Mission pour les initiatives transverses et interdisciplinaires	**Interactions complexes et comportements collectifs** **AAP 2025** Présentation du projet scientifique

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DATE LIMITE de CANDIDATURE : mercredi 16 octobre 2024 à midi (heure de Paris)

IDENTIFICATION

Civilité/Nom/Prénom du porteur ou de la porteuse du projet	M. Clément CANONNE
Titre long du projet (150 caractères maximum)	Resisting Entrainment: A Dynamical Systems Approach
Acronyme du projet	R-TRAIN

PROJET DE RECHERCHE 2025-2026

R-TRAIN
Resisting entrainment: a dynamical systems approach

State of the art

When humans do anything together, they exhibit a seemingly irresistible tendency to synchronize their movements and actions. This has been observed in countless studies on joint activities as diverse as walking together (Hajnal & Durgin, 2023), conversation (Shockley et al., 2003), or collective music making (Kavaliauskaitė et al., 2024). Such synchronization can occur unintentionally, through mere visual or auditory exposure to other people's rhythmic activities (see for example Richardson et al. (2007)'s famous study on how people oscillating at various speed on rocking chairs end up in sync, or Néda et al. (2000)'s equally influential study on audience clapping). Several studies have even shown that participants often cannot *resist* being attracted to other participants' motion even when explicitly instructed to maintain their own individual speed (Schmidt & O'Brien, 1997; Issartel et al., 2007; Rosso et al., 2021).
The dominant interpretation for such phenomena, emerging in the past 20 years or so, is that they do not result from explicit information processing (e.g., tracking time intervals, see Repp & Su, 2013) but from a lower-level emergent sensorimotor mechanism akin to how oscillators adapt their period to an external forcing stimulus (Knoblich et al., 2011; Large et al., 2023) – something referred to as "entrainment" in the psychological community. This interpretation has motivated a large number of computational models, based on dynamical system theory, exploring e.g., how synchronization depends on the ratio of signal period to oscillator period, or on coupling strength (Large & Palmer, 2002), and shown how such systems can not only synchronize to isochronous events but can resonate to complex rhythmic sequences which may display little or no energy at the beat frequency (see Large et al. 2023, for a review).
While these models have provided important mechanistic insights into how/why an individual may entrain to an external source (including another individual), they leave out an important class of phenomena in which two individuals, instead, try to *resist* entraining to one another. Indeed, while entrainment is generally considered crucial for coordination in joint action to emerge and persist, there are cases in which synchronization between agents isn't desirable or should even be actively avoided. In conversations, for instance, one can signal disagreement by reducing in-phase body synchrony with a conversation partner

(Paxton & Dale, 2013). Similarly, in competitive sports, breaking from synchrony is used strategically to make oneself less predictable and outwit opponents (McGarry & De Poel, 2016). Perhaps more importantly, desynchronization also play a critical role in creative endeavors. Contemporary dance practices, for example, are replete with choreographies in which the dancers' motions dissociate from the music's rhythm or tempo (see for example Xavier Leroy's works based on the music of Igor Stravinsky or Helmut Lachenmann; and see Himberg et al., 2018, and Miura et al., 2015, for empirical considerations on resistance to entrainment in a dance context). In music in particular, deliberately divergent or heterophonic interactional strategies are stable stylistic markers of musical traditions (see Pärtlas, 2016 on heterophony; see also Lucas et al., 2011, on Brazilian *Congado*, in which bands that meet on the streets during the ritual must attempt to maintain their own tempo and avoid being attracted by the other group's tempo), and are sought actively as a means of expressivity and creativity in e.g., jazz (Michaelsen, 2019, on Miles Davis' second quintet) or collective free improvisation (Wolf et al., 2023). Independent rhythmical behaviors and desynchronization processes can even be explicitly composed for, and precisely rehearsed (John Cage's indeterminate music, see Iddon et al., 2019; Steve Reich's phasing music, see Schutz, 2019).
To model such phenomena, current dynamical-theory models of entrainment fall short in several important respects. First, while existing models allow to simulate behaviors that mimic simple case of interactions, they typically do not allow learning parameters from actual performance data, i.e., doing "system identification" (in the sense of control engineering) of the model's parameters. Second, while existing models allow to model interactions with external (forcing) signals, they do not allow to account for close-loop coupled dynamics between two continuous (i.e., for which one cannot compute/define a sequence of successive onset asynchronies) and autonomous signals (i.e., where each signal may successively react and anticipate the other). Finally, while a few studies have investigated resistance to synchronization by tapping against a metronome (Repp & Keller, 2004; Kim et al., 2023), we currently have no experimental data in full-fledged interactional settings – i.e., with two or more people simultaneously and continuously involved in such a complex behavior.

