With, against, or without? Familiarity and co-presence increase interactional dissensus and relational plasticity in freely improvising duos

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Abstract

Agents engaged in creative joint actions might need to find a balance between the demands of doing something collectively, by adopting congruent and interacting behaviors, and the goal of delivering a creative output, which can eventually benefit from disagreements and autonomous behaviors. Here, we investigate this idea in the context of collective free improvisation – a paradigmatic example of group creativity in which musicians aim at creating music that is as complex and unprecedented as possible without relying on predefined plans or individual roles. Controlling for both the familiarity between the musicians and their physical co-presence, duos of improvisers were asked to freely improvise together and to individually annotate their performances with a digital interface, indicating at each time whether they were playing "with", "against", or "without" their partner. At an individual level, we found that musicians largely intended to converge with their co-improviser, making only occasional use of non-cooperative or non-interactive modes such as "playing against" or "playing without". By contrast, at the group level, musicians tended to combine their relational intents in such a way as to create interactional dissensus. We also demonstrate that co-presence and familiarity act as interactional smoothers: they increase the agents' overall level of relational plasticity and allow for the exploration of less cooperative behaviors. Overall, our findings suggest that relational intents might function as a primary resource for creative joint actions.

Acting jointly generally involves two key ingredients: cooperation – the commitment to, and organization of individual actions towards the achievement of a shared goal – and interaction – the fact that agents' decisions or actions "mutually […] affect one another's" (Schönherr & Westra, 2019). For instance, two friends moving a couch need both to cooperate – e.g., by agreeing to grab the couch on different sides in order to be able to actually lift it and move it – and to interact with one another – e.g., by mutually adjusting the speed at which they are individually moving. In fact, interaction and cooperation seem so integral to joint action that those notions are sometimes simply equated (Sebanz et al., 2006). But they are nonetheless distinct and can be dissociated.

On the one hand, some joint actions do not rely on interactions. For example, in highly compartmentalized processes of industrial production, each agent is receiving her own sub-task to do, without any interference with the sub-tasks of the others. Some joint actions can also rely on a mere asymmetrical coupling of agents, with one agent "acting or deciding as she does at least in part because of the observed or expected actions or decisions of the other agent" (Michael et al., 2020), while the other remains impervious to what her co-agent is doing – think of a capricious singer expecting from her accompanist to follow her every move but making no effort in adjusting to her. In those cases, agents are not really interacting, yet, they still cooperate, in the sense that their individual actions are organized towards the achievement of some shared goal.

On the other hand, joint actions are not always cooperative: in joint actions involving some degree of negotiation, such as two friends discussing in order to decide which movie to watch, or conflict, such as two friends playing a tennis match, cooperation can be sporadic, or only present in a very weak sense. Indeed, while the two friends can still be said to organize their own individual actions in order to achieve some broad overarching goal (e.g., actually playing a match of tennis or actually watching a movie), they are doing so by aiming at proximate goals that are clearly distinct (e.g., watching such or such movie), or even incompatible (e.g., winning the game). Yet, in those cases, agents are still interacting, in the sense that each one's actions and decisions are dependent on the other's own actions and decisions.

Creative joint actions are an interesting class of actions to consider in that perspective. Agents engaged in creative joint actions (such as dance contact improvisation, or brainstorming meetings) typically aim at producing something that has some novel character and/or some degree of unpredictability (Amabile, 1982). However, it is not clear that such creative endeavors are always the results of strictly cooperative and interactive joint actions. For

example, it has recently been shown that synchrony in joint action can be negatively associated with aesthetic appeal when the goal of the joint action is the creation of a complex product rather than interpersonal coordination itself (Wallot et al., 2016). Similarly, Bjørndahl et al. (2015) highlight the critical role of miscommunication, including disagreements and misunderstandings, in collaborative creative activities such as jointly constructing LEGO models for abstract concepts such as "Justice" or "Knowledge". The studies discussed in Nemeth & Nemeth-Brown (2019) also point in the same direction – with dissent taken to be a stimulator for creative thought in group tasks such as word associations.

Taken together, these results open up the possibility that agents engaged in creative joint action might *deliberately* avoid to interact or to cooperate with one another on a continuous basis. On the contrary, they might strategically attempt to create phases of non-interaction – consisting of uncoupled or desynchronized individual actions – and/or phases of non-cooperation – consisting of opposing or incongruent actions – as a way to reinforce the creativity of their endeavor.

We investigate here this hypothesis by using as an experimental paradigm the musical genre of collective free improvisation (CFI for short). In CFI, musicians typically play together without any pre-established plans or individual roles (Pressing, 1984; Bailey, 1992). Nothing is specified in advance beyond the very general and abstract goal of making some (aesthetically satisfying) music that is as unprecedented as possible (Wilson & MacDonald, 2012). In many ways, CFI provides a paradigmatic example of group creativity (Cook, 2018). First, CFI performances are typically a case of *emergent creativity* (Sawyer, 2003). Since there is no pre-existing blueprint upon which the performance is built, the whole performance emerges entirely, and more or less unpredictably, from the interactional dynamics at play between the improvisers. Second, CFI performances are typically a case of *distributed creativity* (Sawyer & DeZutter, 2009). CFI performances generally take place within an egalitarian framework, with no pre-established leader. As such, individual roles and creative contributions to the overall output are constantly shifting and renegotiated over the course of the performance, and the creativity of the performance crucially depends on the way improvisers dynamically relate to one another. Interpersonal relations are thus at the very core of the practice of CFI (Clarke, 2005), the musicians' dialogical engagements with one another acting as one of the primary locus of CFI's aesthetic distinctiveness (Canonne, 2018a).

Based on the conceptual framework introduced above, we distinguish here between three main *relational intents* – three distinct ways of intending to relate to what one's co-improviser is doing. "Playing with" can be seen as a kind of default relational intent for joint

musical improvisation, in which a given musician *intends to both interact and cooperate* with the other musician, by offering something which is broadly consistent with what she is doing. "Playing against" can be seen as a relational intent in which a given musician *does not intend to cooperate* with the other musician, by willingly opposing what she is doing. Finally, "playing without" can be seen as a relational intent in which a given musician *does not intend to interact* with the other musician, by simply ignoring what she is doing. Note that we refer here to *intentions*. A musician might intend to play "without" her co-improviser but fail to do so, because she simply cannot avoid being influenced by her co-improviser. In other words, it might not always be easy to infer a given musician's relational intent based on the overall musical result.

The study we report here had two main goals. Our first goal was to empirically investigate how improvisers dynamically relate to one another over the course of the performance. To what extent improvisers actually endorse "non-cooperating" and "non-interacting" relational intents? To what extent do they tend to endorse identical or similar relational intents towards one another? Are there some combinations of relational intents that are more frequent than others? Are "playing against" or "playing without" used in the same way and with the same stability as "playing with"?

