SynchMuse: a novel paradigm to study embodied coordination in musical ensembles using virtual agents

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Goal: Decoding Humans' Coordination

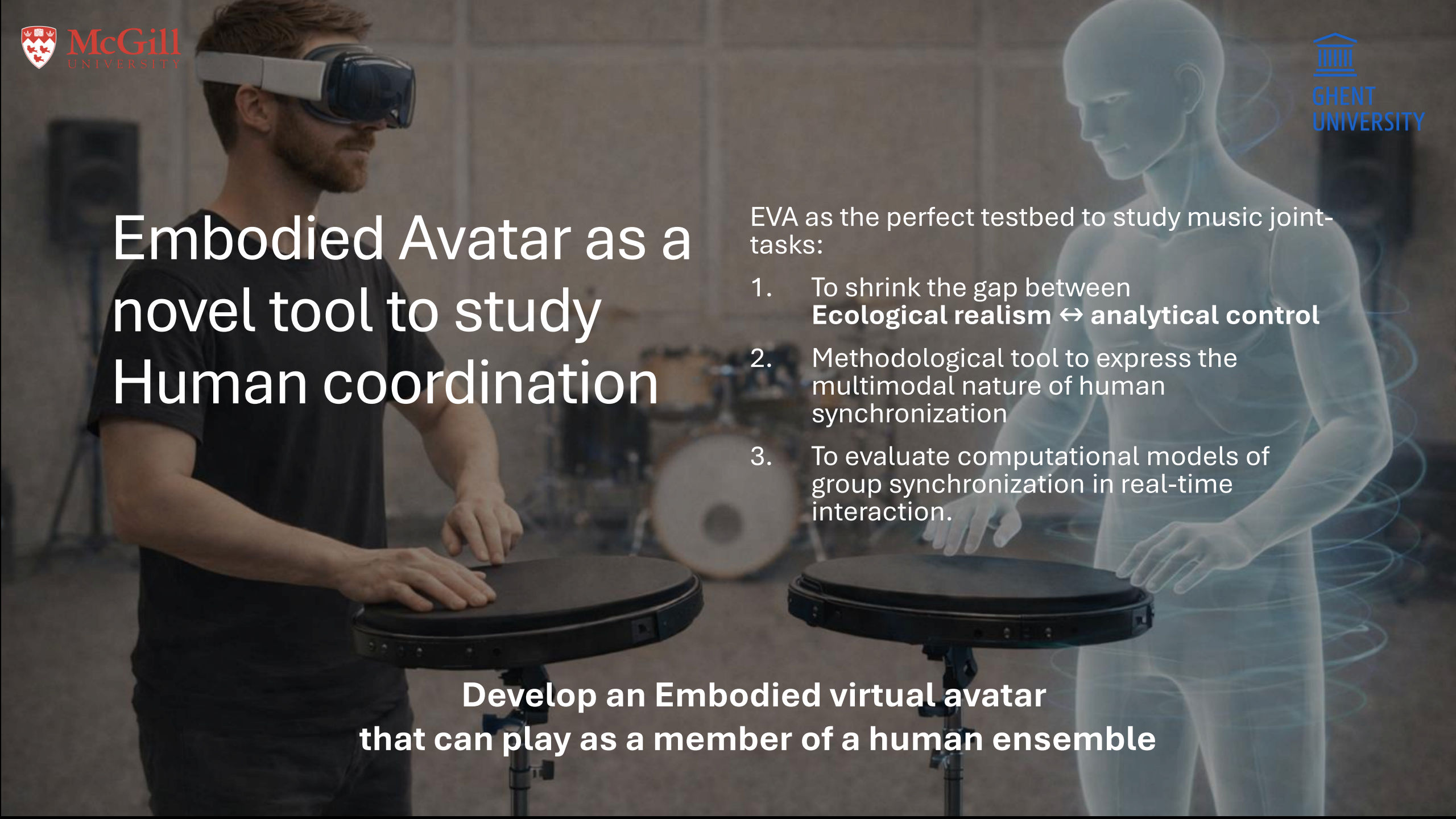
Investigating and explaining the hidden dynamics underlying human synchronization.

We consider musical ensembles as an ecological setting to investigate human joint action.



Research Question: How can **interpersonal** synchronization be **formalized** and **embodied** using computational models, without losing its **dynamical** nature?

Video of our artistic collaborator: the Sixtrum Percussion Ensemble



Embodied Avatar as a novel tool to study Human coordination

EVA as the perfect testbed to study music joint-tasks:

1. To shrink the gap between **Ecological realism ↔ analytical control**
2. Methodological tool to express the multimodal nature of human synchronization
3. To evaluate computational models of group synchronization in real-time interaction.

Develop an Embodied virtual avatar that can play as a member of a human ensemble

Literature Gaps

Human synchronization is a multimodal, non-linear process, well depicted by a music ensemble. Yet, much of the existing literature on joint musical tasks focus on simplified scenarios:

- Dyad interaction (S. Chakraborty et al. 2021, D. Dotov et al. 2022)
- Modelling Simple Rhythm (e.g. 4:4) (C. L. E. Peper et al. 1995)
- Lack of studies on quantitative measure for group synchrony (M. J. Richardson et al. 2012)

