Introduction:

Human posses an unique ability to collectively engage in coordinated activity, often expressed in rituals through dance and music. Music is a naturally social phenomenon (Kirschner & Tomasello, 2009), and numerous researchers noted that music has a significant effect on **social cohesion** and **cooperative behavior** (Cross & Morley, 2008; Dunbar, 1998; Freeman, 2000; Kirschner, 2012). One of the working mechanism facilitating this effect can be rhythm – a basic feature of music – which increases inter-personal coupling through temporal organization of behavior (Brown, 2000). **The question is, however, if this audio-motor integration can be extended on a group level.** The present study aimed at investigating if rhythm itself can contribute to a self-other overlap, thus pointing to an important role of rhythmic entertainment in human inter-personal motor coupling.

Methods and materials

Stimuli:
One hundred subjects (50 males; mean age = 23.8, range = 21 - 29) were recruited as dyads on the basis of same sex (female-female and male-male), same dominant hand and similar height. The stimuli was presented through speakers to two participants sitting in one room. After listening to stimuli they completed the joint task.

Condition/ Parameters	Rhythmic	Arrhythmic	Control (white noise)
BPM	120	120	None
Meter	4\4	None	None
Duration	4 minutes	4 minutes	4 minutes

Task:
The task was to jointly navigate a steel ball through the labyrinth as quickly as possible (from Valdesolo, 2010). The completion times were recorded for five trials to observe development of motor interactions. The task was used as an indicator of inter-personal coupling strength, pointing to possible shared audio-motor representations. We **hypothesized there will be a difference between conditions in decrease between individual trials.** Furthermore, we collected data with ActiGraph Motion Sensors measuring subjects' hand movements.

Results:

Labyrinth times:
The times needed to complete the labyrinth task for each dyad ($N = 50$) were analysed with a mixed-plot two-way ANOVA, in which Condition comprised the between-subject factor, and Trial the repeated-measures factor. There was a significant main effect of a Condition*Trial interaction [$F(8,84) = 2.40$, $P < .05$]. This demonstrated differences between conditions in terms of the predicted linear decreases in completion time [$F(2,44) = 3.26$, $P < .05$]; specifically, the differences in completion time across trials were significant for the arrhythmic [$F(4,44) = 14.02$, $P < .001$] and control conditions [$F(4,44) = 5.60$, $P = .001$], but not for the rhythmic condition [$F(4,44) = 1.97$, $P > .05$]. These results suggest prolonged motor coupling between individuals in rhythmic condition, leading to a slower increase in performance.

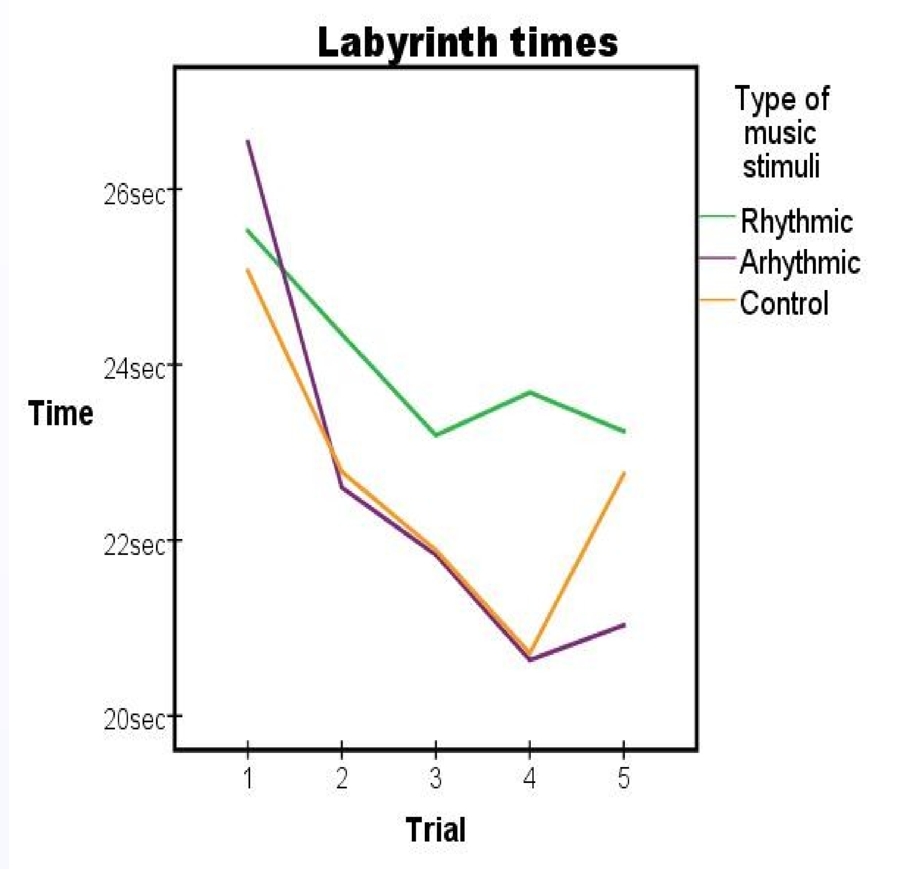

Fig. 1: Difference in linear decreases of completion times for five trials of labyrinth task. Linearity is significant for arrhythmic and control conditions.