The second main goal of our study was to assess the impact on the musicians' relational intents of two factors that are often taken to play an important role in explaining coordination during CFI, namely the familiarity between the musicians and the co-presence of the musicians within the same physical space (Bishop, 2018). Familiarity could impact musicians' interactions in two directions: on the one hand, musicians who are used to play with each other are likely to develop an increased sense of trust and confidence towards one another, which might help the group to take more risks (King, 2013), or to allow for a less conscious approach to interaction (Wilson & MacDonald, 2017); but on the other hand, low familiarity can also enable less predictable interactions, and be an incentive for more creative behaviors (Levine et al., 2019). As for physical co-presence, it enables the perception of subtle visual and somatic cues (Novembre & Keller, 2018) which might play an important role in the musicians' co-regulation, supporting the emergence of a "we-space" in which a feeling of togetherness can emerge (Krueger, 2011). Conversely, physical separation might impair musicians' empathetic attunement (Seddon & Biasutti, 2009), potentially resulting in the musicians taking fewer risks (Iowerth and Knox, 2019). Beyond their impact on musical coordination, we thus expect familiarity and co-presence to have an impact on the way CFI performers actually intend to

relate to one another when improvising, notably by allowing for more divergence or more autonomy between the performers.

Our study provides a first step in investigating those different issues, by enabling the quantitative exploration of the musicians' relational intents in a newly recorded corpus of 40 freely improvised duo performances, and by controlling for both the familiarity between the musicians and their physical co-presence.

Methods

Participants

Our participants were recruited from the Parisian Free Improvisation scene. The Parisian Free improvisation scene is one of the most dynamic scenes in Europe, with many concert venues and a dense network of musicians, both professional and amateur, coming from a wide variety of stylistic backgrounds, such as noise music, western contemporary music, jazz/free jazz, or minimalism (Roueff, 2006). After an extensive fieldwork conducted over the last years, the last author of this paper had gathered the contact information from many professional improvisers active in the Parisian Free Improvisation scene (Canonne, 2018b). An invitation was thus sent through email to 50 professional musicians to participate in our study. The email indicated that we were looking for professional musicians to participate in an experiment on collective improvisation, that the experiment would consist in both performing and listening, that the duration of the experiment would be roughly 2 hours, and that the musicians would be paid for their contribution. Twenty improvisers accepted this invitation, and were available to participate in the experiment (male: 14, mean age = 39, sd = 10.7). All were highly trained musicians (range: 17-50 years of musical practice) and had substantial improvisation practice (range: 5-30 years of free improvisation practice). Half of the participants was recruited as duos of musicians who had previous experience improvising with one another, whereas the other half was paired so as to create duos who had close to none. Their instruments were saxophone (N = 6), trumpet (N = 3), piano, guitar, cello (N = 2), double bass, viola, bass guitar, voice, euphonium (N = 1). All participants gave their informed written consent.

Procedure

The experiment took place in a professional recording studio at the Institute for Research and Coordination in Acoustics/Music (IRCAM) in Paris. Each duo was asked to perform 4 improvisations running from approximately 5 to 10 minutes (mean = 386s, sd = 152s). Two of

these were performed in the same room ("Co-present" condition) whereas the two others were performed in separate booths ("Isolated" condition). In this latter condition, musicians could not see each other but were hearing each other through headphones, as is standard in studio recording practice. Duos 1-5 played in the Co-present condition first, while duos 6-10 played in the Isolated condition first. All the performances were recorded by a professional sound engineer.

Immediately after the recording session, participants were asked to listen back in randomized order to the improvisations they had performed and to annotate them using a web application (see Figure 1). The web client, running in a regular web browser, was connected to a server through a bidirectional and persistent communication channel to send and store annotations on the server in real-time as well as to provide information to the experimenters through a remote monitoring panel (Matuszewski, 2019).

INSERT FIGURE 1

Figure 1. Interface used by the participants for the annotation task. Participants navigated continuously within the triangle to indicate the intensity with which they conformed with a given relational intent, with white dashed lines delineating the limits of each area. The black area in the center corresponds to an area of interactional indeterminacy. The green dot shows the mean position of the musicians in the interactional space across the overall corpus.

The graphical user interface took the form of a triangle whose vertices corresponded to 3 different relational intents described to the participants in the following way:

- *With ("Avec"): You intend to converge with what the other musician is doing*
- *Against ("Contre"): You intend to diverge from what the other musician is doing*
- *Without ("Sans"): You intend to ignore what the other musician is doing.*

The Center zone of the triangle (in black in Figure 1) was described as a zone of interactional indeterminacy, to be used in cases where the participants thought that their behavior did not conform to any of the aforementioned relational intents. The position of each of the relational intents on the three vertices were randomized for each participant.

While listening back to the performances, participants could drag a white dot on the triangle with a mouse to indicate what was their relational intent towards their partner at each time during their improvisations (see this link for a few video examples of participants' annotations). Each time a change occurred in the interface, the normalized position of the dot

according to the center of the triangle was sent to the server to be stored in a file along with the current time of the sound file. Four areas were clearly delineated on the triangle to help the participants navigate the interface, but in our instructions we emphasized the fact that the interface was continuous, and participants were encouraged to indicate the intensity to which they conformed to each relational intent by varying the distance to the corresponding vertex.

After the annotation task, we assessed musicians' familiarity with each other by asking the participants to report how much they were used to play with each other in the context of CFI on a scale from 1 (not familiar at all) to 7 (very familiar). For each duo, the two musicians' familiarity ratings were then averaged to assess the overall level of familiarity of the duo. We also asked the musicians to report how aesthetically close they felt to the other musician on a scale from 1 (not close at all) to 7 (extremely close). Because of the strong correlation between aesthetical proximity and familiarity (ρ (pearson) = 0.56, $p = 0.01$), we decided to use only the latter in our analysis to avoid redundancy. Due to some technical issues in communicating with the server for collecting the data, annotations for duo 1 (tracks 3 & 4) and duo 2 (track 2) were lost.

Data pre-processing

Annotation data were preprocessed by linearly interpolating between time points with a resolution of 4 Hz. This value was chosen as a compromise between being low enough as to capture most of the movements of the participants in the interface, and high enough so as to reduce the size of the dataset for data analysis.

Synoptic graphs of the annotations were produced indicating at each time which area of the triangle (i.e., "with", "against", "without" or "center") each musician was in. Two examples of such graphs can be seen in Figure 2[1]. As can be seen in Figure 2, there was a lot of variability between the performances (including between performances by the same duo): for example, the musicians' relational intents were much more stable and continuous in Duo 5 Track 4 than in Duo 6 Track 1. Similarly, the relational intents were much more symmetrical in Duo 5 Track 4, in which both musicians reported intending playing "with" one another for a large amount of the performance, than in Duo 6 Track 1, in which musicians often reported distinct relational intents. Below, we investigate some of the factors that might account for this variability.

INSERT FIGURE 2

[1] The remaining graphs cans be found here: https://archive.org/details/synoptic_graphs.

Figure 2. Graph indicating in which area of the triangle each musician was at each time for duo 6, track 1 (top) and duo 5, track 4 (bottom). Green (resp. red, blue) indicates that the musician was in the "with" (resp. "against", "without") area. The further from the corresponding vertex, the lighter the color. White corresponds to the center area

Variables

The interface used in our annotation task allowed us to identify the *relational intents* (i.e., intentions to play "with", "against", or "without" their co-improviser) endorsed by the musicians at each time during the performance, simply by examining in which area of the triangle the participants were at each time. But our interface also allowed us to gather information on several important aspects of the musicians' interactional dynamics that could be impacted by the musicians' familiarity with one another and/or their co-presence within a shared physical space.