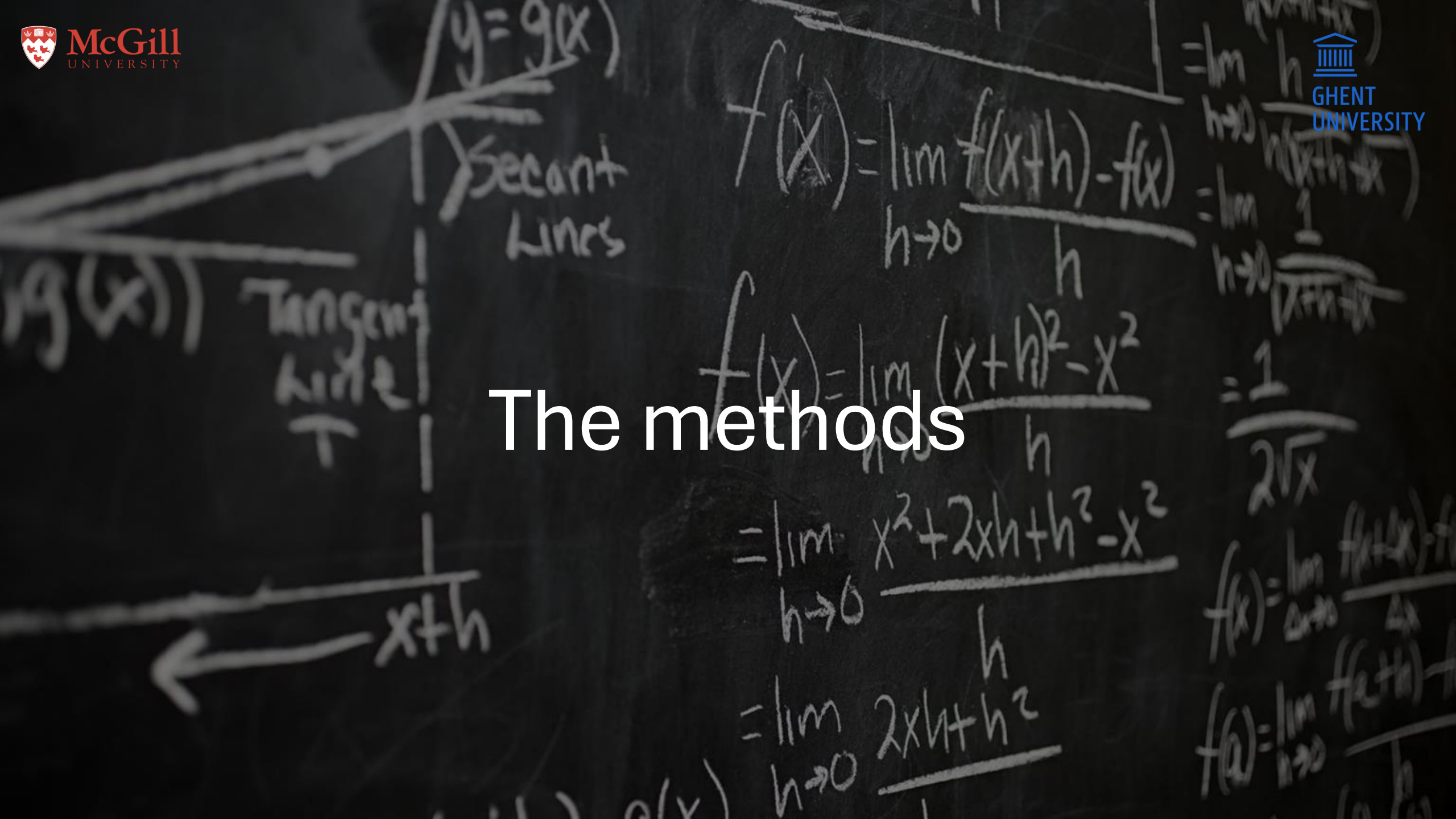


With a Dynamical System Perspective

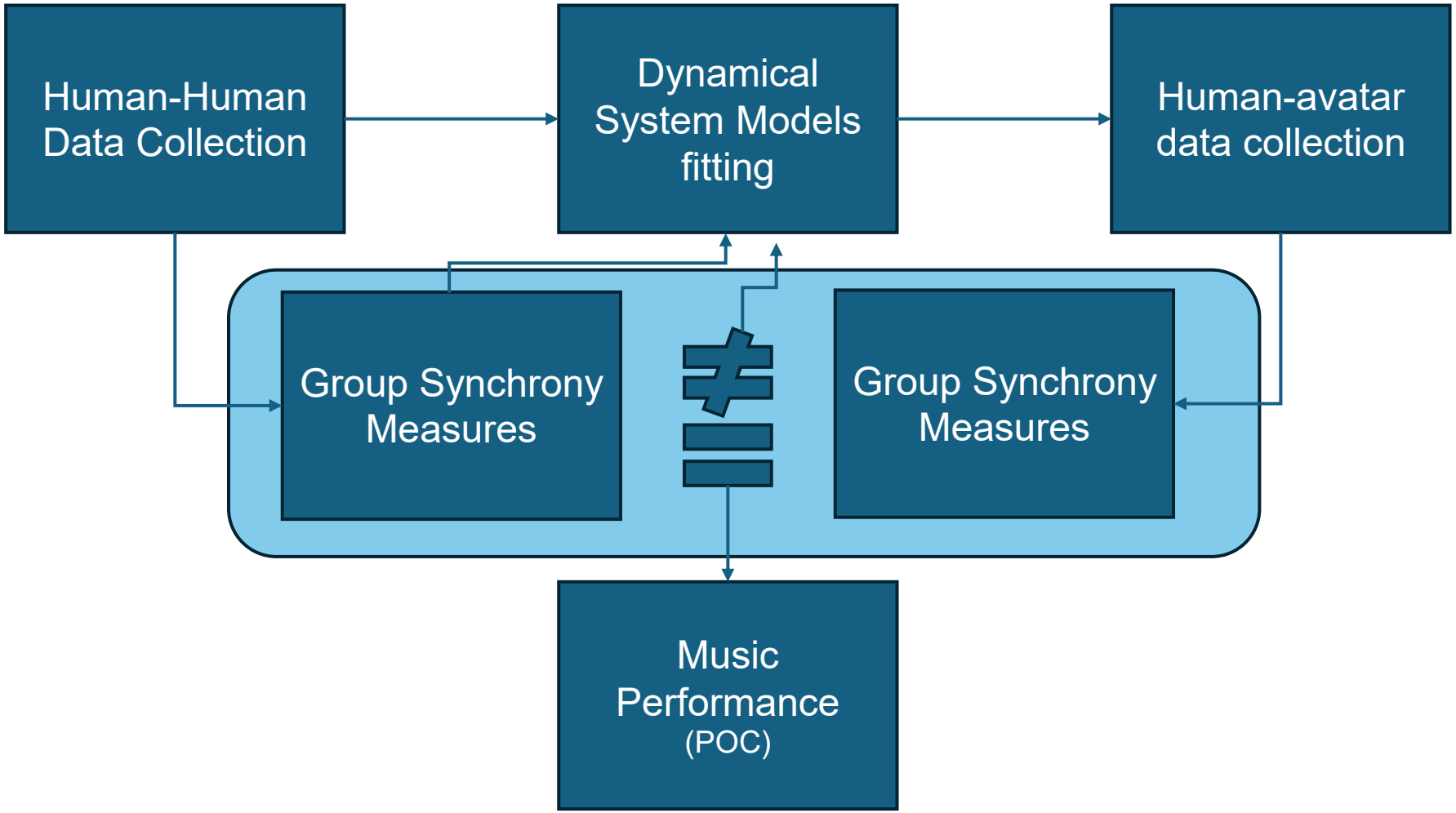
SynchMuse Challenges

Scaling up from:

