating higher predictability) in Group (H1), Matched (H2), and Post than in Pre (H3).

Effects of Condition on Ratings of Playing Experience

Results from the models testing the effects of condition on individual rating scales are listed in Table 3. All of the observed effects were in line with the hypotheses, though not all predicted effects were observed. Notably, only two negative effects occurred: pianists rated their enjoyment lower in Self than Pre and rated their partner's responsivity lower in Mismatched-timing than Pre. To follow up on these results, correlations were calculated between togetherness and the other scales. All correlations were positive (in order of descending strength: group playing quality, $r = .67$; enjoyment, $r = .58$; responsivity, $r = .57$; control, $r = .49$; individual playing quality, $r = .39$; all $p < .001$).

The model that tested the effects of condition on summed ratings showed higher ratings than Pre in Matched, Estimate = 3.68, $t(126) = 3.19$, $p = .002$, and Post, Estimate = 4.27, $t(126) = 3.71$, $p < .001$ (Figure 4). No other effects were significant.

Table 2

Frequency Table Showing the Number of Performances Where the Strongest Period Fell Into the Range of Each Bar Level

Body part	Bar level					
	<1	1	2	4	8	Other
Head	33	40	26	23	5	41
Right arm	62	94	2	2	0	8
Left arm	81	73	2	2	0	10

Note. The reported bar levels include < 1 bar (i.e., periods below the 1 bar range) and other (i.e., all periods that are not captured by one of the reported bar levels).

Effects of Condition on Head/Arm Motion

Results from the models testing the effects of condition on head and arm motion are listed in Table 4, and distributions for the measures of motion are shown in Figures 5 & 6. Compared to Pre, there was less head and arm motion in Self, more head motion in Post, and greater

Table 3

Results of LMMs Evaluating the Effects of Condition on Ratings of Playing Experience

Rating scale	Estimate	*SE*	*t*
Individual quality			
Post	.82	.25	3.31
Group quality			
Matched	.77	.24	3.28
Post	.86	.24	3.67
Responsivity			
Mismatched-timing	−.68	.25	2.68*
Control			
Post	.82	.26	3.15
Togetherness			
Group	.86	.27	3.17
Matched	.95	.27	3.51
Post	.95	.27	3.51
Enjoyment			
Self	−.91	.27	3.32

Note. LMM = linear mixed-effects modeling; *SE* = standard error. The columns show the magnitude of the estimate produced by the models for each rating scale, the *SE*, and the value of the *t*-statistic. Only results significant at $p < .008$ (*or marginally significant, $p = .008$) are listed.

Surprisal in arm motion in Mismatched-timing. These findings were in line with the hypotheses. Several effects were also observed in contrast to the hypotheses. These included, again compared to Pre, lower CWT power in head and right arm motion in Matched and Post, more head and arm motion in Mismatched-timing, and lower Surprisal in head motion in Mismatched-timing.

The LMM testing the combined effects of the different head motion measures on summed performance ratings showed a positive effect of Surprisal, Estimate = .73, $t(124) = 2.97$, $p = .004$, and a negative effect of CWT power, Estimate = −.46, $t(124) = 2.57$, $p = .01$, with no significant interactions. In other words, body motion became less predictable and coupling became weaker as ratings increased. There were no significant effects on arm motion.

Relationships Between Measures of Motion

Follow-up analyses were carried out to assess the relationships between CWT power, QoM, and Surprisal. In part, this was driven by the finding that motion measures were affected differently by the attention conditions (e.g., CWT power in head motion was lower in Post than Pre, while QoM was higher).

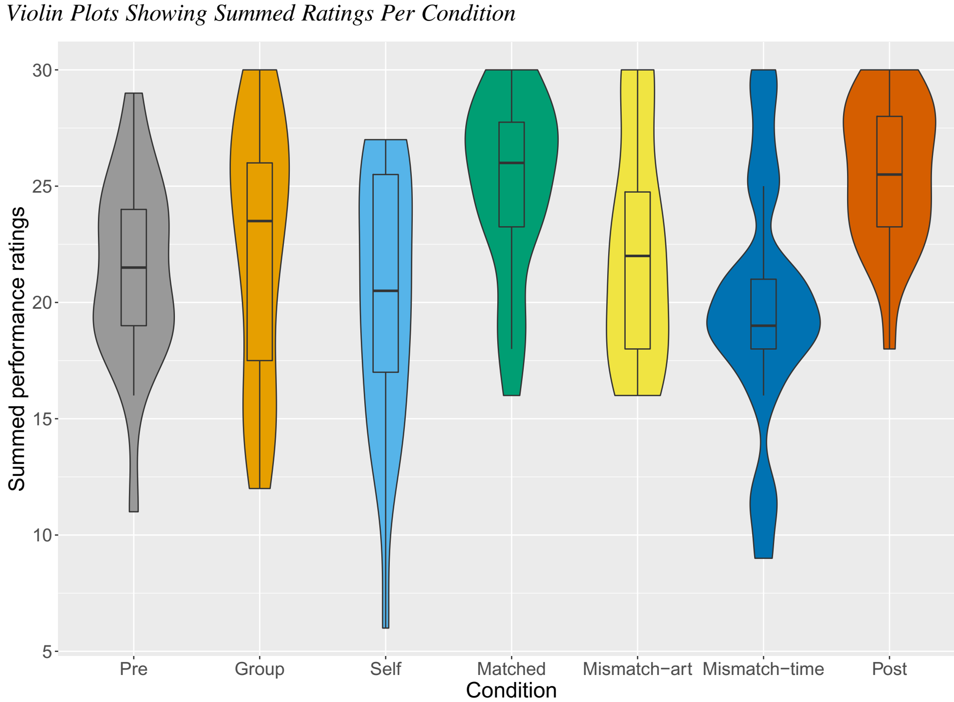
Linear mixed effects models were run to test the predictive effects of QoM on CWT, Surprisal on CWT, and QoM on Surprisal. The models included pianist and condition as crossed random effects. All motion measures were standardized so that the magnitude of their effects would be comparable. Significance was evaluated at $\alpha = .05$.

QoM had a negative effect on CWT power for head motion, Estimate = −.17, $t(131) = 2.63$, $p = .01$, and arm motion, Estimate = −.39, $t(130) = 3.39$, $p < .001$. QoM also had a negative effect on Surprisal for head motion, Estimate = −.10, $t(130) = 2.10$, $p = .04$, but not for arm motion. The effect of Surprisal on CWT power was nonsignificant for head and arm motion.