To assess the improvisers' *relational plasticity* (i.e., the improvisers' general tendency to change their relational intent over the course of the performance), we computed two complementary measures for each musician and each performance. First, we estimated the mean speed of the navigation in the interface (computed as the total distance covered in the interface divided by length of improvisation). Second, we computed the number of areas that the musician visited during the performance (normalized by the length of the improvisation).

To assess the degree of *interactional consensus* between the two musicians (i.e., the improvisers' general tendency to intend to play "with" one another or to endorse identical relational intents), we used three complementary variables. First, we computed, for each musician and each performance, the proportion of time she was in the "with" area, as delineated by the dashed lines in our interface. Second, we computed, for each performance, the proportion of time the two musicians were in the "with" area (first-order agreement). Lastly, we computed, for each performance, the proportion of time the two musicians were in the same area (second-order agreement, e.g., musicians agreeing on playing against each other).

Finally, to assess the *intensity* with which improvisers conformed to each relational intent (i.e., the extent to which each one of the three main relational intents tended to "attract" the improvisers), we computed, for each musician and each performance, the mean distance between her position within the interface and each one of the three vertices of the triangle. This gave us three variables: Distance to the "with" vertex; Distance to the "against" vertex; and Distance to the "without" vertex.

Statistical analysis

We assessed the effects of co-presence and familiarity on each of the variables introduced in the previous section. Importantly, we tested for both a *linear* and a *quadratic* relation between our variables and the familiarity between the musicians, as the relationship between familiarity and relational intents may follow a U-shaped function (as explained in the introduction).

For each variable, hierarchical regressions were conducted by comparing nested models (Gelman & Hill, 2006), starting with a null model and adding first co-presence and then powers of familiarity (using the R function *ordered*) to examine both potential linear and quadratic effects. Duo (when the dependent variable was dyadic) or musician (when the dependent variable was individual) ID were entered as a random intercept, and co-presence as a random slope (as it varied within duo). Potential interactions between co-presence and familiarity were also tested. Thus, the successive models were the following:

$m_{0\ (null\ model)}$: *dependent variable ~ 1 + (copresence | musician OR duo)*
m_1: *dependent variable ~ copresence + (copresence | musician OR duo)*
m_2: *dependent variable ~ copresence + ordered (familiarity) + (copresence | musician OR duo)*
m_3: *dependent variable ~ copresence * ordered (familiarity) + (copresence | musician OR duo)*

The models were fitted with the function *lmer* from the R package *lme4* and compared using a likelihood ratio test, with Satterthwaite estimations of degrees of freedom. In the section "*Effects of co-presence and familiarity on musicians' interactional dynamics*" below, we report the results of model comparisons, as well as beta, standard errors, t-values and p-values for the effect of co-presence and familiarity on each dependent variable.

Acoustic analysis

Our experimental set-up made it possible to systematically compare the relational intents indicated by the participants with the music they had actually performed. In particular, we were interested in investigating whether there was something distinctive in their musical behavior when improvisers intended to both play "with" one another, as compared to situations in which at least one musician did not intend to play "with" her partner. The general idea was to test whether musicians were more acoustically coordinated in the former case than in the latter. Since we did not have access to the musicians' individual tracks for the improvisations performed in the "co-present" condition (because the music produced by one of the musician's

was necessarily picked up by the microphone used to record the other musician's microphone), we thus only relied on the improvisations performed in the "isolated" condition to run our acoustic analysis.

We selected three acoustic features that reflect meaningful properties of CFI performances (Goupil et al., 2021) to run our analysis:

- Root-Mean-Square (related to the musician's loudness)
- Spectral centroid (related to the musician's timbre)
- Fundamental frequency (f0) estimate (related to the fundamental frequency of the sounds produced by the musician)

These features were computed on all of the individual WAV files, using the python library *Librosa* with a window size of 46 milliseconds, ending up with three vectors of data for each musician and each performance. These data were linearly interpolated between time points with a resolution of 4 Hz so as to match the same time points as the annotation data. We then computed two Pearson correlation coefficients for each performance: one between the vectors of data at the times when both musicians intended to play "with" one another ("with-with" condition) and the other between the vectors of data at the times when at least one musician did not intend to play "with" her partner ("other" condition). We then assessed whether or not improvisers' musical outputs were more correlated whenever they both reported having played "with" one another. To do this, we performed a logistic mixed regression including "with" (yes or no) as a dependent variable, RMS correlations, f0 correlations, and spectral centroid correlations as independent variables, and duo as a random intercept.

Results

Relational intents in freely improvised duets

Our experimental setup allowed us to gather some crucial insights on the distribution of the musicians' relational intents in freely improvised duets. Figure 3 shows a pie chart of the distribution of the relational intents within our corpus. We found that, on average, musicians spent 58.3% (sd: 21.3) of their individual playing time in "with", 11.2% (sd: 13.3) in "against", 13.4% (sd: 13.4) in "without" and the rest in the "center" area. As expected, "playing with" the other musician was, by far, the most common relational intent. However, it should be noted that, even if they were largely attracted by the "with" area, musicians seemed to favor relational intents that had some degree of ambiguity, as reflected by the fact that the mean positioning of

the musicians within the interface was in fact situated in the "center" area, albeit quite close from the "with" area (see Figure 1 above). Musicians also allowed for non-cooperative or non-interactive intents in a more occasional but still significant way, "playing against" and "playing without" the other musician amounting for 24.6% of the total playing time.

INSERT FIGURE 3

Figure 3. Distribution of the relational intents within the corpus.

Interestingly, "playing against" and "playing without" were used in a much more transient fashion than "playing with". The average duration of a stay in the "with" area (M = 41.6s, sd: 60.4) was significantly longer than the average stay in the "against" area (M = 11.1s, sd: 13.4; t = 4.23, df = 80, p-value = 6.1e-05) and in the "without" area (M = 17.3s, sd: 24.2; t = 3.20, df = 96, p-value = 0.0018). This is consistent with the idea that non-cooperative and non-interactive relational intents were mainly used as a way to momentarily disrupt the ongoing situation. "Playing against" and "playing without" could also have been used as short interactional signals, "open angles" which afford the other musician with the possibility of introducing a new idea or modifying her own behavior (Denzler & Guionnet, 2020: 26).

Musicians' combinations of relational intents

Figure 4 shows a pie chart of the distribution of the combination of relational intents observed in our corpus. A few conclusions can be drawn from it.

INSERT FIGURE 4

Figure 4. Distribution of the combinations of relational intents within our corpus.

First, we found that cases of symmetrical intentions to be independent were fairly rare: musicians were both intending to "play without" each other only 1.3% of the time. However, asymmetrical couplings between the musicians (i.e., cases in which one of the musicians was intending to play "without" the other) were much more common, amounting to 24.6% (sd: 17.2) of the total playing time.