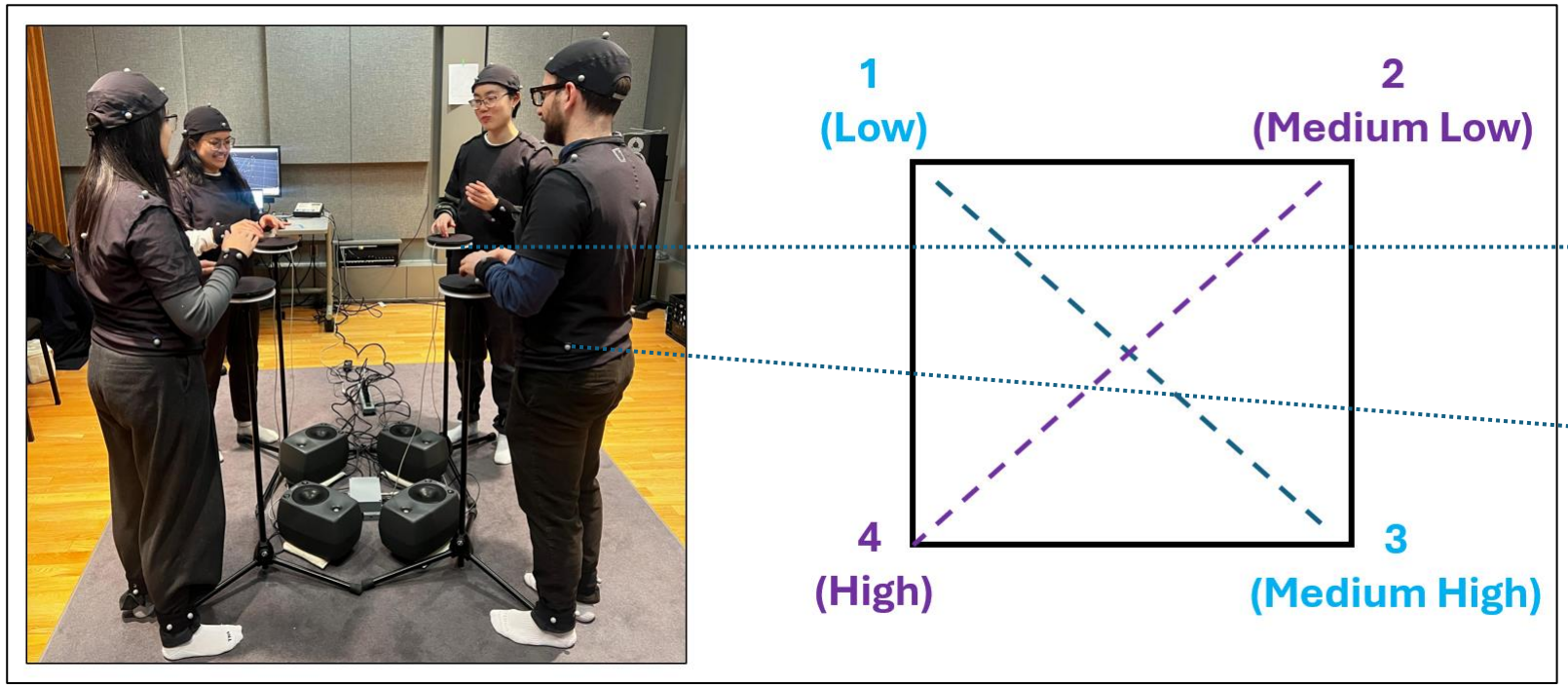
1. Dyad to quartet scenarios
2. Simple to Complex Rhythms
3. from 2D to 3D Embodied Virtual Agent


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The methods

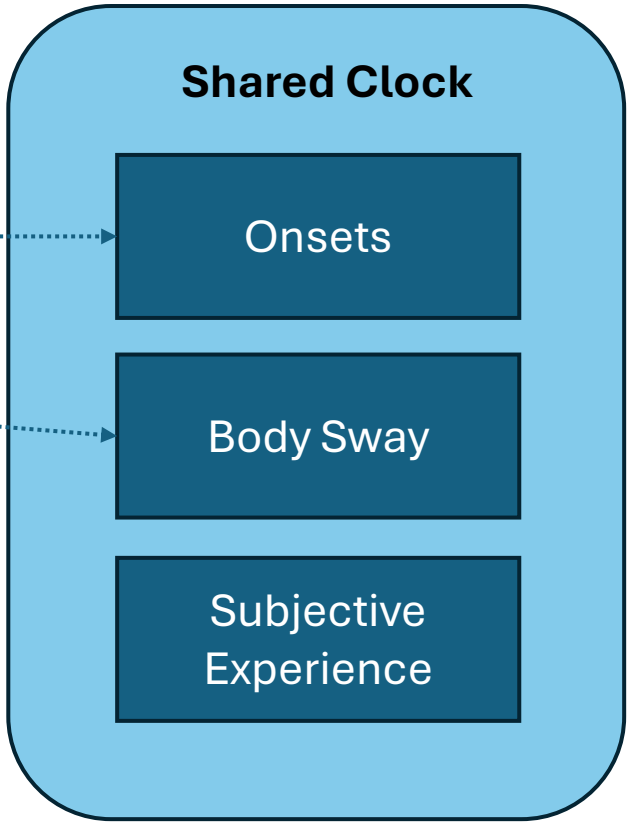
The development Agenda



Experimental paradigm: Multimodal Data Collection



Data collection in Montreal at CIRMMT, McGill University



Aligned multimodal dataset

- Independent Variables: Complex-Simple Rhythmic Tasks
- Perturbation audio cues to induce restabilization
- Cross-site replication with 64 participants (Ghent–Montréal)