Additional models were tested to assess the temporal relationship between QoM and CWT power trajectories. These models were run using the package "glmmTMB" in R (Brooks et al., 2017) and included pianist, piece, and condition as crossed random effects and an autoregressive (order 1) component. For head motion, the effect of standardized QoM on standardized CWT power was

Figure 4

Violin Plots Showing Summed Ratings Per Condition



Note. See the online article for the color version of this figure.

Table 4
Results of LMMs Evaluating the Effects of Condition on Head and Arm Motion

Body part	Motion measure	Estimate	*SE*	*t*
Head	CWT			
	Matched	−.12	.03	3.53
	Post	−.17	.03	4.87
	QoM			
	Self	−.07	.02	4.03
	Mismatched-timing	.08	.02	4.67
	Post	.07	.02	4.55
	Surprisal			
	Mismatched-timing	−.02	.01	4.34
Arms	CWT (right arm)			
	Matched	−.11	.03	3.73
	Post	−.09	.03	2.90
	QoM (both arms averaged)			
	Self	−.03	.01	3.33
	Mismatched-timing	.03	.01	3.51
	Surprisal (left arm)			
	Mismatched-timing	.17	.06	2.99

Note. LMM = linear mixed-effects modeling; CWT = cross-wavelet transformation; *SE* = standard error; QoM = quantity of motion. The columns show the magnitude of the estimate produced by the models for each motion measure, the *SE*, and the value of the *t*-statistic. Only results significant at $p < .008$ are listed.

negative, Estimate = −.11, $SE = .01$, $z = 10.68$, $p < .001$. For left arm motion, the effect was positive, Estimate = .06, $SE = .01$, $z = 5.16$, $p < .001$. For right arm motion, the effect was nonsignificant.

In summary, complex patterns of relationships were found between motion measures, with differences between head and arm motion. Notably, for the head, coupling strength decreased as QoM and predictability increased.

Discussion

This study addressed the broad question of how togetherness arises during classical piano duo playing. The aim was to show how joint and mutual attention contribute to togetherness experiences and expressive body motion, and to what extent experienced togetherness can be indexed through measurable qualities of body motion.

Analysis of pianists' ratings of playing experience showed that the condition that encouraged joint attention (Matched) elicited improvement in perceived playing quality and togetherness, while the condition that encouraged mutual attention (Group) elicited improvement in togetherness. The condition that discouraged joint attention (Mismatched-timing) elicited reduced perceived responsivity, and the condition that discouraged mutual attention (Self) elicited reduced enjoyment. Pianists responded most positively to Matched and Post, where the sum of all ratings was greater than in Pre. Analysis of pianists' body motion showed some predicted effects, including increased motion in Post and reduced motion in Self relative to Pre, but also several unexpected effects, including, notably, reduced interperformer coupling in Matched and Post and increased motion in Mismatched-timing. These findings suggest that focus of attention has variable effects on expressive body motion, and points toward a complex relationship between experiences of togetherness and qualities of expressive body motion that likely depends on the specific demands of the performance. These results are interpreted in more detail below.

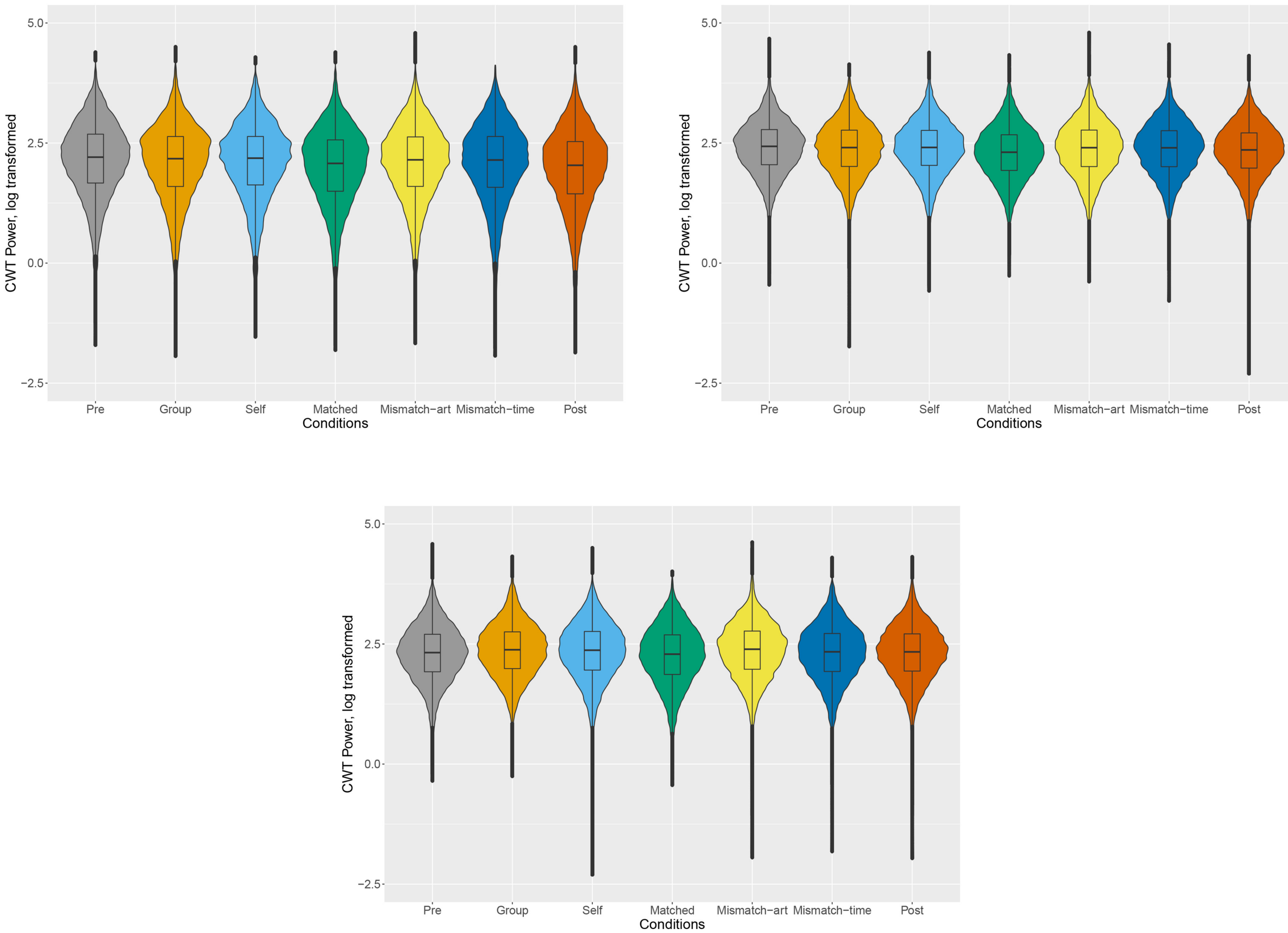
In this study, pianists' ratings were treated as ground truth for their togetherness experiences. Pianists were asked to rate a number of scales representing presumed component factors of togetherness. This task was in contrast to some other studies that have assessed the quality of relationship between ensemble members through pictorial tasks (e.g., the Inclusion of Other in Self scale; Aron et al., 1992), measures of affiliation (Hove & Risen, 2009), indirect measures of cooperation (e.g., economic games; Launay et al., 2013), or interviews (Saint-Germier et al., 2021; Smetana et al., 2022). The scales that were used in the current study allowed for testing how different factors fed into pianists' concepts of togetherness. Ratings of togetherness correlated positively with ratings on all other scales, with the highest correlations arising for group playing quality, partner responsivity, and enjoyment, and lower correlations arising for individual playing quality and individual control. Thus, the scales that were most representative of positive group relations rather than individual contributions related more strongly to togetherness.