Second, and similarly, we found that highly antagonistic interactions were rather uncommon: musicians were both intending to "play against" each other only 2.8% of the time. However, interactions with some degree of antagonism (i.e., cases in which one of the

musicians was intending to play "against" her partner), while still occasional, seemed to represent a viable strategy for our participants, amounting to 17.8% (std : 17.4) of the total playing time.

Third, we found that, on average, musicians spent 41.8% (sd: 19.1) of the time in the same area – the case in which both musicians were both intending to play "with" one another amounting for a vast majority of that time (36.2% of the total playing time). This also means that, for more than half of their playing time, musicians actually had distinct relational intents. In other words, musicians tended to combine their relational intents so as to avoid strict relational alignment, and to create a certain amount of interactional dissensus. Interestingly, musicians were much more likely to intend to play "against" or "without" the other when their co-improviser was actually trying to play "with" them. This could suggest that improvisers were only allowing themselves to explore more incongruent relational intents if they felt that their co-improviser was, for her part, displaying a cooperative behavior, thus providing a minimal degree of stability at the level of the dyad.

Effects of relational intents on acoustic coordination

As a preliminary result, it should be noted that we found that the improvisers' musical behaviors were significantly correlated to one another for RMS ($t(8) = 8.55$, $p < 0.001$) and spectral centroid ($t(8) = 3.96$, $p = 0.004$), and marginally so for f0 ($t(8) = 2$, $p = 0.08$). This means that, independently of how they intended to relate to one another, musicians manifested a substantial degree of acoustic alignment over time, at least in terms of loudness (i.e., they tended to play with a similar level of energy) and timbre (i.e., they tended to use instrumental timbres that had a similar level of brightness).

More importantly, we found that these correlations varied as a function of the musicians' relational intents. In a logistic mixed regression including "with" (yes or no) as a dependent variable, RMS correlations, f0 correlations, and spectral centroid correlations as independent variables, and duo as a random intercept, we found that the probability that musicians would both be attempting to play "with" one another was higher when improvisers' sonic behaviors were more correlated in terms of RMS (beta = 6.37, sem = 3.1, z = 2.06, p = 0.03, X2 = 4.97) and marginally so for f0 (beta = 5.9, sem = 3.5, z = 1.7, p = 0.08, X2 = 3.14) (the effect of spectral centroid was not significant, $p > 0.9$).

As shown in Figure 5, post-hoc paired comparisons revealed that musicians' RMS were significantly correlated when both musicians intended to play "with" one another ($t(8) = 6.53$,

$p < 0.001$) but also in cases in which at least one musician did not intend to play "with" her partner ($t(8) = 11.5$, $p < 0.001$). Crucially, however, we found that musicians' RMS were significantly more correlated in the former case than in the latter case ($t(8) = 2.82$, $p = 0.02$). Musicians' f0s were significantly correlated when both musicians intended to play "with" one another ($t(8) = 2.23$, $p = 0.05$) but not when at least one musician did not intend to play "with" her partner ($t(8) = 0.83$, $p = 0.4$), although the difference between the two cases was not significant ($t(8) = 1.7$, $p = 0.12$). Finally, musicians' spectral centroids were significantly correlated when both musicians intended to play "with" one another ($t(8) = 3.45$, $p = 0.009$) and also when at least one musician did not intend to play "with" her partner ($t(8) = 3.45$, $p = 0.009$), with a non-significant difference between the two cases ($t(8) = 0.25$, $p = 0.8$).

Overall, these results show that when both musicians intended to play "with" one another, they tended to display a higher degree of acoustic coordination, at least in terms of loudness: they were particularly careful to balance their individual levels of energy. Conversely, the greater imbalance observed when at least one musician intended to play "against" or "without" her partner gives additional support to the idea that such relational intents could have effectively been used by the musicians as a way to disrupt the ongoing situation or challenge their partner.

INSERT FIGURE 5.

Figure 5. Acoustic analysis. We show the average correlation values between musicians' volumes (Root-Mean-Square, left), spectral centroids (middle) and fundamental frequencies (right), computed separately for time periods during which both musicians were in the "with" area (dark green) or in other areas or configurations (light green). Error bars show the 95% confidence intervals. Black asterisks show the results of a logistic regression testing whether RMS/spectral centroid and pitch correlations predicted whether both musicians were in the "with" area or not. White asterisks show one-sample t-test comparisons against zero (two-tailed); * indicates significance with $p < 0.05$, ** $p < 0.01$; *** $p < 0.001$.

Effects of co-presence and familiarity on musicians' interactional dynamics.

Having examined in detail the relational intents reported by the participants in this study and the way such intents translated in the performers' acoustic production, we next turned to assessing whether the musicians' interactional dynamics was impacted as a function of our two variables of interest: co-presence and familiarity. The full output of the models described above is given in Table 1. Note that no significant interactions were found between co-presence and familiarity. Although model comparisons indicated a significant interaction between co-presence and powers of familiarity in the case of the "mean speed" variable, as can be seen in

Table 1 below, this interaction did not concern the linear and quadratic terms of power of familiarity (it actually concerned the sixth order term) and it is thus uninterpretable in this context.

Variables	Model comparison (ANOVA)			Linear Mixed Models					
	Model	χ^2	p	Effect	Estimate	SE	t	df	p
distance to "with"	m1	6.56	0.010 *	co-presence	0.099	0.037	2.65	54.8	0.011 *
	m2	6.89	0.331	familiarity	-0.023	0.074	-0.31	22.0	0.076
				familiarity^2	0.166	0.073	2.28	21.7	0.033
	m3	5.72	0.456	interaction	0.052	0.104	0.50	56.0	0.621
distance to "against"	m1	7.17	0.007 **	co-presence	-0.084	0.031	-2.74	49.9	0.008 **
	m2	7.80	0.253	familiarity	0.051	0.058	0.88	19.4	0.391
				familiarity^2	-0.113	0.056	-2.01	19.1	0.059
	m3	10.6	0.100	interaction	-0.016	0.081	-0.19	53.5	0.848
distance to "without"	m1	1.94	0.164	co-presence	-0.041	0.028	-1.43	49.4	0.160
	m2	5.63	0.467	familiarity	-0.035	0.066	-0.54	21.7	0.597
				familiarity^2	-0.066	0.064	-1.02	21.5	0.318
	m3	2.25	0.895	interaction	0.037	0.081	0.46	52.1	0.648
time in "with"	m1	9.74	0.009 **	co-presence	-0.106	0.039	-2.71	51.3	0.009 **
	m2	6.16	0.405	familiarity	0.063	0.080	0.78	21.5	0.442
				familiarity^2	-0.163	0.079	-2.06	21.2	0.052
	m3	6.44	0.376	interaction	-0.042	0.107	-0.40	55.6	0.694
time in "with-with"	m1	6.39	0.011 *	co-presence	-0.158	0.048	-3.27	37.0	0.002 **
	m2	13.9	0.030 *	familiarity	0.126	0.069	1.82	37.0	0.077
				familiarity^2	-0.189	0.068	-2.80	37.0	0.008 **
	m3	5.42	0.491	interaction	-0.025	0.132	-0.19	37.0	0.851
Time in same area	m1	6.17	0.013 *	co-presence	-0.132	0.045	-2.95	37.0	0.005 **
	m2	15.8	0.015 *	familiarity	0.152	0.064	2.38	37.0	0.023 *
				familiarity^2	-0.149	0.063	-2.38	37.0	0.023 *
	m3	5.21	0.517	interaction	0.030	0.122	0.24	37.0	0.809