The experiment tasks

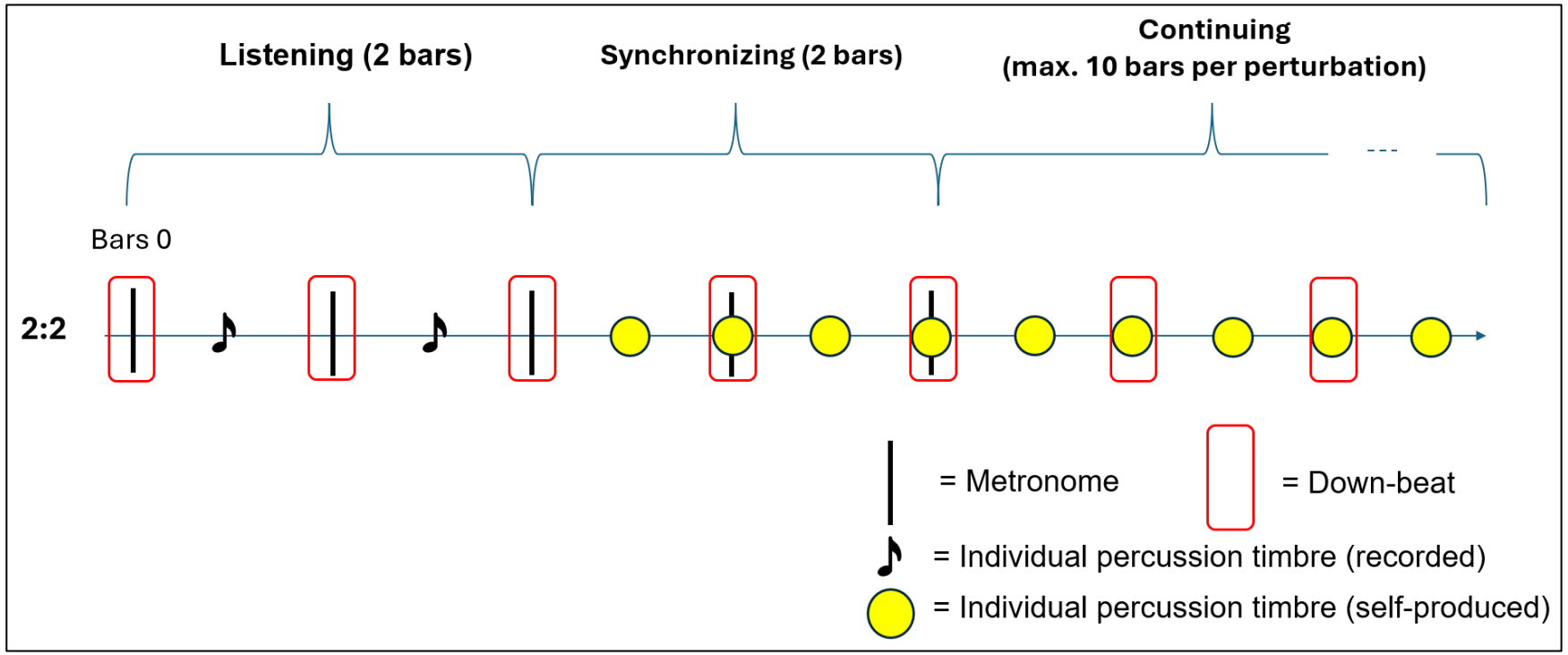
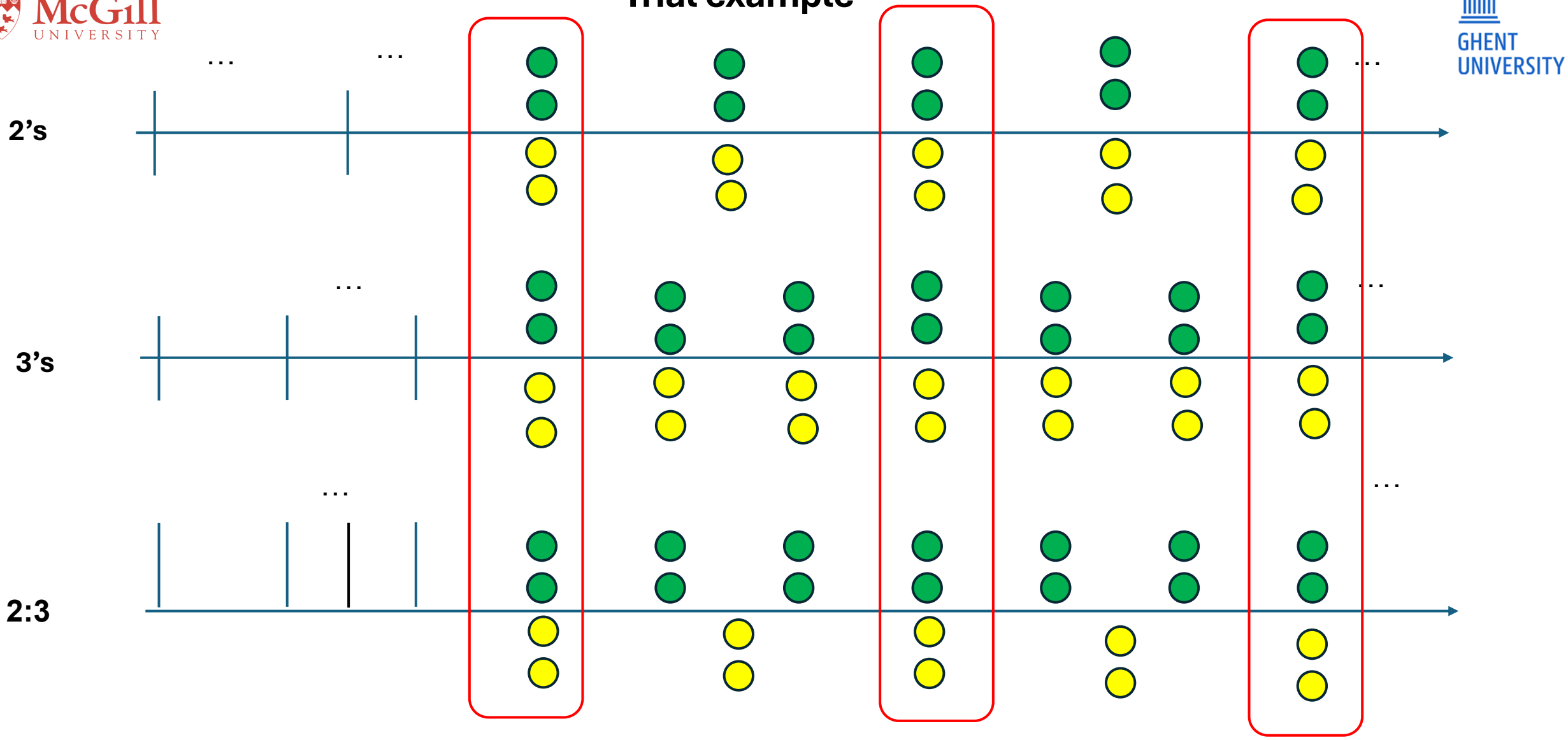


Figure: Example of the first 7 bars of a trial in the Binary Meter and Simple Rhythm condition.