In terms of head motion, a greater quantity of motion arose in Post than in Pre. This effect builds on previous findings showing that even a brief period of rehearsal (20–60 min) encourages musicians in small ensembles to move more (Bishop et al., 2019b; D'Amario et al., submitted). In the study by Bishop et al. (2019b), the increased quantity of motion was perhaps less surprising than in the current study, because the baseline performance took place before the musicians had rehearsed the music at all, so they had to focus on reading the score. In the present study (as in D'Amario et al., submitted), the musicians had already rehearsed together for up to 30 min before recording the baseline performance (Pre), and still, a difference between the first and last performances was seen. The increased quantity of motion in Post that was observed in the present study was accompanied by strengthened ratings of togetherness, playing quality, and control. This co-occurrence suggests that the conditions surrounding Post (i.e., a performance that was given freely, with no specific instructions, following a series of repeated performances of the same music, and the final performance of the experiment), may have encouraged a more positive playing experience and greater energy and overtness in body expressivity.

Quantity of motion also differed from Pre in Self and Mismatched-timing. The reduced motion that was seen in Self is in line with the hypothesis that self-directed attention discourages ensemble musicians from moving their bodies in an overtly expressive, communicative way. A parallel finding was reported by Dell'Anna, Buhmann, et al. (2020), who found that musicians' peripersonal space decreased after they improvised with an uncooperative partner. In that study, the playing conditions may have encouraged a more self-directed focus. This is also likely what tends to happen naturally during the earliest phases of ensemble rehearsal, when the musicians do not yet know the music very well and have to focus attention on monitoring their own playing (Bishop et al., 2019b), or when ensemble musicians play together in visually isolated conditions (Bishop, González Sánchez, et al., 2021). Whether musicians also move less when playing their part individually (without the rest of their ensemble) is unclear. Bishop and Goebl (2020) observed the opposite effect with pianists, who moved more when playing apart than together, but this may have occurred because the pianists sat together at the same piano during the duet condition and, therefore, had less space.

Figure 5

Violin Plots Showing Cross-Wavelet Transformation (CWT) Power Per Condition for the Head (Top Left), Right Arm (Top Right), and Left Arm (Bottom Left)



Note. See the online article for the color version of this figure.

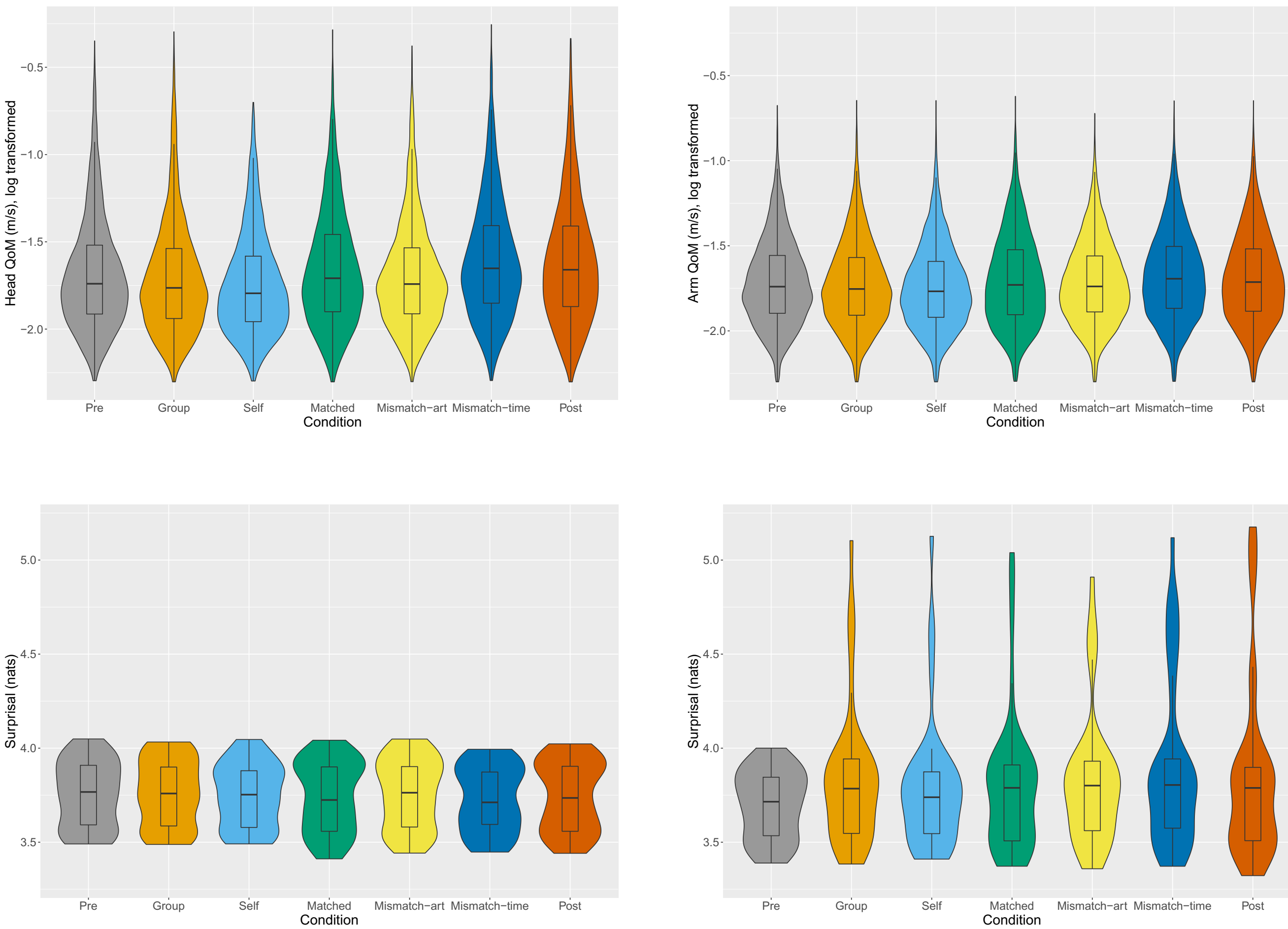
In Mismatched-timing, the quantity of motion increased, while the Surprisal of left arm motion increased and the Surprisal of head motion decreased. These differences were accompanied by reduced ratings of partner responsivity. The increased quantity of motion, which occurred for the head and arms, was contrary to the hypothesis that pianists would detect that their partner was not following the assigned instructions (recall that pianists were unaware that their partner sometimes received different instructions), and consequently experience reduced togetherness and expressive bodily engagement with the music. Rather, it seems that pianists detected that their partner was not following the instructions, as evidenced by the low ratings of partner responsivity, and responded with more body motion, perhaps in an attempt to grab their partner's attention and/or regulate their own timing amidst conflicting demands (i.e., following the instructions for a faster tempo vs. maintaining synchrony with their partner).