Variables	Model comparison (ANOVA)			Linear Mixed Models					
	Model	χ^2	p	Effect	Estimate	SE	t	df	p
Mean speed	m1	0.57	0.449	co-presence	0.006	0.004	1.82	53.1	0.075
	m2	21.6	0.001 **	familiarity	0.022	0.010	2.11	18.9	0.048 *
				familiarity^2	0.042	0.010	4.16	18.8	<0.001 ***
	m3	13.6	0.035 *	interaction	0.018	0.010	1.83	53.5	0.073
Visited areas (s^{-1})	m1	0.41	0.523	co-presence	0.003	0.003	0.97	14.5	0.348
	m2	17.1	0.009 **	familiarity	0.013	0.006	2.08	15.5	0.055
				familiarity^2	0.026	0.006	4.10	15.5	<0.001 ***
	m3	11.3	0.080	interaction	-0.007	0.008	-0.95	38.2	0.347

Table 1. Comparison of models and coefficient of regression testing the effects of familiarity and co-presence for different variables. Models m1, m2, m3 refer to the nested models described above. * indicates significance with $p < 0.05$, ** $p < 0.01$; *** $p < 0.001$.

Co-presence favor more antagonism between the musicians and higher interactional dissensus

There was a statistically significant relationship between co-presence and distance to "with" ($\chi^2 = 6.56$, $p = 0.01$), and between co-presence and distance to "against" ($\chi^2 = 7.17$, $p = 0.007$). As shown in Figure 6, co-presence was found to increase the distance to "with" ($\beta = 0.099$, sem = 0.037, df = 54.8, t = 2.65, $p = 0.011$) and conversely to decrease the distance to "against" ($\beta = -0.084$, sem = 0.031, df = 49.9, t = -2.74, $p = 0.008$).

INSERT FIGURE 6

Figure 6. Mean distances between the position of the musician and the "with" (left) and "against" (right) vertices, depending on co-presence. Error bars show the 95% confidence intervals. * indicates significance with $p < 0.05$, ** $p < 0.01$.

Similarly, co-presence had a main effect on the time spent in "with" ($\chi^2 = 9.74$, $p = 0.009$), the time in which both musicians were in the "with" area ($\chi^2 = 6.39$, $p = 0.011$), and the time in which the two musicians were in the same area ($\chi^2 = 6.17$, $p = 0.013$). As shown in Figure 7, musicians in co-presence tended to spend less time in the "with" area ($\beta = -0.106$, sem = 0.039, df = 51.3, t = -2.71, $p = 0.009$). Moreover, when in co-presence, the two musicians

tended to be less often in the "with" area at the same time (β = -0.158, sem = 0.048, df = 37.0, t = -3.27, p = 0.002), and to spend less time in the same area (β= -0.132, sem = 0.045, df = 37.0, t = -2.95, p = 0.005).

INSERT FIGURE 7

Figure 7. Proportion of time spent by the musicians in the "with" area (left), proportion of time in which the two musicians were both in the "with" area (middle), and proportion of time in which the two musicians were in the same area (right), depending on co-presence. Error bars show the 95% confidence intervals. ** indicates significance with $p < 0.01$.

Overall, our results thus show that, when co-present, musicians were less likely to intend to converge with their co-improviser and to adopt similar relational intents. This suggests that co-presence allows for the exploration of more ambiguous and less consensual relationships, with both a higher degree of antagonism (as attested by the fact that participants tended to be closer from the "against" vertex when co-present), and a higher degree of interactional dissensus (as attested by the fact that participants tended to spend less time playing with the same relational intent).

High and low familiarity favor higher interactional dissensus between the musicians and higher relational plasticity

As with co-presence, familiarity was found to have a significant effect on the amount of time during which the two musicians were in the same area ($\chi^2 = 15.8$, p = 0.015), and the time in which they were both in the "with" area ($\chi^2 = 13.9$, p = 0.030). As shown in Figure 8, and as predicted, these variables varied in a "inverted U-shaped" way as a function of familiarity: both high and low familiarity were associated with less time spent with similar relational intents (quadratic effect of familiarity on the time spent in the same area: β = -0.149, sem = 0.063, df = 37, t = -2.38, p = 0.023) and intentions to "play with" one another (quadratic effect of familiarity on the time spent in with-with: β= -0.189, sem = 0.068, df = 37, t = -2.80, p = 0.008).

INSERT FIGURE 8

Figure 8. Proportion of time in which the two musicians are in the same area (left) and proportion of time in which the two musicians were both in the "with" area (right), depending on familiarity. Data points show individual data. Blue line shows the best fitting quadratic regression line, with 95% confidence intervals

Moreover, the analysis revealed a main linear and quadratic effect of familiarity on variables associated with relational plasticity such as mean speed of movement ($\chi^2 = 21.6$, $p < 0.001$) and number of visited areas per second ($\chi^2 = 17.1$, $p = 0.009$). Given our initial hypothesis that familiarity should have a quadratic effect, and the fact that the quadratic term more closely captured the overall complexity of our data, we focus on interpreting the quadratic term over the linear term in the remaining. As shown in Figure 9, both high and low familiarity were found to be associated with a higher speed (quadratic effect of familiarity on mean speed: $\beta = 0.042$, sem = 0.010, df = 18.8, $t = 4.16$, $p < 0.001$) and a greater number of visited areas per second ($\beta = 0.026$, sem = 0.006, df = 15.5, $t = 4.10$, $p < 0.001$).

INSERT FIGURE 9

Figure 9. Mean speed (left) and number of visited areas per second (right), depending on familiarity. Data points show individual data. Blue line shows the best fitting quadratic regression line, with 95% confidence intervals.

Overall, our results thus show that musicians with both high and low familiarity were less likely to intend to converge with the other at the same time and to endorse similar relational intents. Interestingly, they also changed more swiftly and more frequently from one relational intent to another. This suggests that both high and low familiarity stimulate musicians' relational plasticity in a context such as collective free improvisation, and we come back to this issue in the discussion.

Discussion

Dissensus in Collective Free Improvisation

Our study sheds light on the relational strategies used by musicians when they freely improvise together. In particular, we show that, while, at an individual level, musicians largely intend to converge with their co-improviser, making only occasional use of non-cooperative or non-interactive strategies such as "playing against" or "playing without" their co-improviser, they nonetheless tend to combine their relational intents in such a way as to create focal interactional dissensus.

Such emphasis on "dissensual" interactions seems to challenge the dialogue metaphor that is so widely used to describe collective improvisation (Benson, 2003). The fact that musicians typically improvise together in CFI without previously agreeing upon on a shared

framework necessarily increases divergences in understanding and appreciation among the performers (Pras et al., 2017). There is also a wider cultural aspect at play, here: CFI has a long history of operating as an improvisation *forum* (Borgo, 2005), bringing together performers from various musical backgrounds. This conception was for example at the core of Derek Bailey's famous *Company Weeks* festival (Watson, 2004). As a result, free improvisers "will inevitably bring contrasting shades of understanding to what they play together" (MacDonald & Wilson, 2020, p. 99), that are likely to reinforce feelings of playing "against" or "without" one's partner amongst CFI performers.