Trial example



Binary: 1 beat = 675 ms
Ternary: 1 beat = 450 ms

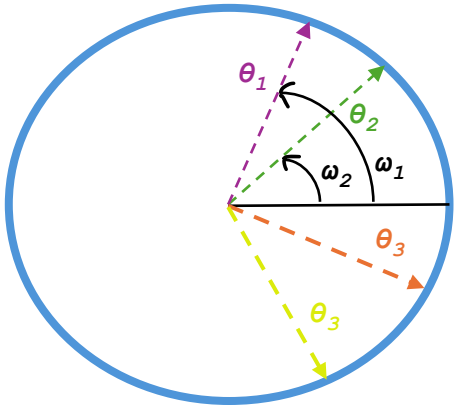
P1 / P2 / P3 / P4 =
Highest pitch to lowest pitch

= A-Dyad (P1/P3)
= B-Dyad (P2/P4)

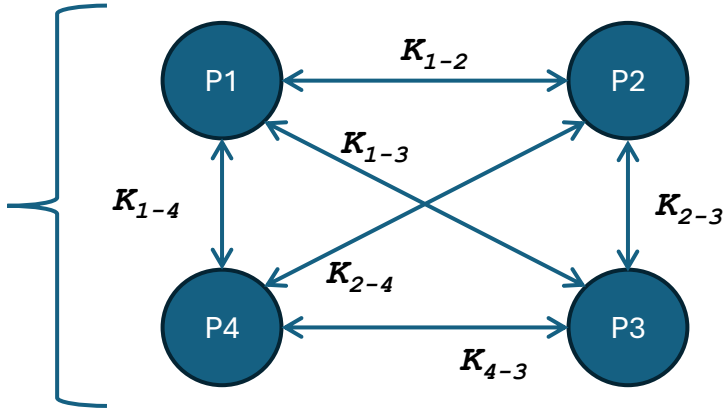
How Dynamical Systems Work

From a dynamical systems perspective, ensemble coordination pattern is described as the **entrainment**: the self-organized alignment of coupled-oscillatory-processes through continuous interaction
(S. H. Strogatz 2003, O. A. Heggli et al. 2019).

Unit Circle



Couplings Matrix



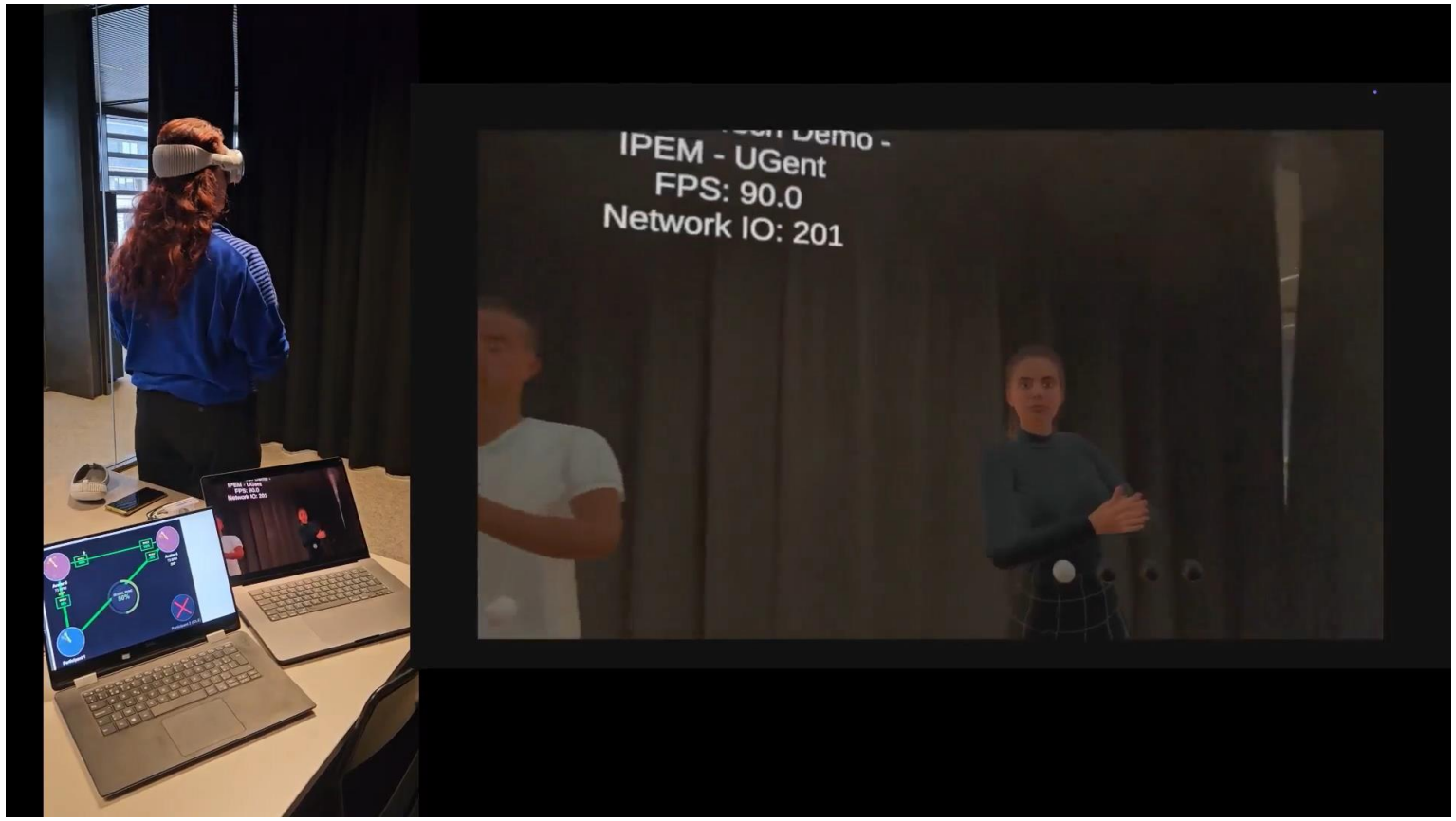
$$d\theta_i/dt = \omega_i + \sum_j K_{ij} \sin(\theta_j - \theta_i)$$

Where:

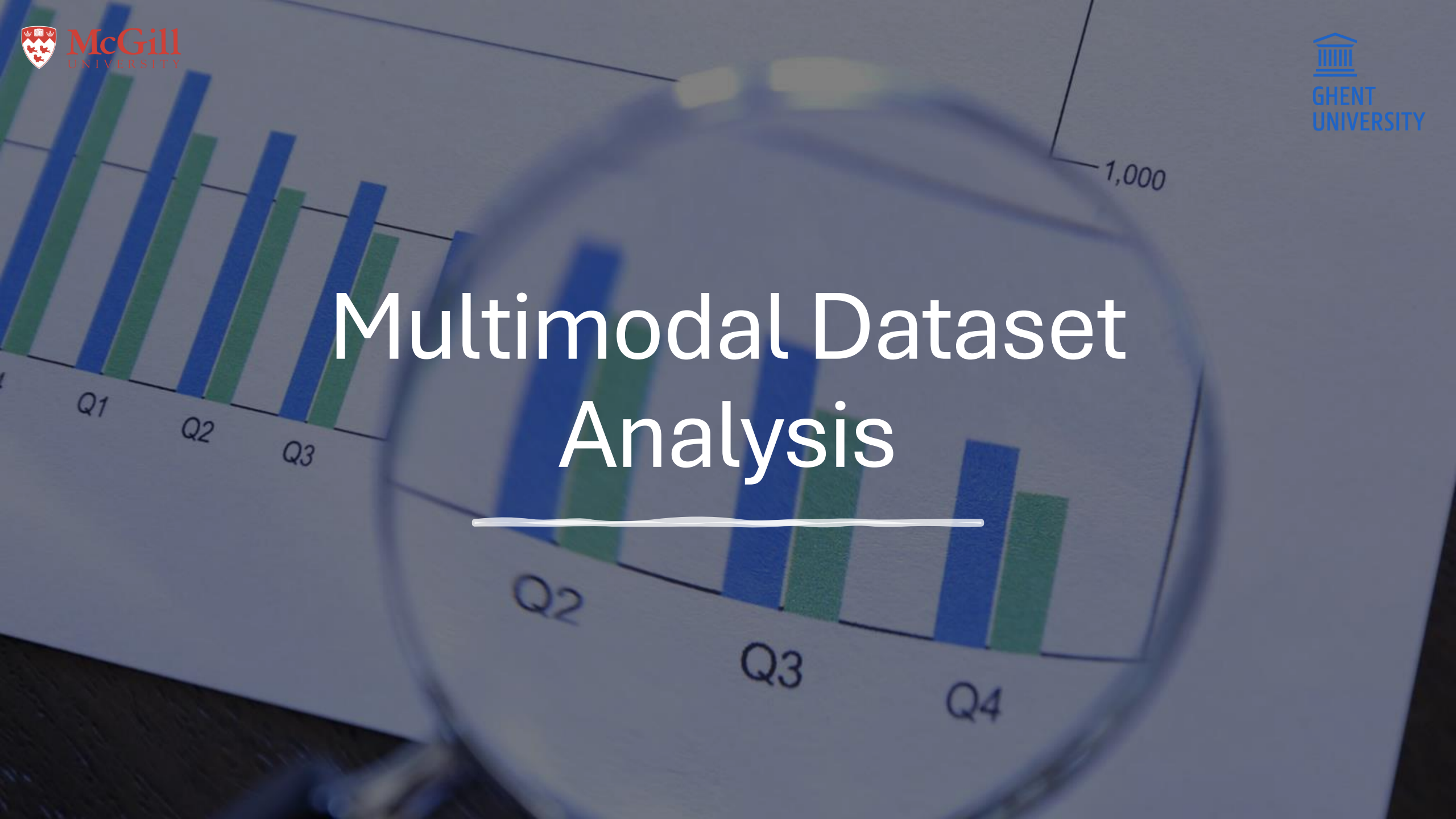
θ_i = Phase of oscillator i (radians)
ω_i = Natural frequency of oscillator i
K_{ij} = Coupling strength: $j \rightarrow i$
$\sin(\theta_j - \theta_i)$ = Phase difference term

Initial Results

Embodied Virtual Agent Development



Interim evaluation of two avatar-prototypes driven by fitted dynamical system



Multimodal Dataset Analysis

Relaxation Time Analysis

Methodological Question: How long does an ensemble need to recover stable coordination after a perturbation?

Result
Recovery time reveals coordination cost: polyrhythms slow down re-stabilization, and meter transitions are asymmetric.

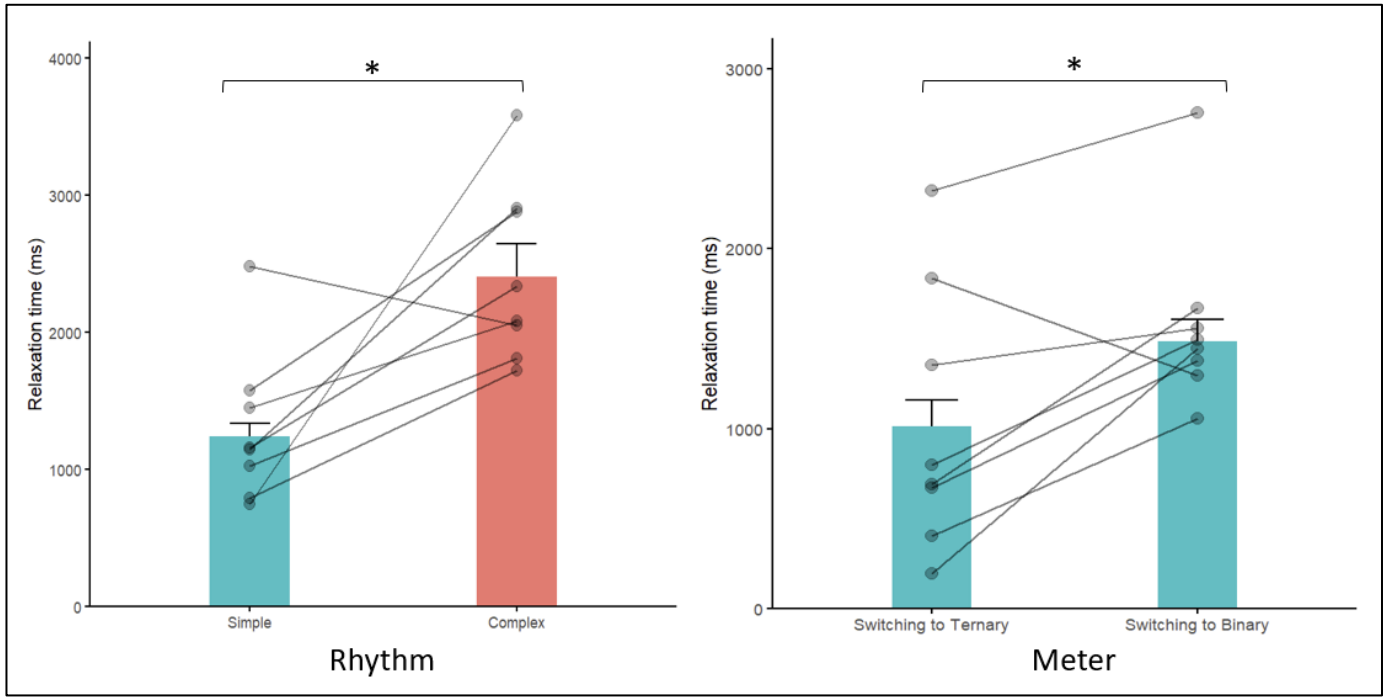


Figure: Relaxation time of eight quartets, defined as the time each quartet takes to find stability again after the perturbation (the second synchronized downbeats)