Goal of the project

Project R-TRAIN is a highly exploratory research project which aims to investigate the important and under-studied phenomena of human *resistance to entrainment* by providing both novel experimental data and novel computational methodologies that are able to model such data. To do so, we will, first, collect open-sourced datasets from expert musicians placed in well-controlled experimental situations, inspired by our extensive previous work with various performers and improvisers. Music offers many general advantages for investigating joint action – allowing for an ideal balance between experimental control and ecological validity (D'Ausilio et al., 2015); it is particularly well-suited to investigate joint actions with a strong rhythmical component and/or joint actions that are highly temporally structured (Michael, 2017); and it lends itself to comparison with a large corpus of existing computational models (Large et al., 2023). Second, we will provide a novel data-driven model for such data by using a recently emerging approach in physics-informed machine learning, Sparse Identification of Non-Linear Dynamics (SINDY), which offer to treat the coupled performance data as the observation of a hidden, lower-dimensional dynamical system and to learn its parameters and functional form from data (Brunton et al., 2016).
Project R-TRAIN is thus a radically interdisciplinary endeavor, which requires to combine methodologies from empirical musicology and engineering science, within a broader art-science context. Indeed, we will need to establish a close dialogue with musicians that have developed a strong expertise in rhythmical practices associated with resistance to entrainment, to abstract various experimental situations from a diverse range of musical situations, and to identify (through interviews and observations) parameters of variation that make both experimental and musical senses, while also bringing to the table advanced skills in modelling, machine learning, and computational analysis. The collaboration at the heart of the R-TRAIN project – between a CNRS Sciences Informatiques/Sciences Humaines & Sociales laboratory in Paris (STMS, PI: Clément Canonne) and a CNRS Ingénierie laboratory in Besançon (FEMTO-ST, PI: JJ Aucouturier) – should allow us to do just that.
Finally, we believe that the project's objectives are innovative, both on a thematic level and epistemological level. On the one hand, we will radically shift the focus of joint actions studies, which have been almost exclusively concerned with identifying the mechanisms underlying synchronization, and shed light on a highly overlooked, yet crucial aspect of joint action – the possibility of temporally independent individual behaviors within a collective context. On the other hand, we will aim at extending the relevance of dynamical systems approach to behaviors that seem to be *prima facie* highly dependent on intentions and representations, thus providing new insights for dynamical systems approaches of cognition at large.

Workplan/methodologies

Ideally, the R-TRAIN project will unfold over the course of two years.

Year 1:

First, a group of six highly expert musicians will be invited over the course of a 4-day session in a professional recording studio with separated individual booths to perform a large number of rhythmical tasks (alternatively using MIDI devices, for additional experimental control, and their own instruments, for additional ecological validity) in which they will have to resist being entrained to an external beat. Several factors will be considered in our experimental manipulations:

- Nature of the coupling (playing against a metronome vs playing against another musician)
- Strength of the coupling (audio-visual communication vs audio-only communication or visual only communication; playing against another musician vs playing against a group of musicians)
- Group size (pair vs trio vs sextet)
- Tempi and tempi relations (faster vs slower tempi; close tempi vs distant tempi)
- Joint representation of the overall outcome (i.e., the resulting superposition of the two tempi is conceived as a polyrhythm) or not (i.e., the two superposed tempi are conceived as being independent from one another)
- Presence of a joint goal (i.e., the musicians having to coordinate their actions on another level, for example on the dynamic/pitch level) or not.