Previous studies in music and other domains have shown that people modify their body motion in a variety of ways when performing a collaborative task; for example, exaggerating their movements or moving more predictably (Pezzulo et al., 2019; Vesper et al., 2011). Ensemble musicians move more when playing music that is difficult to coordinate (Bishop et al., 2019b; Bishop & Goebl, 2015). In the current study, the reduced Surprisal (i.e., increased predictability) in head motion that arose in Mismatched-timing is also suggestive of an attempt to communicate more clearly. The increased Surprisal of the left arm is less readily explained, but may reflect decreased fluency in sound-producing motion as a result of uncertainty about musical timing (Gonzalez-Sanchez et al., 2019).

It is notable that this combination of effects was observed only for Mismatched-timing, and not for Mismatched-articulation. In the latter condition, the manipulation may not have been strong enough for pianists to detect, whereas Mismatched-timing threatened their temporal alignment and synchronization. These are fundamental musical features in the classical piano repertoire (just as with many other musical forms). MacRitchie et al. (2018) showed that pianists prioritize synchronizing with their partner when presented with incongruent indications of tempo, but prioritize their individual

Figure 6

Violin Plots Showing Quantity of Motion (Top) and Surprisal (Bottom) for Head Motion (Left) and Averaged Left–Right Arm Motion (Right) Per Condition



Note. See the online article for the color version of this figure.

instructions when presented with incongruent indications of dynamics. Maintaining synchronization might be not only artistically important, but also more difficult to avoid given that synchronization to regularly timed rhythms is largely automatic (e.g., Keller et al., 2014; van der Steen & Keller, 2013). In piano-playing, articulation is a composite musical feature that involves manipulations of both timing (relating to note attacks and offsets and spacing between phrases; Bresin & Umberto Battel, 2000) and force (loudness). Articulation also contributes to other composite, higher-order expressive features such as timbre (Bernays & Traube, 2014). Pianists may need to listen more attentively, and with a more analytic ear, to pick up on discrepancies in intended articulation, while asynchronies are disruptive enough to be noticed without effort. Anecdotally, it is also relevant that when the pianists of the current study were debriefed after the experiment and told for the first time that their partner sometimes received different conditions, most duos immediately recalled Mismatched-timing and remembered that something seemed wrong in that condition.

In Matched and Post, coupling between players in head and right arm motion was lower than in Pre (as measured by CWT power), though the magnitude of the effect was small. This reduced coupling was in contrast to the hypothesis that coupling would increase in these conditions alongside greater togetherness. These results suggest that conditions that encourage togetherness can have variable effects on musicians' communicative and expressive body motion, prompting some aspects to change in one direction (e.g., quantity of motion increases) while other aspects change in a different direction (e.g., strength of coupling decreases). Indeed, further analysis showed a negative relationship between the quantity of head motion and strength of coupling and a negative relationship between the quantity of head motion and Surprisal.

Conditions that were designed to encourage togetherness may have prompted more freedom of motion, leading to a dissociation between the quantity of motion and strength of coupling. Perhaps under different performance conditions or with different musical repertoires, different relationships between motion measures might arise. For example, in the study by D'Amario et al. (submitted), the quantity of motion increased across successive performances while the strength of coupling remained the same. Other studies have shown that the strength of coordination in upper body motion, measured using cross-wavelet transform analysis, predicts human viewers' judgments of interaction (Eerola et al., 2018) and togetherness (D'Amario et al., 2022). Further research is needed to show whether coupling between players is equally as important from players' perspectives as from audiences' perspectives.

These findings have important methodological implications for research on musical togetherness and interaction, first, demonstrating how objective and subjective measures of togetherness can be related in a critical and systematic way. Second, in this domain, it is common to select one or two motion parameters to represent the degree of coordination or the strength of the relationship between performers. Such an approach should be taken with caution, since the specific parameters that are selected may lead to very different conclusions about the quality of musical interaction. An approach similar to that taken by Laroche et al. (2022), who used a number of measures in both time and frequency domains to construct a comprehensive depiction of ensemble coordination, would be more effective.