Hand movements:
To further address this issue, we analyzed the data from hand movements recorded by ActiGraph Motion Sensors. Interestingly, there was a significant negative correlation of standard deviation of movements and labyrinth completion time ($r = -.51$, $P < .001$). A mixed-plot two-way ANOVA revealed a main effect of Condition*Trial interaction [$F(6,368) = 5.38$ $P < .001$], as well as differences in linear increase of standard deviation [$F(2,185) = 14.4$ $P < .001$]. Again, there was no linear trend in the rhythmic condition, indicating rigid and less variable movements.
Furthermore, we expected the movements to exhibit intermittency, i.e. a fluctuation in dynamics ("on" and "off" states). Specifically, we used cross-recurrence quantification analysis to look for differences in trapping time, which is the mean time of system staying in a specific state ("on" or "off"). A mixed-plot two-way ANOVA showed a main effect of Condition*Trial interaction [$F(8, 366) = 3.4$, $P < .001$] and differences in linear decrease [$F(2,185) = 8.93$ $P < .001$]. The differences in trapping time decrease were significant for the arrhythmic and control conditions, but not for the rhythmic condition.

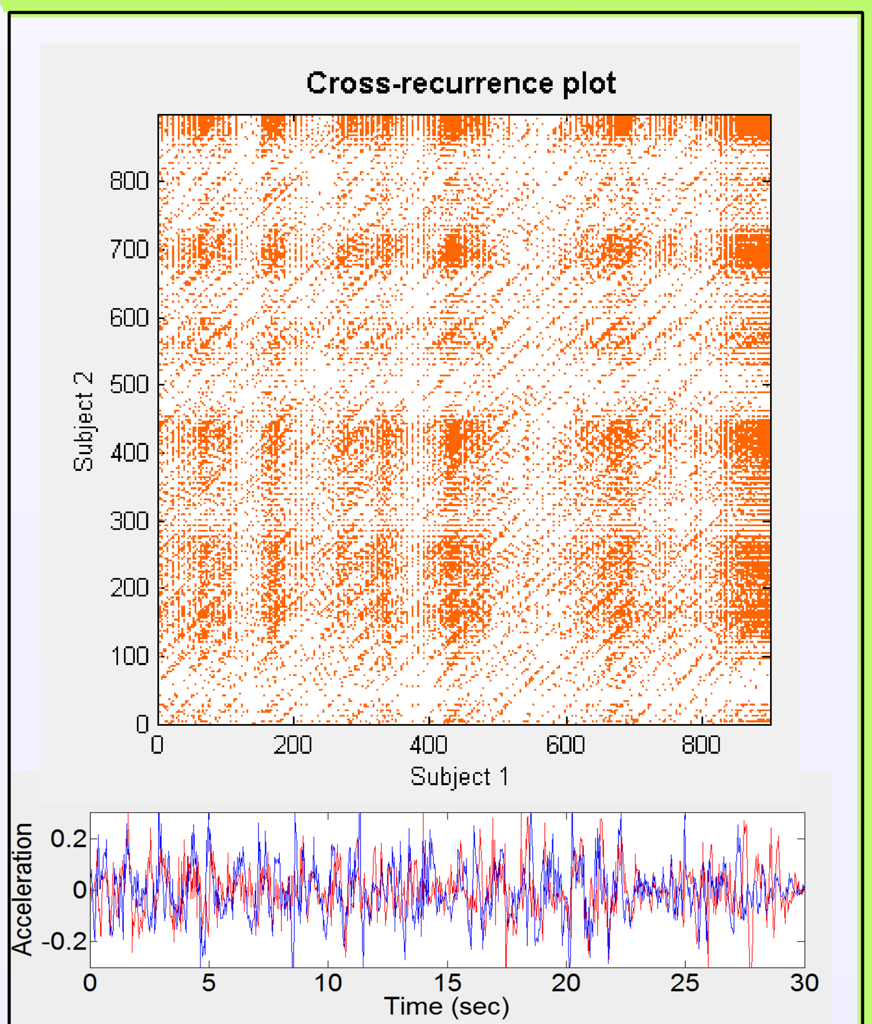

Fig. 2: Cross-recurrence plot with a signal of hand movements of two subjects (m=6, t=8, average RR=2%). Box-like structures signals intermittency.

Conclusion:

The results show a significant effect of rhythm on human motor coupling, expressed in rhythmically unrelated task. More rigid and structured movements in the rhythmic condition indicate common motor coding and synchronized timing ability. Interestingly, this finding can be supported by neuroimaging studies, which show an activation of brain structures responsible for timing and sequencing of movements during passive listening to rhythms (Baumann et al., 2007; Chen et al., 2009; Grahn & Brett, 2007). More importantly, our study shows that the effect of shared rhythmic entertainment persists even after listening to music, thus prolonging the inter-personal coupling. Therefore, we suggest that rhythm can be a powerful facilitator of social units.

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Future directions:

- Rhythm study (lab)
  - Test directly shared motor representations (synchrony)
    - Explore an influence of arrhythmic beat with EEG or fMRI (prediction error)
- Music as a contextual cue (lab&field)
  - Ceremonial music as a prime, associated with specific modes of behaviour
- Synchrony and endorphin release (lab)
  - Measure of pain treshold