We will also take advantage of this session – which will in fact work as a short residency in which musicians and researchers will spend 4 full days together – to collect various observational data through informal interviews with the musicians and more formal post-hoc annotations (following the methodology used e.g., in Saint-Germier et al., 2021, or in Golvet et al., 2024) on various dimensions (e.g., attention to the other(s), sense of self, sense of joint agency, sense of duration, etc.) that will ultimately help inform the interpretation of our results as well as their potential implications for musical practices. Another advantage of this format of data collection is its iterative dimension: preliminary analyses will be conducted at the end of each day, allowing us to take their results into account in adjusting the experimental design of the next-day session, and so on.

Second, we will extract onsets data and other relevant timing-related data (e.g., inter-onsets intervals, etc.) either directly from the MIDI information or from the audio signals (using onset detection plugins developed for the IRCAM software Partiels).

Third, and finally, we will use these data to infer the various equations governing the dynamical systems at play in our different cases of resistance entrainment (relying on the methodology described in Brunton et al., 2016). This will allow us to assess whether the various sets of equations obtained are organized along different modes, and the extent to which the forces and constraints at play are dependent on our experimental factors. Identifying the temporal structure underlying dynamic resistance to entrainment (whether there are distinct phases, for example) will also allow us to formulate new hypotheses, e.g., on how phase correction and period correction might interact in such social contexts, that could drive future research in the area.

Year 2:

If the project is allowed to goes on for another year, we will develop the project in two directions. First, we will try to further connect our results to actual artistic practices by designing a tool for musical composition inspired by closed-loop systems. Following James Saunders' ideas on "group behaviors as music" (see Saunders, 2021), and based on the models identified within the project, Simon Kanzler (http://www.simonkanzler.de), a composer in residency in the STMS lab, will explore various interface designs to organically organize performers' rhythmical behavior as a function of their actual behavior by, e.g., manipulating in real-time the individual tempi they receive through a click track. In other words, the goal here will be to imagine musical situations whose dynamics is based on our previous findings on how entrainment and resistance to entrainment might interact in complex collective rhythmic production (e.g., prescribing a given initial tempo relationship that will tend to result in a group accelerando; changing the individual tempi or rhythmical patterns at strategic time points to counter or further reinforce the entrainment effect; etc.). Such "composed collective rhythmical behaviors" will be tested and refined over a final 3-day residency with a group of four performers, resulting in the composition of a new musical work deeply rooted in the results gathered during the project.

Second, we will seek to place our results in a broader context by organizing in Besançon an international conference on the theme "Joint action and dynamical systems" (possibly associated with the bi-annual JAM conference: https://somby.ceu.edu/jam), which will explore how dynamical systems can be used not only as theoretical tools to model social interactions but also as experimental tools to investigate crucial aspects of collective behaviors.

Expected results

We will disseminate our results through scientific publications in journals with a broad, interdisciplinary readership such as *Current Biology* or *Cognition*. On a more practical level, we will also aim at inferring recommendations from our analyses (e.g., when attentional suppression is the most efficient, to which extent one could accelerate or decelerate one's own tempo to help resisting entrainment, etc.) that could be useful for performers involved in musical practices which rely on rhythmically complex collective behaviors (see Hartenberger, 2016, for an example of this kind of approach). This will lead to a publication in an artistic research journal such as *Music&Practice*.

Team

The R-TRAIN project will combine forces from two research teams: the « Analyse des Pratiques Musicales » team at *Sciences et Technologies de la Musique et du Son* (UMR 9912, CNRS-IRCAM-Sorbonne Université) and the « Sciences des Données et Santé des Systèmes » team at *Franche-Comté Électronique Mécanique Thermique et Optique* (UMR 6174, CNRS-Université Bourgogne Franche-Comté).