More generally, the interactional dissensus observed in CFI is highly dependent on the specificities of the musical medium. First, the "floating intentionality" of the musical medium (Cross, 2014) – the fact that, musical semantics is, at best, highly underspecified (Schlenker, 2017) – means that musicians can actively play "against" their partner without actually *contradicting* each other and bringing the interaction to a deadlock. Second, the simultaneity of the improvisers' individual contributions to the overall musical output favors a higher degree of independence, making the improvisers' behaviors less contingent on one another. Those two features put CFI in stark contrast with the interactional dynamics of improv theater, which relies on turn-taking and, at least most of the time, on the avoidance of both semantic and fictional contradictions. As such, the "yes-and" mantra – acknowledging your co-improviser's offer and building on it – that is often considered to be improv's one essential rule (Besser et al., 2013) does not capture the complexity of CFI, musicians being able to explore a wider range of interactions, including local dissensus.

Our results also suggest that, in a mostly egalitarian framework such as CFI, in which musicians are thought to be contributing equally to the overall output, interactional dynamics are also largely driven by the manipulation of more "horizontal" relationships. Such ways of relating to one another that do not necessarily translate into "vertical" relationships such as leading or following, but rather unfold on a spectrum that goes from cooperation to indifference and conflict. This does not mean that leader/follower patterns – understood either in terms of sent information (Pelz-Sherman, 1998) or in terms of temporal precedence in initiating a musical phrase or situation (Aucouturier and Canonne, 2017) – do not emerge locally during the performance. But our study invites to consider those "horizontal" relationships as a relevant complementary axis for the analysis of social interactions in collective musical performances, beyond the more traditionally studied leader/follower relationships (Volpe et al., 2016; Chang et al., 2017).

Non-interactive behaviors in Collective Free Improvisation

One of the most striking result of our study is probably the significant amount of performance time during which the improvisers were, in fact, not intending to interact with their partner. Musicological scholarship has already discussed the possibility that the importance of interaction in jazz performances had been overemphasized, because of a tendency to frame as interactional processes what is just musicians "independently fulfilling their own musical functions in a creative way" (Rinzler, 1988, p. 156; see also Givan, 2016). Providing a computational analysis of interactions within a jazz quintet, Pachet et al. (2017) come to similar conclusion, showing that musicians' acoustical outputs do not exhibit a higher degree of correlation than what is already provided by the musical script they all share.

However, the occasional absence of interactions might be more surprising in the context of CFI, in which there is no external script, or even no clearly shared and well-defined stylistic idiom that can "glue" together the individual contributions into a joint musical outcome. In CFI, the feeling of playing together crucially depends on the degree of contingency each performer displays towards the actions of her co-performers. The fact that free improvisers are sometimes willing to put the jointness of their performance at risk – as shown by the lower degree of acoustic coordination displayed in situations where at least one musician was not intending to play "with" her partner – is thus not trivial. Several non-exclusive reasons might be offered here to explain such behavior. First, this might reflect the wider influence of a post-Cagean aesthetics on some "eurological" strains of CFI (Lewis, 1996), according to which there is much beauty to be found in the serendipitous juxtapositions and superpositions of independent sounds. Second, asymmetrical couplings (i.e., one musician's behavior being contingent on the other's, but not reciprocally) might be enough to preserve a feeling of jointness while still offering the musicians with many surprising events, prompting their musical behavior in unexpected directions. Third, it might be that, even when they intend to "play without", improvisers are not really able to fully abstract their playing from what their physically and/or sonically co-present partner is doing, and still display some minimal degree of contingency in their behaviors. Indeed, research has shown that agents' tendency to align their behaviors can be very pervasive, and remain even when they have no intention to coordinate with one another (Issartel et al., 2007). Further experiments could test this last hypothesis by comparing the perceived degree of togetherness in real duets in which free improvisers are actually trying to play without each other, with that of "fake" duets made up of randomly combined individual tracks.

Co-presence and familiarity act as interactional smoothers

Another main contribution of our study is to demonstrate that co-presence and familiarity notably impact improvisers' relational intents towards one another. While both factors similarly increased the overall level of interactional dissensus, they also modulated differently improvisers' individual behavior, with co-presence increasing the degree of antagonism improvisers were willing to inject in their interactions, and both low and high familiarity increasing their relational plasticity. They thus deserve separate discussions.

Regarding co-presence, two explanations might explain its impact on the musicians' interactions. First, many studies have highlighted the role played by facial expressions and perception of bodily movements in musical coordination and synchronization (Davidson, 2012; D'Ausilio et al., 2012; Hilt et al., 2019). Such visual cues enhance coordination mainly because they allow musicians to better monitor the expressive intentions of their fellow group members, through a variety of mechanisms such as perceptual-motor couplings (Novembre & Keller, 2014), or audio-visual integration (McGurk & MacDonald, 1976; Thompson et al., 2008; Bishop & Goebl, 2014). This is likely to make it easier for musicians to coordinate, e.g., to synchronize their attacks or to match each other's levels of loudness. Here, co-present improvisers might have been better able to perceive their partner's intention to play "with" them, which in turn made it possible for them to explore more antagonistic modes of interactions that could have, in less favorable contexts, put at risk the musicians' felt connection to one another. In a similar perspective, they may also have been able to play "against" their partner in a more robust fashion, because they were able to better anticipate the musical direction taken by their partner, which made it easier for them to actually diverge from their co-improviser when they wanted to do so. Conversely, it is likely that musicians tended to play "with" their partner more often in the "Isolated" condition precisely to try to make themselves more predictable, thus counterbalancing for the increased difficulty of coordination caused by the absence of visual and bodily cues (Vesper et al., 2011; Goupil et al., 2021).

Second, in the case of collective improvisation, Moran et al. (2015) found evidence of a backchannel of communication between soloing improvisers and momentarily silent co-performers based on bodily cues. In particular, third-party listeners were able to tell whether musicians were actually playing together or not simply by looking at their bodily movements. Such back-channeling communication, accessible through bodily and visual cues, might thus comfort improvisers that they are indeed playing music together, and reinforce a shared feeling

of togetherness. It is then likely that "Isolated" musicians felt that they had to make up for the lack of subtle visual and somatic cues that are so crucial in creating a feeling of togetherness by overly emphasizing that they were playing "with" their partner.