A few limitations of the study should be noted. First, a limitation of the design is that it is not possible to separate the effects of matched versus mismatched attention focus from the specific musical parameters that were selected for these conditions. Ideally, both attention focus and musical parameters would have been counterbalanced, but this would have necessitated many more conditions and led to an unreasonably long and repetitive experiment session. A second limitation of the design was the subtlety of the manipulations of attention. This subtlety was deliberate, as part of an effort to maintain ecological validity. However, stronger manipulations might have had clearer effects. A third limitation relates to the ecological validity of the experiment. Due to university health regulations at the time of data collection in light of the COVID-19 pandemic, research participants had to maintain physical distance from each other; therefore, they played on separate pianos, even though the repertoire was intended to be played on a single piano. The environment and equipment setup was also new to most of the pianists, and this, as well as the knowledge that their body motion was being studied, may have had some influence on how they moved and played. Finally, this study only considered the context of classical piano duo performance. The results may not generalize to other musical styles, especially those where it is less important for performers to share intentions or musical goals.

In conclusion, this study shows that joint and mutual attention can promote togetherness experiences and changes in the quantity and quality of expressive body motion in classical piano duos. Body motion was found to be an unreliable indicator of togetherness, as experienced by the performers. Measures of motion that have previously been found to support joint action and/or perceived strength of interpersonal interaction were differently affected by attention manipulations and did not always relate to togetherness as expected. These findings show that musical togetherness is a complex phenomenon that cannot be reduced to measures of synchronization or alignment. Future research should focus on identifying patterns of behavioral change that reliably occur across performance settings and with different musical repertoires.

References

Aron, A., Aron, E. N., & Smollan, D. (1992). Inclusion of other in the self scale and the structure of interpersonal closeness. *Journal of Personality and Social Psychology*, *63*(4), 596–612. https://doi.org/10.1037/0022-3514.63.4.596

Bernays, M., & Traube, C. (2014). Investigating pianists' individuality in the performance of five timbral nuances through patterns of articulation, touch, dynamics, and pedaling. *Frontiers in Psychology*, *5*, Article 157. https://doi.org/10.3389/fpsyg.2014.00157

Biasutti, M. (2013). Orchestra rehearsal strategies: Conductor and performer views. *Musicae Scientiae*, *17*(1), 57–71. https://doi.org/10.1177/1029864912467634

Bilalovic Kulset, N., & Halle, K. (2020). Togetherness!: Adult companionship—The key to music making in kindergarten. *Music Education Research*, *22*(3), 304–314. https://doi.org/10.1080/14613808.2020.1765155

Bishop, L., Cancino-Chacón, C., & Goebl, W. (2019a). Eye gaze as a means of giving and seeking information during musical interaction. *Consciousness and Cognition*, *68*, 73–96. https://doi.org/10.1016/j.concog.2019.01.002

Bishop, L., Cancino-Chacón, C., & Goebl, W. (2019b). Moving to communicate, moving to interact: Patterns of body motion in musical duo performance. *Music Perception*, *37*(1), 1–25. https://doi.org/10.1525/mp.2019.37.1.1

Bishop, L., & Goebl, W. (2015). When they listen and when they watch: Pianists' use of nonverbal audio and visual cues during duet performance. *Musicae Scientiae*, *19*(1), 84–110. https://doi.org/10.1177/1029864915570355

Bishop, L., & Goebl, W. (2020). Negotiating a shared interpretation during piano duo performance. *Music & Science*, *3*, Article 205920431989615. https://doi.org/10.1177/2059204319896152

Bishop, L., González Sánchez, V., Laeng, B., Jensenius, A. R., & Høffding, S. (2021). Move like everyone is watching: Social context affects head motion and gaze in string quartet performance. *Journal of New Music Research*, *50*(4), 392–412. https://doi.org/10.1080/09298215.2021.1977338

Bishop, L., Jensenius, A. R., & Laeng, B. (2021). Musical and bodily predictors of mental effort in string quartet music: An ecological pupillometry study of performers and listeners. *Frontiers in Psychology*, *12*, Article 653021. https://doi.org/10.3389/fpsyg.2021.653021

Bolt, N. K., & Loehr, J. D. (2017). The predictability of a partner's actions modulates the sense of joint agency. *Cognition*, *161*, 60–65. https://doi.org/10.1016/j.cognition.2017.01.004

Bolt, N. K., Poncelet, E. M., Schultz, B. G., & Loehr, J. D. (2016). Mutual coordination strengthens the sense of joint agency in cooperative joint action. *Consciousness and Cognition*, *46*, 173–187. https://doi.org/10.1016/j.concog.2016.10.001

Bresin, R., & Umberto Battel, G. (2000). Articulation strategies in expressive piano performance analysis of legato, staccato, and repeated notes in performances of the andante movement of Mozart's Sonata in G major (K 545). *Journal of New Music Research*, *29*(3), 211–224. https://doi.org/10.1076/jnmr.29.3.211.3092

Brooks, M. E., Kristensen, K., van Benthem, K. J., Magnusson, A., Berg, C. W., Nielsen, A., Skaug, H. J., Machler, M., & Bolker, B. M. (2017). glmmTMB balances speed and flexibility among packages for zero-Inflated generalized linear mixed modeling. *The R Journal*, *9*(2), 378–400. https://doi.org/10.32614/RJ-2017-066

Chang, A., Kragness, H. E., Livingstone, S. R., Bosnyak, D. J., & Trainor, L. J. (2019). Body sway reflects joint emotional expression in music ensemble performance. *Scientific Reports*, *9*(1), Article 205. https://doi.org/10.1038/s41598-018-36358-4

Chang, A., Livingstone, S. R., Bosnyak, D. J., & Trainor, L. J. (2017). Body sway reflects leadership in joint music performance. *Proceedings of the National Academy of Sciences*, *114*(21), E4134–E4141. https://doi.org/10.1073/pnas.1617657114

Clarke, E., Williams, W. A. E., & Reynolds, D. (2018). Musical events and perceptual ecologies. *The Senses and Society*, *13*(3), 264–281. https://doi.org/10.1080/17458927.2018.1516023

Clayton, M., Jakubowski, K., & Eerola, T. (2019). Interpersonal entrainment in Indian instrumental music performance: Synchronization and movement coordination relate to tempo, dynamics, metrical and cadential structure. *Musicae Scientiae*, *23*(3), 304–331. https://doi.org/10.1177/1029864919844809

Dalmaso, M., Castelli, L., & Galfano, G. (2020). Social modulators of Gaze-Mediated orienting of attention: A review. *Psychonomic Bulletin & Review*, *27*(5), 833–855. https://doi.org/10.3758/s13423-020-01730-x

D'Amario, S., Goebl, W., & Bishop, L. (2022). Judgment of togetherness in performances by musical duos. *Frontiers in Psychology*, *13*. Article 997752. https://doi.org/10.3389/fpsyg.2022.997752

D'Amario, S., Schmidbauer, H., Roesch, A., Goebl, W., & Bishop, L. (submitted). *Interperformer coordination in piano-singing duo performances: Metrical structure and empathy impact*.