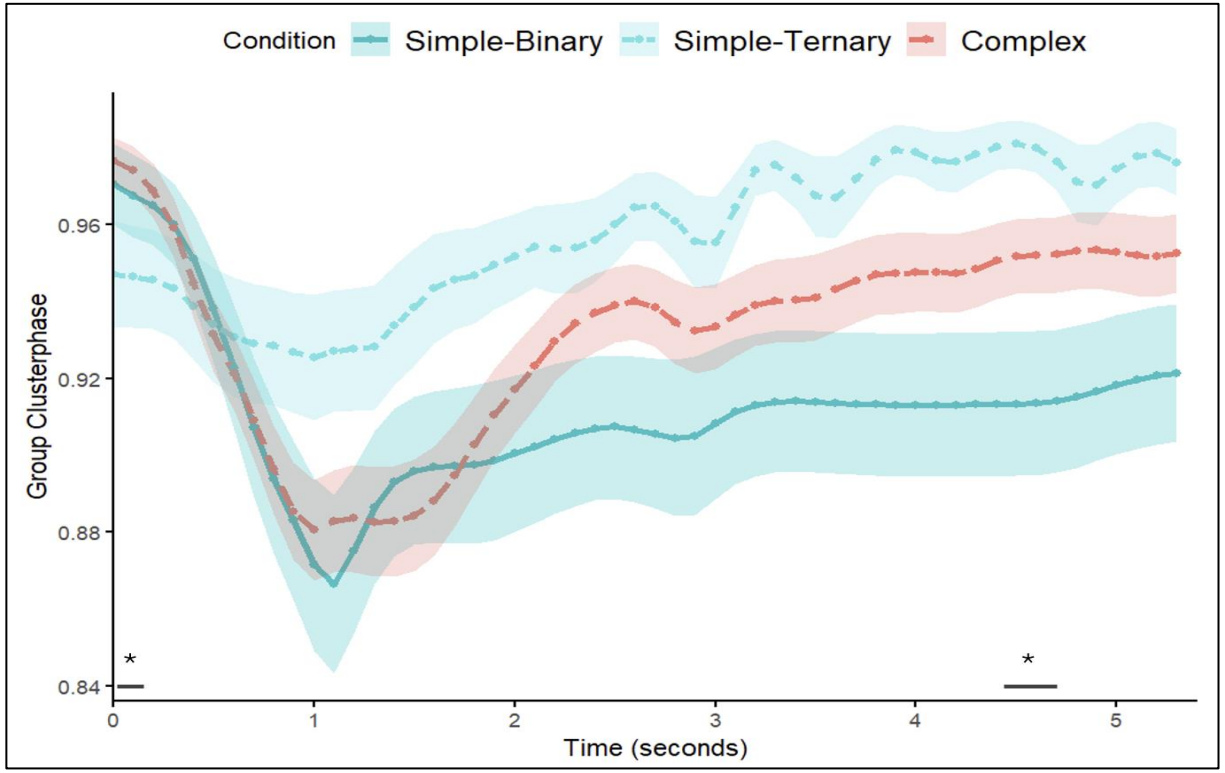
Relaxation time = time to restore the synchrony

Cluster phase Analysis

Methodological Question: How coherent is the ensemble as a collective system over time? Cluster phase reflects the degree to which individual performers' phases are aligned around a common group phase.

Results

1. Collective coherence evolves differently across rhythmic conditions.
2. Polyrhythm condition takes less time to stabilize than switching from a faster to a slower rhythm



Group cluster phase timeseries across the three conditions. Horizontal lines at bottom indicate time intervals showing significant differences ($p < .047$) between conditions.

Inter-Onset-Interval Analysis

Methodological Question: Does coordination reorganize differently depending on how the task changes?

Result: Participants tend to perform better in switching to a rhythm with a faster periodicity

- IOI histograms show **asymmetric adaptation across the two Rhythms**
- **Hysteresis Effect** → *stabilization is context dependent*