The results we obtained regarding familiarity also deserve further discussion, as they reveal a complex, non-linear effect of familiarity. We found that the degree of relational plasticity was increased when musicians had virtually never played together before. Two interpretations of these results are possible. On the one hand, it might be that the novelty of the situation encouraged the improvisers to explore a wider variety of musical relationships and to change their interactional behavior more rapidly as a way to get to know their partner. On the other hand, it might be that the lack of familiarity, and the higher stylistic or aesthetic heterogeneity that might often come with it, made it simply more difficult for the musicians to monitor and anticipate their partner's behavior (Ragert, Schroeder & Keller, 2013), thus preventing them to stabilize their interactions for a longer stretch of time. In the absence of more detailed data regarding the improvisers' subjective evaluations and descriptions of the performances, it is difficult to assess the respective relevance of these two interpretations. In any case, a clearer result is that musicians that were somewhat familiar with each other displayed a lower relational plasticity than musicians with higher familiarity or no familiarity at all. In a way, those musicians knew each other well-enough for having established a minimal common ground that made it unnecessary to "uncover" through the performance the range of viable musical relationships they could explore together. But they were not familiar enough with one another as to share an implicit mental model of what it is to improvise together, in the same way as improvisers who are highly familiar with one another do (Canonne & Aucouturier, 2016). Such shared mental models may entail similar mappings between sound-types and action-types, making it more likely for the improvisers to "pick up" on the same sonic events, thus strongly contributing to the feeling of trust and confidence improvisers might feel towards one another. It also made it possible for them to engage in a more playful performance, in which they could constantly change their relations to one another as a way to surprise each other and reinforce the unpredictability of the performance. As such, it would appear that Derek Bailey's position – which claims that the most stimulating improvisations come from groups that are still "fresh" – and the position of many contemporary improvisers within the CFI scene (Canonne, 2018b) – who insist on the importance of knowing each other "very well" to be able "to stretch it further" (Denzler & Guionnet, 2020, p. 19) – are less incompatible than it would seem at first sight. In both cases, albeit probably for different reasons, musicians seem able to create the kind of interactional tension that is often thought to be so crucial to CFI. On a more

general note, our results point towards the existence of a U-shaped relationship between familiarity and relational plasticity within a group. Future experiments could assess this hypothesis further by investigating more extensively the temporal dynamics of the impact of group familiarity on group members' interactional behaviors over a wider range of artistic and creative practices.

Co-presence and familiarity are often thought to unilaterally favor behavioral alignment. For instance, co-presence is thought to increase synchronized body movement and convergent emotional response through entrainment, even when people are not explicitly interacting (Richardson et al., 2007). As for higher familiarity between the group members, it is typically thought to lead to better synchronization in chamber music performance, through the progressive calibration of internal prediction models (Keller, 2014). But a more general interpretation would be that those factors act as *interactional smoothers*, increasing the agents' overall level of relational plasticity, and allowing for the exploration of a wider range of interpersonal relations. In other words, co-presence and familiarity can allow for both more congruent *and* more divergent behaviors, depending on what the context of action requires. In that sense, the fact that co-present musicians and highly familiar musicians were less likely to intend to converge with one another or to seek for relational alignment, can precisely be seen as a sign that CFI typically strives when there is some degree of interactional dissensus between the musicians.

Relational intents as creative resources in Collective Free Improvisation

Overall, our study gives additional empirical ground to the idea that agents engaged in creative joint actions typically oscillate between convergent behaviors and divergent behaviors, agreement and dissensus, contingency and autonomy, as a way to negotiate between the demands of doing something collectively and the goal of delivering a creative output. In that perspective, CFI's aesthetic success seems to have much to do with exploring the tension (and finding a balance) between individual autonomy and group cohesion. That free improvisers skillfully negotiate between the requirements of joint action (i.e., coordinating individual actions, feeling a sense of togetherness) and the requirements of creativity (i.e., favoring the serendipitous emergence of novel musical situations) is clearly reflected in the way they organized their interactions at the group-level, by favoring associations in which one musician was engaged in a disruptive behavior (e.g., challenging their improvisation partner by playing non-cooperatively) while the other was endorsing a more stabilizing behavior. As we showed,

this typically resulted in musical situations in which the musicians' individual outputs were more acoustically incongruent, at least in terms of properties as fundamental as loudness. However, it remains an open question whether such combination of behaviors actually result in a more creative or expressive result. Follow-up experiments could further investigate the relation between interactional behaviors and the aesthetic and creative properties of the musical output. For instance, we could ask third-party listeners to rate musical outputs with different combinations of relational intents (e.g., "with-with", "with-against", etc.) along several dimensions (e.g., "originality", "togetherness", "pleasantness", "arousal", etc.).

Relational intents might well function as a primary resource for creative joint actions, particularly when shared external resources are scarce, as it is the case in CFI; they are not just a parameter of the situation, set once and for all, but something that agents can actively work with over the course of the action. Musical improvisers work with such interpersonal relations in the same way as they work with notes or rhythms: they manipulate them as to create expressive effects, playing with our (and their own) expectations to build tension and momentum. Extending this insight to other forms of collective creative practice to explore how the diversity of interactional behaviors can modulate group creativity should open promising research avenues in understanding joint creative actions at large.

Ethical approval and consent. Ethical approval for this study was obtained at INSEAD/ Sorbonne University Center for Behavioural Science, Paris, France. All methods were carried out in accordance with their guidelines and regulations. All participants signed an informed consent.

References

Amabile, T. M. (1982). Social psychology of creativity: A consensual assessment technique. *Journal of personality and social psychology*, *43*(5), 997.

Aucouturier, J. J., & Canonne, C. (2017). Musical friends and foes: The social cognition of affiliation and control in improvised interactions. *Cognition*, *161*, 94-108.

Bailey, D. (1992). *Improvisation Its nature and practice in music*. Da Capo Press.

Benson, B. E. (2003). *The improvisation of musical dialogue: A phenomenology of music*. Cambridge University Press.

Besser, M., Roberts, I., Walsh, M. (2013) *The Upright Citizens Brigade Comedy Improvisation Manual*. Comedy Council of Nicea.

Bishop, L. (2018). Collaborative musical creativity: How ensembles coordinate spontaneity. *Frontiers in psychology*, *9*, 1285.

Bishop, L., & Goebl, W. (2014). Context-specific effects of musical expertise on audiovisual integration. *Frontiers in psychology*, *5*, 1123.

Bjørndahl, J. S., Fusaroli, R., Østergaard, S., & Tylén, K. (2015). Agreeing is not enough: The constructive role of miscommunication. *Interaction Studies*, *16*(3), 495-525.

Borgo, D. (2005). *Sync or swarm: Improvising music in a complex age*. A&C Black.

Canonne, C. (2018a). Listening to improvisation. *Empirical Musicology Review*,*13*(1–2).

Canonne, C. (2018b). Rehearsing Free Improvisation? An Ethnographic Study of Free Improvisers at Work. *Music Theory Online*, *24*(4).

Canonne, C., & Aucouturier, J. J. (2016). Play together, think alike: Shared mental models in expert music improvisers. *Psychology of Music*, *44*(3), 544-558.

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.

Clarke, E. F. (2005). Creativity in performance. *Musicae Scientiae*, *9*(1), 157-182.

Cook, N. (2018). *Music as creative practice*. Oxford University Press.

Cross, I. (2014). Music and communication in music psychology. *Psychology of Music*, *42*(6), 809-819.

D'Ausilio, A., Badino, L., Li, Y., Tokay, S., Craighero, L., Canto, R., Aloimonos, Y., & Fadiga, L. (2012). Leadership in orchestra emerges from the causal relationships of movement kinematics. *PLoS one*, *7*(5), e35757.

