Movement Synchronization Fails during Non-Adaptive Human Robot Interaction

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Movement Synchronization…

Human movement synchronization is a fundamental principle for human motor coordination and social interaction.

Humans synchronize e.g.

…their postural sway when talking [1]

…their gait when walking next to each other [2]

…their hand movements also during goal-directed tasks [7]

Social purpose: Movement synchronization …

…enhances perceptual sensitivity among agents [3] which potentially enhances their ability to pursue joint goals.

…creates rapport and altruism among people [4, 5].

→ **Movement synchronization could serve as a key concept to enhance the social competence of robots in human-robot joint action tasks [6].**

Do humans synchronize their hand movements to a non-adaptive robot in goal-directed tasks?

Participants

- 4 male
- 4 female
- Ø 28.8 years

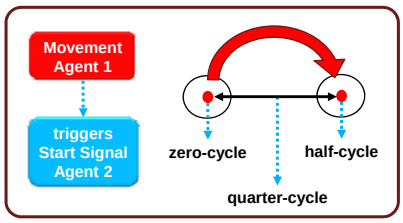
Robot

- Human-size mobile robot [9], [10]
- 2 seven degrees-of-freedom arms [8] with two-finger parallel grippers *(Schunk)*
- Movements between the tapping points: minimum-jerk profiles at **constant frequency (**Ø of observed frequency in [7])

Setup

- Human and robot sit vis-à-vis on a round table and hold a pen in their right hand/ gripper
- LED-markers for real time motion tracking (*PTI-Phoenix*) attached to pens
- Human wears stereo headphones.
- Colored dots mark start and target for each agent

Task & Procedure



Instructions

1. Place pen in start position
2. Start signal (auditory via headphone for the human)
3. Lift pen and tap in the target position
4. Move back and tap the start position

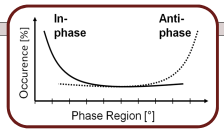
} **= 1 cycle**

→ **To be continued until stop signal was given after 10 cycles**

Conditions: Start delay

- Zero-cycle : both agents start simultaneously
- Quarter-cycle: the 2nd agent starts when the 1st agent passed half the way to the target
- Half-cycle: the 2nd agent starts when the 1st agent reached the target)

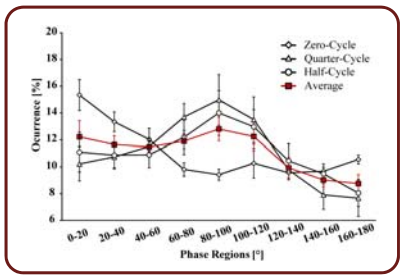
→ **Being 1st agent was counterbalanced throughout the experiment**



Data Analysis

- Instantaneous phase of movement trajectory obtained by Hilbert transform
- Relative phase difference between movement signals per trial
- Occurrence data averaged for each start condition [11, 12]
- 3 x 9 ANOVA on *Start* (ZC, QC, HC) and *Phase region* (0°-180°)

Results & Discussion



1. **Phase region**: $F(8,56) = 3.23$, $p < .01$
   → Lower frequency of occurrence in the regions ranging from 120° to 180°
   → No peak for neither in-phase nor anti-phase synchronization can be found

2. **Phase Region x Start**: $F(16,112) = 3.36$, $p < .001$
   - **ZC:** Peak at 0-20° phase region:
     → Human and robot had to start off at the same time → no delay was triggered
     → Human could move with no phase delay to the robot by maintaining original speed
     → "Trivial" synchronization
   - **QC or HC:** Peak at 80-100° phase region / **neither in-phase nor anti-phase synchronization visible**
     → Human and robot were triggered to start moving with delay
     → Performing at constant velocity without adaptation results in maintaining a phase shift of about 90°

Humans do NOT synchronize their hand movements to a non-adaptive robot in goal-directed tasks!

Summary & Conclusion

Synchronization does not emerge naturally with a non-adaptive robot,

→ whereas it did during the interaction of two humans in a similar task (see [7], [11]).

Open Questions:

→ Does robotic adaptation encourage humans to synchronize during goal-directed tasks, i.e. does synchronization rely on bidirectionality?

→ Do adaptive robotic movements lead to successful human-robot movement synchronization and a subjectively pleasant sense of interaction?

Next step: the synchronization model developed in [11] will be implemented which will allow to investigate bidirectional human-robot synchronization behavior.

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