Davidson, J. W., & Good, J. M. M. (2002). Social and musical co-ordination between members of a string quartet: An exploratory study. *Psychology of Music*, *30*(2), 186–201. https://doi.org/10.1177/0305735602302005

Dell'Anna, A., Buhmann, J., Six, J., Maes, P. J., & Leman, M. (2020). Timing markers of interaction quality during Semi-Hocket singing. *Frontiers in Neuroscience*, *14*, Article 619. https://doi.org/10.3389/fnins.2020.00619

Dell'Anna, A., Rosso, M., Bruno, V., Garbarini, F., Leman, M., & Berti, A. (2020). Does musical interaction in a jazz duet modulate peripersonal space? *Psychological Research*, *85*, 2107–2118. https://doi.org/10.1007/s00426-020-01365-6

Eerola, T., Jakubowski, K., Moran, N., Keller, P. E., & Clayton, M. (2018). Shared periodic performer movements coordinate interactions in duo improvisations. *Royal Society Open Science*, *5*(2), Article 171520. https://doi.org/10.1098/rsos.171520

Fiebich, A., & Gallagher, S. (2013). Joint attention in joint action. *Philosophical Psychology*, *26*(4), 571–587. https://doi.org/10.1080/09515089.2012.690176

Fitch, W. T. (2015). Four principles of bio-musicology. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *370*(1664), Article 20140091. https://doi.org/10.1098/rstb.2014.0091

Gaggioli, A., Chirico, A., Mazzoni, E., Milani, L., & Riva, G. (2017). Networked flow in musical bands. *Psychology of Music*, *45*(2), 283–297. https://doi.org/10.1177/0305735616665003

Gaggioli, A., Riva, G., Milani, L., & Mazzoni, E. (2013). *Networked flow*. Springer. https://doi.org/10.1007/978-94-007-5552-9

Gibson, J. J. (1979). *The ecological approach to visual perception*. Houghton, Mifflin and Company.

Ginsborg, J., & King, E. (2012). Rehearsal talk: Familiarity and expertise in singer-Pianist duos. *Musicae Scientiae*, *16*(2), 148–167. https://doi.org/10.1177/1029864911435733

Glowinski, D., Bracco, F., Chiorri, C., & Grandjean, D. (2016). Music ensemble as a resilient system: Managing the unexpected through group interaction. *Frontiers in Psychology*, *7*, Article 1548. https://doi.org/10.3389/fpsyg.2016.01548

Glowinski, D., Gnecco, G., Piana, S., & Camurri, A. (2013). Expressive nonverbal interaction in string quartet. In *2013 Humaine Association Conference on Affective Computing and Intelligent Interaction* (pp. 233-238). IEEE. 10.1109/ACII.2013.45

Glowinski, D., Mancini, M., Cowie, R., Camurri, A., Chiorri, C., & Doherty, C. (2013). The movements made by performers in a skilled quartet: A distinctive pattern, and the function that it serves. *Frontiers in Psychology*, *4*, Article 841. https://doi.org/10.3389/fpsyg.2013.00841

Goebl, W., & Palmer, C. (2009). Synchronization of timing and motion among performing musicians. *Music Perception*, *26*(5), 427–438. https://doi.org/10.1525/mp.2009.26.5.427

Gonzalez-Sanchez, V., Dahl, S., Hatfield, J. L., & Godøy, R. I. (2019). Characterizing movement fluency in musical performance: Toward a generic measure for technology enhanced learning. *Frontiers in Psychology*, *10*, Article 84. https://doi.org/10.3389/fpsyg.2019.00084

Gooley, D. (2018). *Fantasies of improvisation: Free playing in nineteenth-century music*. Oxford University.

Granot, R., Spitz, D. H., Cherki, B. R., Loui, P., Timmers, R., Schaefer, R. S., Vuoskoski, J. K., Cárdenas-Soler, R.-N., Soares-Quadros Jr., J. F., Li, S., Lega, C., Rocca, S. L., Marchiano, M., Martínez-Castilla, P., Pérez-Acosta, G., Martínez-Ezquerro, J. D., Gutiérrez-Blasco, I. M., Jiménez-Dabdoub, L., Coers, M., … Israel, S. (2021). "Help! I need somebody": Music as a global resource for obtaining wellbeing goals in times of crisis. *Frontiers in Psychology*, *12*, Article 648013. https://doi.org/10.3389/fpsyg.2021.648013

Hamilton, A. F. D. C. (2016). Gazing at me: The importance of social meaning in understanding direct-Gaze cues. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *371*(1686), Article 20150080. https://doi.org/10.1098/rstb.2015.0080

Hart, Y., Noy, L., Feniger-Schaal, R., Mayo, A. E., & Alon, U. (2014). Individuality and togetherness in joint improvised motion. *PLoS ONE*, *9*(2), Article e87213. https://doi.org/10.1371/journal.pone.0087213

Heerink, M., Kröse, B., Evers, V., & Wielinga, B. (2010). Relating conversational expressiveness to social presence and acceptance of an assistive social robot. *Virtual Reality*, *14*(1), 77–84. https://doi.org/10.1007/s10055-009-0142-1

Hilt, P. M., Badino, L., D'Ausilio, A., Volpe, G., Tokay, S., Fadiga, L., & Camurri, A. (2019). Multi-Layer adaptation of group coordination in musical ensembles. *Scientific Reports*, *9*(1), Article 5854. https://doi.org/10.1038/s41598-019-42395-4

Hove, M. J., & Risen, J. L. (2009). It's all in the timing: Interpersonal synchrony increases affiliation. *Social Cognition*, *27*(6), 949–960. https://doi.org/10.1521/soco.2009.27.6.949

Hurley, B. K., Fink, L. K., & Janata, P. (2018). Mapping the dynamic allocation of temporal attention in musical patterns. *Journal of Experimental Psychology: Human Perception and Performance*, *44*(11), 1694–1711. https://doi.org/10.1037/xhp0000563

Jakubowski, K., Eerola, T., Blackwood Ximenes, A., Ma, W. K., Clayton, M., & Keller, P. E. (2020). Multimodal perception of interpersonal synchrony: Evidence from global and continuous ratings of improvised musical duo performances. *Psychomusicology: Music, Mind, and Brain*, *30*(4), 159–177. https://doi.org/10.1037/pmu0000264

Jones, M. R., & Boltz, M. (1989). Dynamic attending and responses to time. *Psychological Review*, *96*(3), 459–491. https://doi.org/10.1037/0033-295X.96.3.459

Kawase, S., & Obata, S. (2016). Audience gaze while appreciating a multipart musical performance. *Consciousness and Cognition*, *46*, 15–26. https://doi.org/10.1016/j.concog.2016.09.015

Keller, P. E. (2008). Joint action in music performance. In F. Morganti, A. Carassaand, & G. Riva (Eds.), *Enacting intersubjectiviy: A cognitive and social perspective on the study of interactions* (pp. 205–221). IOS Press.