Davidson, J. W. (2012). Bodily movement and facial actions in expressive musical performance by solo and duo instrumentalists: Two distinctive case studies. *Psychology of Music*, *40*(5), 595-633.

Denzler, B., & Guionnet, J.-L. (2020). *The practice of musical improvisation*. Bloomsbury Academics.

Gelman, A., & Hill, J. (2006). *Data analysis using regression and multilevel/hierarchical models*. Cambridge University Press.

Givan, B. (2016). Rethinking interaction in jazz improvisation. *Music Theory Online*, *22*(3).

Goupil, L., Wolf, T., Saint-Germier, P., Aucouturier, J. J., & Canonne, C. (2021). Emergent Shared Intentions Support Coordination During Collective Musical Improvisations. *Cognitive Science*, *45*(1), e12932.

McGurk, H., & MacDonald, J. (1976). Hearing lips and seeing voices. *Nature*, *264*(5588), 746-748.

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), 1-10.

Iorwerth, M., & Knox, D. (2019). Playing together, apart: Musicians' experiences of physical separation in a classical recording session. *Music Perception: An Interdisciplinary Journal*, *36*(3), 289-299.

Issartel, J., Marin, L., & Cadopi, M. (2007). Unintended interpersonal co-ordination: “can we march to the beat of our own drum?” *Neuroscience Letters*, *411*(3), 174–179.

Keller, P. E. (2014). Ensemble performance: Interpersonal alignment of musical expression. In D. Fabian, R. Timmers, & E. Schubert (Eds.), *Expressiveness in music performance: Empirical approaches across styles and cultures* (pp. 260–282). Oxford: Oxford University Press.

King, E. (2013). Social familiarity: styles of interaction in chamber ensemble rehearsal. In E. King & H. M. Prior (Eds), *Music and Familiarity: Listening, Musicology and Performance* (pp. 253-70). Routledge.

Krueger, J. (2011). Extended cognition and the space of social interaction. *Consciousness and cognition*, *20*(3), 643-657.

Levine, J. M., Choi, H. S., & Moreland, R. L. (2019). Newcomer influence and creativity in work groups. In P. B. Paulus & B. A. Nijstad, *The Oxford handbook of group creativity and innovation* (pp. 51-72). Oxford University Press.

Lewis, G. E. (1996). Improvised music after 1950: Afrological and Eurological perspectives. *Black music research journal*, 91-122.

MacDonald, R. A., & Wilson, G. B. (2020). *The Art of Becoming: How Group Improvisation Works*. Oxford University Press.

Matuszewski B. (2019). Soundworks – A Framework for Networked Music Systems on the Web - State of Affairs and New Developments. *Proceedings of the Web Audio Conference (WAC) 2019*.

Michael, J., McEllin, L., & Felber, A. (2020). Prosocial effects of coordination – What, how and why?. *Acta Psychologica*, *207*, 103083.

Moran, N., Hadley, L. V., Bader, M., & Keller, P. E. (2015). Perception of 'back-channeling' nonverbal feedback in musical duo improvisation. *PLoS One*, *10*(6), e0130070.

Nemeth, C., & Nemeth-Brown, B. (2019). Better than individuals? Dissent and group creativity. In P. B. Paulus & B. A. Nijstad, *The Oxford handbook of group creativity and innovation* (pp. 73-83). Oxford University Press.

Novembre, G., & Keller, P. E. (2014). A conceptual review on action-perception coupling in the musicians' brain: what is it good for?. *Frontiers in Human Neuroscience*, *8*, 603.

Novembre, G., & Keller, P. E. (2018). Music and action. In R. Bader (Ed.), *Springer handbook of systematic musicology* (pp. 523-537). Springer.

Pachet, F., Roy, P., & Foulon, R. (2017). Do jazz improvisers really interact?. In M Lesaffre, P. J. Maes, & M. Leman (Eds.), *The Routledge companion to embodied music interaction* (pp. 167–176). Routledge.

Pelz-Sherman, M. (1998). *A framework for the analysis of performer interactions in western improvised contemporary art music*. [Unpublished doctoral dissertation]. University of California San Diego.

Pras, A., Schober, M. F., & Spiro, N. (2017). What about their performance do free jazz improvisers agree upon? A case study. *Frontiers in psychology*, *8*, 966.

Pressing, J. (1984). Cognitive processes in improvisation. *Advances in Psychology*, *19*, 345-363).

Ragert, M., Schroeder, T., & Keller, P. E. (2013). Knowing too little or too much: the effects of familiarity with a co-performer's part on interpersonal coordination in musical ensembles. *Frontiers in psychology*, *4*, 368.

Richardson, M. J., Marsh, K. L., Isenhower, R. W., Goodman, J. R., & Schmidt, R. C. (2007). Rocking together: Dynamics of intentional and unintentional interpersonal coordination. *Human movement science*, *26*(6), 867-891.

Rinzler, P. (1988). Preliminary thoughts on analyzing musical interaction among jazz performers. *Annual Review of Jazz Studies*, *4*, 153-160.

Roueff, O. (2006). L'invention d'une «scène» musicale, ou le travail du réseau. *Sociologie de l'art*, *1*, 43-76.

Sawyer, R. K. (2003). *Group creativity: Music, theater, collaboration*. Psychology Press.

Sawyer, R. K., & DeZutter, S. (2009). Distributed creativity: How collective creations emerge from collaboration. *Psychology of aesthetics, creativity, and the arts*, *3*(2), 81.

Schlenker, P. (2017). Outline of music semantics. *Music Perception: An Interdisciplinary Journal*, *35*(1), 3-37.

Schönherr, J., & Westra, E. (2019). Beyond 'interaction': How to understand social effects on social cognition. *The British Journal for the Philosophy of Science*, *70*(1), 27-52.

Sebanz, N., Bekkering, H., & Knoblich, G. (2006). Joint action: bodies and minds moving together. *Trends in cognitive sciences*, *10*(2), 70-76.

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.

Thompson, W. F., Russo, F. A., & Quinto, L. (2008). Audio-visual integration of emotional cues in song. *Cognition and Emotion*, *22*(8), 1457-1470.

Vesper, C., Van Der Wel, R. P., Knoblich, G., & Sebanz, N. (2011). Making oneself predictable: Reduced temporal variability facilitates joint action coordination. *Experimental Brain Research*, *211*(3-4), 517-530.

Volpe, G., D'Ausilio, A., Badino, L., Camurri, A., & Fadiga, L. (2016). Measuring social interaction in music ensembles. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *371*(1693), 20150377.

Wallot, S., Mitkidis, P., McGraw, J. J., & Roepstorff, A. (2016). Beyond synchrony: joint action in a complex production task reveals beneficial effects of decreased interpersonal synchrony. *PloS one*, *11*(12), e0168306.

Watson, B. (2004). *Derek Bailey and the story of free improvisation*. Verso.

Wilson, G. B., & MacDonald, R. A. (2012). The sign of silence: Negotiating musical identities in an improvising ensemble. *Psychology of Music*, *40*(5), 558-573.

Wilson, G. B., & MacDonald, R. A. (2017). The construction of meaning within free improvising groups: A qualitative psychological investigation. *Psychology of Aesthetics, Creativity, and the Arts*, *11*(2), 136-146.