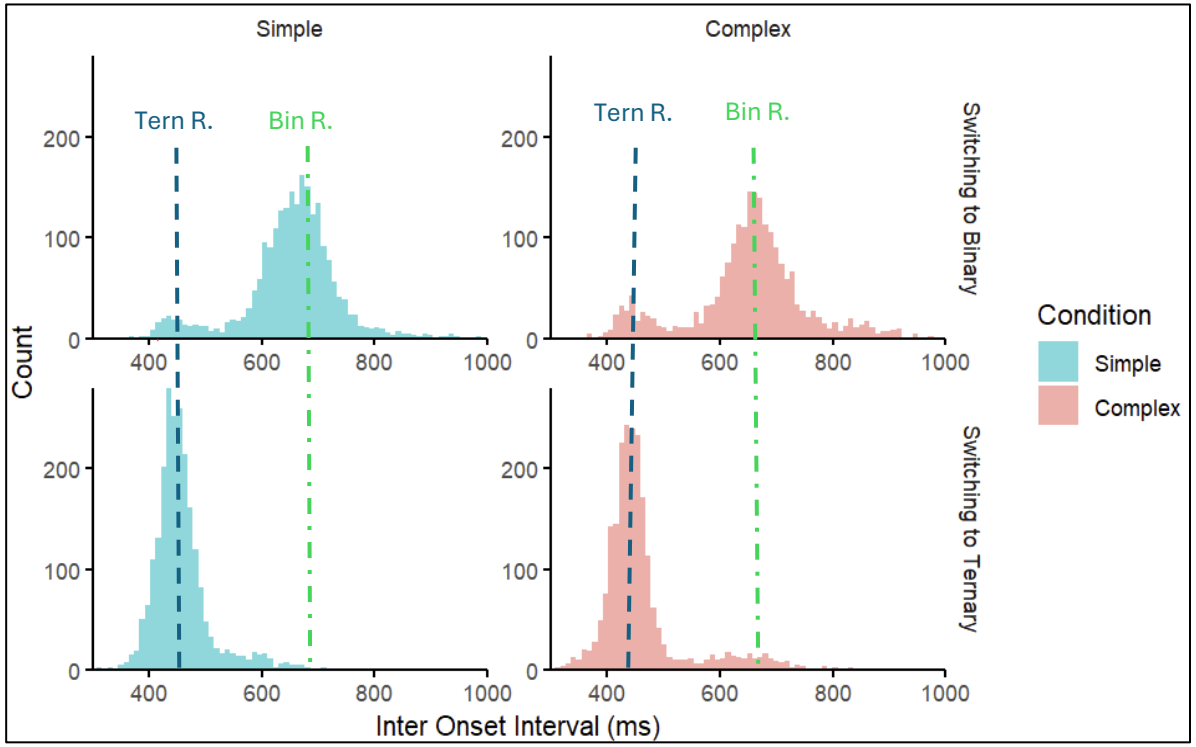


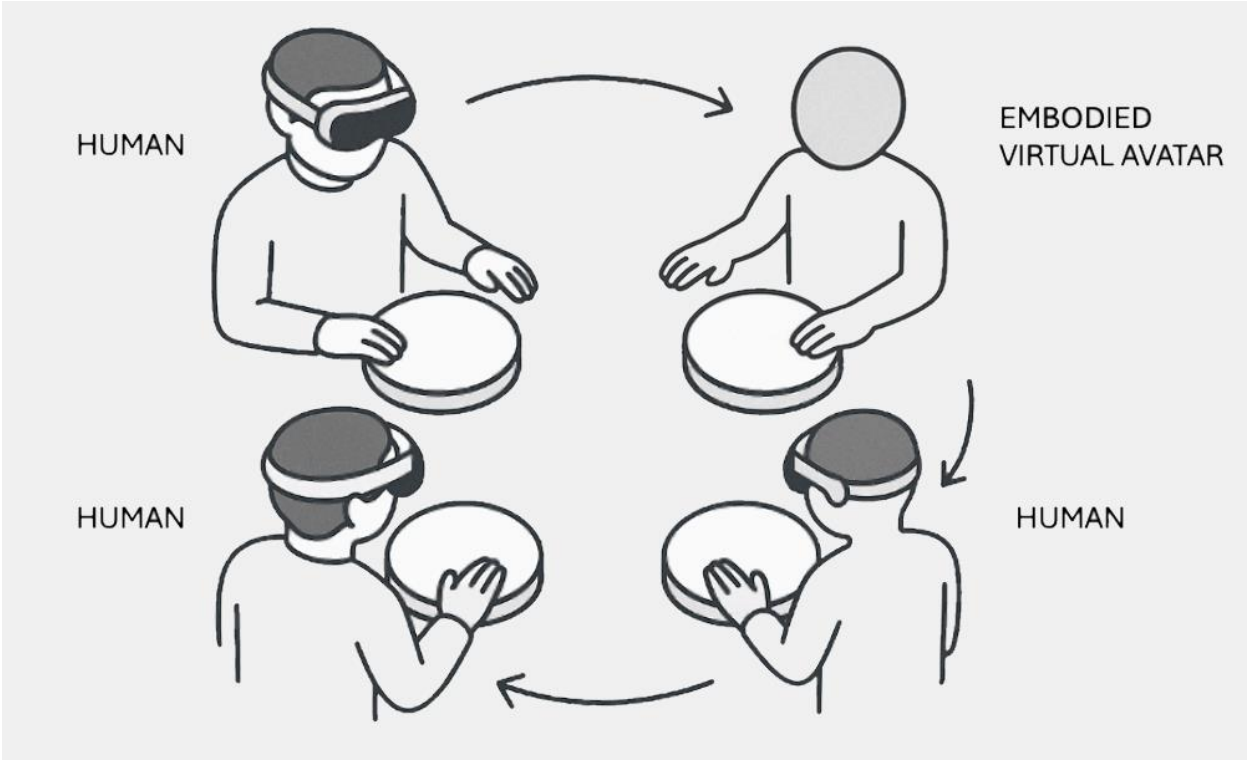
Figure: Histograms of individual inter onset intervals across the Simple (left column) and Complex (right column) Rhythm, and across the Binary (top row) and Ternary (bottom row) Meters.

What next? The H-A experiment

We apply the same systematic experimental paradigm but replacing one ensemble participant with the avatar

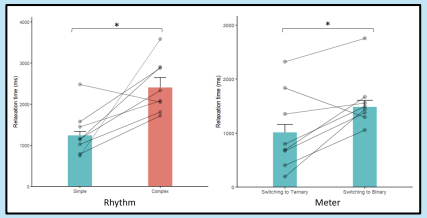
Three fitted Dynamical Systems will drive the EVA:

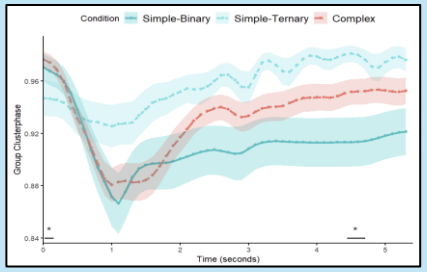
1. Kuramoto
   (O. A. Heggli et al, 2019)
2. Haken-Kelso-Bunz
   E. Tognoli et al., 2020)
3. Time-delay Coupled.
   (A. P. Demos et al., 2019)

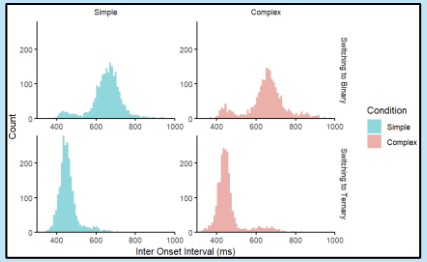


Quantitative Validation

Human-human analysis

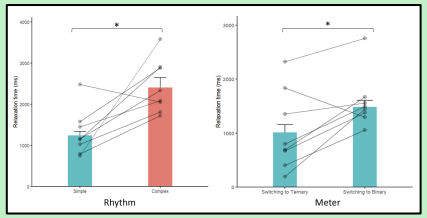


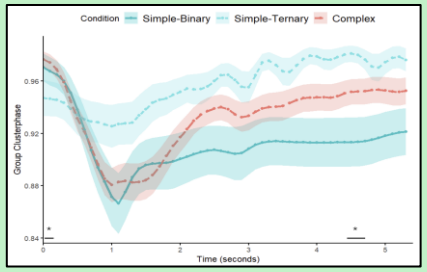


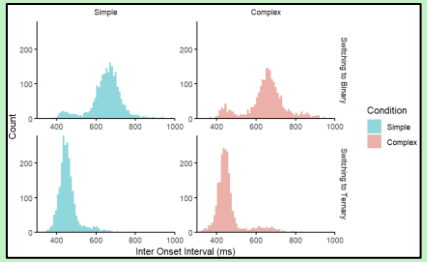


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Human-agent analysis











Two Music Performances

Across Continents

Final ecological validation of the developed paradigm, to inform a roadmap report about the rule of immersive technologies in future creative practices.





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Thank you for your attention

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Special thanks to the PIs: Pieter-Jan Maes, Marcelo Wanderley and Carolina Palmer