Keller, P. E., & Appel, M. (2010). Individual differences, auditory imagery, and the coordination of body movements and sounds in musical ensembles. *Music Perception*, *28*(1), 27–46. https://doi.org/10.1525/mp.2010.28.1.27

Keller, P. E., Novembre, G., & Hove, M. J. (2014). Rhythm in joint action: Psychological and neurophysiological mechanisms for real-time interpersonal coordination. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369*(1658), Article 20130394. https://doi.org/10.1098/rstb.2013.0394

Kim, J., Kwon, Y., & Cho, D. (2011). Investigating factors that influence social presence and learning outcomes in distance higher education. *Computers & Education*, *57*(2), 1512–1520. https://doi.org/10.1016/j.compedu.2011.02.005

King, E., & Ginsborg, J. (2011). Gestures and glances: Interactions in ensemble rehearsal. In A. Gritten, & E. King (Eds.), *New perspectives on music and gesture* (pp. 177–201). Ashgate.

Kirschner, S., & Tomasello, M. (2010). Joint music making promotes prosocial behavior in 4-year-old children. *Evolution and Human Behavior*, *31*(5), 354–364. https://doi.org/10.1016/j.evolhumbehav.2010.04.004

Kos, R. P. (2018). Becoming music teachers: Preservice music teachers' early beliefs about music teaching and learning. *Music Education Research*, *20*(5), 560–572. https://doi.org/10.1080/14613808.2018.1484436

Laroche, J., Tomassini, A., Volpe, G., Camurri, A., Fadiga, L., & D'Ausilio, A. (2022). Interpersonal sensorimotor communication shapes intrapersonal coordination in a musical ensemble. *Frontiers in Human Neuroscience*, *16*, Article 899676. https://doi.org/10.3389/fnhum.2022.899676

Launay, J., Dean, R. T., & Bailes, F. (2013). Synchronization can influence trust following virtual interaction. *Experimental Psychology*, *60*(1), 53–63. https://doi.org/10.1027/1618-3169/a000173

Lee, H., Launay, J., & Stewart, L. (2020). Signals through music and dance: Perceived social bonds and formidability on collective movement. *Acta Psychologica*, *208*, Article 103093. https://doi.org/10.1016/j.actpsy.2020.103093

Loehr, J. D. (2022). The sense of agency in joint action: An integrative review. *Psychonomic Bulletin & Review*, *29*, 1089–1117. https://doi.org/10.3758/s13423-021-02051-3

Lüdecke, D., Ben-Shachar, M., Patil, I., Waggoner, P., & Makowski, D. (2021). Performance: An R package for assessment, comparison and testing of statistical models. *Journal of Open Source Software*, *6*(60), Article 3139. https://doi.org/10.21105/joss.03139

MacRitchie, J., Herff, S. A., Procopio, A., & Keller, P. E. (2018). Negotiating between individual and joint goals in ensemble musical performance. *Quarterly Journal of Experimental Psychology*, *71*(7), 1535–1551. https://doi.org/10.1080/17470218.2017.1339098

Malloch, S. N. (1999). Mothers and infants and communicative musicality. *Musicae Scientiae*, *3*(1 suppl), 29–57. https://doi.org/10.1177/10298649000030S104

Mehr, S. A., Krasnow, M. M., Bryant, G. A., & Hagen, E. H. (2021). Origins of music in credible signaling. *Behavioral and Brain Sciences*, *44*, Article e60. https://doi.org/10.1017/S0140525X20000345

Miles, L. K., Nind, L. K., Henderson, Z., & Macrae, C. N. (2010). Moving memories: Behavioral synchrony and memory for self and others. *Journal of Experimental Social Psychology*, *46*(2), 457–460. https://doi.org/10.1016/j.jesp.2009.12.006

Mundy, P., Block, J., Delgado, C., Pomares, Y., Van Hecke, A. V., & Parlade, M. V. (2007). Individual differences and the development of joint attention in infancy. *Child Development*, *78*(3), 938–954. https://doi.org/10.1111/j.1467-8624.2007.01042.x

Noy, L., Levit-Binun, N., & Golland, Y. (2015). Being in the zone: Physiological markers of togetherness in joint improvisation. *Frontiers in Human Neuroscience*, *9*, Article 187. https://doi.org/10.3389/fnhum.2015.00187

Onderdijk, K. E., Swarbrick, D., Van Kerrebroeck, B., Mantei, M., Vuoskoski, J. K., Maes, P. J., & Leman, M. (2021). Livestream experiments: The role of COVID-19, agency, presence, and social context in facilitating social connectedness. *Frontiers in Psychology*, *12*, Article 647929. https://doi.org/10.3389/fpsyg.2021.647929

Pacherie, E. (2012). The phenomenology of joint action: Self-agency versus joint agency. In A. Seemann (Ed.), *Joint attention: New developments in psychology, philosophy of mind, and social neuroscience* (pp. 343–389). MIT Press.