APM team

Clément Canonne (DR CNRS, Section 35) will coordinate the project and bring his expertise in empirical musicology (50% of research time). Research topics relevant to the project: improvisation, collective musical practices, experimental music, music cognition, empirical aesthetics, artistic research.
Simon Kanzler (composer in residency within the APM team in 2025-2026) will bring his expertise in musical composition and computer music.
Pierre Saint-Germier (CR CNRS, Section 35) will bring his expertise in philosophy (15% of research time). Research topics relevant to the project: philosophy of music, philosophy of cognitive sciences, philosophy of artificial intelligence.
Thomas Wolf (post-doctoral fellow at Central European University, visiting researcher in the APM team in 2025) will bring his expertise in joint action studies and experimental design. Research topics relevant to the project: joint action, rhythmical behaviors, music cognition.

DATA-PHM team

Jean-Julien Aucouturier (DR CNRS, Section 7) will bring his expertise in neurosciences and dynamical system modelling (35% of research time). Research topics relevant to the project: social cognition, signal processing, reverse correlation, closed-loop systems.
Manaoj Aravind (post-doc within the DATA-PHM team) will bring his expertise in physics. Research topics relevant to the project: non-linear dynamical systems.
Nathan Kutz (Prof. Applied Mathematics, University of Washington) is a leading figure in data-driven modelling, and one of the authors of the SINDY algorithm. The R-TRAIN project will motivate a broader invitation to Nathan Kutz as a visiting Professor in FEMTO. He will actively contribute to our 4-day data collection residency by bringing his invaluable analysis skills to the table.

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CURRICULUM VITAE du porteur ou de la porteuse

CURRICULUM VITAE

Clément Canonne is a senior CNRS researcher (DR) and head of the Analysis of Musical Practices team at STMS (UMR 9912, CNRS-IRCAM, Sorbonne Université). He holds a Master's degree in piano performance from Lyon's Conservatoire National Supérieur de Musique et de Danse and a PhD in Musicology from the University of Saint-Etienne. His research has been mainly focused on collective improvisation, bringing perspectives from musicology, ethnography and experimental psychology to understand the cognitive and interactional processes of musicians, and, more generally, to shed new light on joint action and social cognition. He has considerable experience working in interdisciplinary contexts, collaborating with physicists, cognitive scientists, psycho-acousticians or computer scientists (PI of the IXXI-funded project "Collective improvisation and non-linear dynamics", 2010-2012; PI of the Labex CAP-funded project "Music & Hacking", 2016-2017; PI of the ANR-funded project "Musical

Improvisation and Collective Action", 2017-2021; PI of the Collegium Musicae-funded project "Tracking musical listening", 2022-2023). He has published extensively in musicology, philosophy, and cognitive sciences journals (see https://www.ircam.fr/person/clement-canonne for a complete list of publications). He is also very interested in exploring new formats for the dissemination of scientific research (see for example the CD *Improvisation in the Lab*, Urborigène Records, 2021: https://www.urborigene.com/produit/improvisation-in-the-lab/), artistic research (see the "Sonic Games" project: https://leslaboratoires.org/article/jeux-sonores-pole-sup-93/lhypothese-continue) and participatory science (see https://medias.ircam.fr/x50a8e2_concert-laboratoire for a recent example).

Main publications in relation with the R-TRAIN project:

C. Canonne & F. Gribenski (forthcoming), *New Methods and New Challenges in Empirical Musicology*, Oxford University Press.

A. Schwarz, A. Faraco, C. Vincent, P. Susini, E. Ponsot and C. Canonne (accepted), « Acoustic salience impacts both auditory attention and interactional dynamics in collective musical improvisations », *Proceedings of the Royal Society B*.

T. Wolf, L. Goupil and C. Canonne (2023), « Beyond togetherness: interactional dissensus fosters creativity and tension in freely improvised musical duos », *Psychology of Aesthetics, Creativity, and the Arts*, https://doi.org/10.1037/aca0000588.

P. Saint-Germier, C. Paternotte and C. Canonne (2021), « Joint improvisation, minimalism, and pluralism about joint action », *Journal of Social Ontology*, https://doi.org/10.1515/jso-2020-0068.

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