Pearce, E., Launay, J., & Dunbar, R. I. M. (2015). The ice-breaker effect: Singing mediates fast social bonding. *Royal Society Open Science*, *2*(10), Article 150221. https://doi.org/10.1098/rsos.150221

Pezzulo, G., Donnarumma, F., Dindo, H., D'Ausilio, A., Konvalinka, I., & Castelfranchi, C. (2019). The body talks: Sensorimotor communication and its brain and kinematic signatures. *Physics of Life Reviews*, *28*, 1–21. https://doi.org/10.1016/j.plrev.2018.06.014

Phillips-Silver, J., & Keller, P. E. (2012). Searching for roots of entrainment and joint action in early musical interactions. *Frontiers in Human Neuroscience*, *6*, Article 26. https://doi.org/10.3389/fnhum.2012.00026

Rabinowitch, T. C., & Knafo-Noam, A. (2015). Synchronous rhythmic interaction enhances children's perceived similarity and closeness towards each other. *PLoS ONE*, *10*(4), Article e0120878. https://doi.org/10.1371/journal.pone.0120878

Reddish, P., Fischer, R., & Bulbulia, J. (2013). Let's dance together: Synchrony, shared intentionality and cooperation. *PLoS ONE*, *8*(8), Article e71182. https://doi.org/10.1371/journal.pone.0071182

Roesch, A., & Schmidbauer, H. (2018). *Waveletcomp: Computational wavelet analysis* (R package version 1.1). https://cran.r-project.org/web/packages/WaveletComp/index.html

Saint-Germier, P., Goupil, L., Rouvier, G., Schwarz, D., & Canonne, C. (2021). What it is like to improvise together? Investigating the phenomenology of joint action through improvised musical performance. *Phenomenology and the Cognitive Sciences*. https://doi.org/10.1007/s11097-021-09789-0

Savage, P. E., Loui, P., Tarr, B., Schachner, A., Glowacki, L., Mithen, S., & Fitch, W. T. (2020). Music as a coevolved system for social bonding. *Behavioral and Brain Sciences*, *44*, Article e59. https://doi.org/10.1017/S0140525X20000333

Schiavio, A., Maes, P. J., & van der Schyff, D. (2021). The dynamics of musical participation. *Musicae Scientiae*, *26*(3), Article 102986492098831. https://doi.org/10.1177/1029864920988319

Sebanz, N., Bekkering, H., & Knoblich, G. (2006). Joint action: Bodies and minds moving together. *Trends in Cognitive Sciences*, *10*(2), 70–76. https://doi.org/10.1016/j.tics.2005.12.009

Seddon, F., & Biasutti, M. (2009). A comparison of modes of communication between members of a string quartet and a jazz sextet. *Psychology of Music*, *37*(4), 395–415. https://doi.org/10.1177/0305735608100375

Shin, M., Song, S. W., Kim, S. J., & Biocca, F. (2019). The effects of 3D sound in a 360-degree live concert video on social presence, parasocial interaction, enjoyment, and intent of financial supportive action. *International Journal of Human-Computer Studies*, *126*, 81–93. https://doi.org/10.1016/j.ijhcs.2019.02.001

Smetana, M., Stepniczka, I., & Bishop, L. (2022). COME_IN: A qualitative framework for content, meanings and intersubjectivity in free dyadic improvisations. *Nordic Journal of Music Therapy*.

Stevens, A., & Ramirez-Lopez, L. (2022). *An introduction to the prospectr package* [Computer software manual]. https://rdocumentation.org/packages/prospectr/versions/0.2.6

Stupacher, J., Maes, P. J., Witte, M., & Wood, G. (2017). Music strengthens prosocial effects of interpersonal synchronization—If you move in time with the beat. *Journal of Experimental Social Psychology*, *72*, 39–44. https://doi.org/10.1016/j.jesp.2017.04.007

Stupacher, J., Mikkelsen, J., & Vuust, P. (2021). Higher empathy is associated with stronger social bonding when moving together with music. *Psychology of Music*, *50*(5), Article 030573562110506. https://doi.org/10.1177/03057356211050681

Swarbrick, D., Seibt, B., Grinspun, N., & Vuoskoski, J. K. (2021). Corona concerts: The effect of virtual concert characteristics on social connection and kama muta. *Frontiers in Psychology*, *12*, Article 648448. https://doi.org/10.3389/fpsyg.2021.648448

Tarr, B. (2014). Music and social bonding: "Self-Other" merging and neurohormonal mechanisms. *Frontiers in Psychology*, *10*, Article 1096. 10.3389/fpsyg.2014.01096

Tarr, B., Launay, J., Cohen, E., & Dunbar, R. (2015). Synchrony and exertion during dance independently raise pain threshold and encourage social bonding. *Biology Letters*, *11*(10), Article 20150767. https://doi.org/10.1098/rsbl.2015.0767

Tarr, B., Launay, J., & Dunbar, R. I. (2016). Silent disco: Dancing in synchrony leads to elevated pain thresholds and social closeness. *Evolution and Human Behavior*, *37*(5), 343–349. https://doi.org/10.1016/j.evolhumbehav.2016.02.004

Trevarthen, C. (2012). Communicative musicality: The human impulse to create and share music. In D. Hargreaves, D. Mielland, & R. MacDonald (Eds.), *Musical imaginations: Multidisciplinary perspectives on creativity, performance, and perception* (pp. 259–284). Oxford University.

Vandemoortele, S., Feyaerts, K., Reybrouck, M., De Bièvre, G., Brône, G., & De Baets, T. (2018). Gazing at the partner in musical trios: A mobile eye-tracking study. *Journal of Eye Movement Research*, *11*(2). https://doi.org/10.16910/jemr.11.2.6

van der Steen, M. C. M., & Keller, P. E. (2013). The ADaptation and anticipation model (ADAM) of sensorimotor synchronization. *Frontiers in Human Neuroscience*, *7*, Article 253 https://doi.org/10.3389/fnhum.2013.00253

Vesper, C., Abramova, E., Bütepage, J., Ciardo, F., Crossey, B., Effenberg, A., Hristova, D., Karlinsky, A., McEllin, L., Nijssen, S. R. R., Schmitz, L., & Wahn, B. (2017). Joint action: Mental representations, shared information and general mechanisms for coordinating with others. *Frontiers in Psychology*, *7*, Article 2039. https://doi.org/10.3389/fpsyg.2016.02039

Vesper, C., van der Wel, R. P. R. D., Knoblich, G., & Sebanz, N. (2011). Making oneself predictable: Reduced temporal variability facilitates joint action coordination. *Experimental Brain Research*, *211*(3–4), 517–530. https://doi.org/10.1007/s00221-011-2706-z

Wolf, W., Launay, J., & Dunbar, R. I. M. (2016). Joint attention, shared goals, and social bonding. *British Journal of Psychology*, *107*(2), 322–337. https://doi.org/10.1111/bjop.12144

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