Movement Synchronization Fails during Non-Adaptive Human-Robot Interaction

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***Abstract*—Interpersonal movement synchronization is a phenomenon that does not only increase the predictability of movements; it also increases rapport among people. In this line, synchronization might enhance human-robot interaction. An experiment is presented which explores to what extend a human synchronizes own movements to a non-adaptive robot during a repetitive tapping task. It is shown that the human does not take over the complete effort of movement adaptation to reach synchronization, which indicates the need for adaptive robots.**

Keywords—Movement synchronization; adaptation; repetitive actions; human-robot interaction;

I. INTRODUCTION

Humans synchronize their movements in many different ways during their daily activities. When talking to each other, they adapt their postural sway [1] and when walking next to each other they synchronize their gait [2]. But synchronization is more. Valdesolo et al. [3] showed that movement synchronization enhances the perceptual sensitivity among agents which potentially enhances their ability to pursue joint goals. Besides that, synchronization also seems to serve a social purpose: it creates rapport and altruism among people [4, 5]. Thus, movement synchronization is a fundamental principle for human motor coordination and social interaction.

Marin et al. [6] suggest that movement synchronization could also serve as a key element for the naturalness of human-like social interactions with robots. However, if synchronization should serve in a meaningful human-robot interaction, further questions have to be investigated. In our previous study [7] we observed that humans not only synchronize purely repetitive movements, they also synchronize when these movements are goal-directed. This is important when for example thinking about joint human-robot pick-and-place tasks.

Another interesting question in this context is, whether movement synchronization is a bidirectional phenomenon, and thus, only occurs if both agents (human and robot) attempt to synchronize or if synchronization is that “important” during repetitive interaction tasks, that the human takes over the complete adaptation effort.

With the study presented in this report we therefore explore the question whether humans synchronize their movements to a non-adaptive robot during a repetitive goal-directed tapping task.

II. METHOD

To explore whether a human would take over the complete adaptation effort in order to synchronize to a non-adaptive robot, we modified the experimental paradigm introduced in [7]. Human and robot were sitting vis-à-vis on a round table holding a pen in their right hand and gripper. LED-markers for motion tracking (*PTI-Phoenix*) were attached to the end of the pens. The human was wearing stereo headphones. On the table, four colored dots were marked which are defined to be start and target for each agent respectively, see Figure 1a. In total, 4 male and 4 female, average age 28.8 years, took part in the experiment.

A. Task and procedure

Both actors’ task was to grasp the pen, and orthogonally place it in the start position on the table. When the start signal was provided (auditory via headphone for the human), the pen was to be lifted and positioned in the target position and back again to the start position. These movement cycles were to be continued until an auditory stop signal was provided. Three start signal delays were introduced and balanced over trials: zero-cycle (ZC, both agents start simultaneously), quarter-cycle (QC, the 2nd agent starts when the 1st agent passed half the way to the target) and half-cycle (HC, the 2nd agent starts when the 1st agent reached the target).

B. Robot

A human-size mobile robot equipped with a pair of seven degrees-of-freedom arms [8] was used for the experiment, see Figure 1b. Details on the robot’s system can be found in [9], [10]. For grasping the pen, the robot's arm is equipped with a two-finger parallel gripper *(Schunk).* At the beginning of the

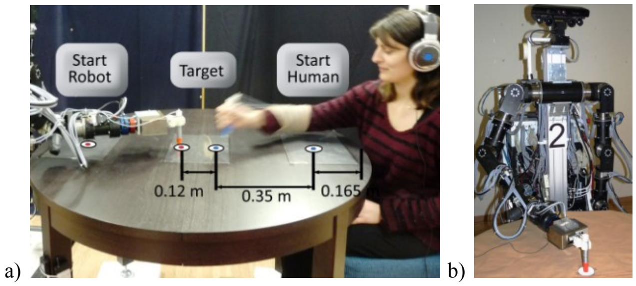

Figure 1. a) Experimental setup; b) Robot.

This work was funded by the German Research Foundation (DFG) as part of the Excellence Cluster “Cognition for Technical Systems” (CoTeSys).

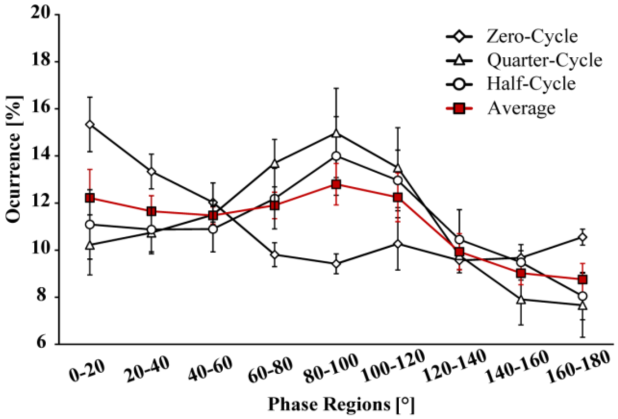

Figure 2. Distribution of relative phase

experiment, the robot grasps the pen once in a predefined rigid grasping position. Using an admittance-type control scheme based on a wrench sensor *(JR3)* in the robot's wrist, compliant behavior of the arm is realized when touching the table in the tapping areas. Movements between the tapping points are generated by minimum-jerk profiles at a constant frequency.

III. RESULTS AND DISCUSSION

In line with [11, 12], the relative phase difference between movement signals was calculated per trial and averaged for each start condition respectively. If in-phase synchronization occurred, a peak for data in the 0-20° region should be found, for anti-phase synchronization in the 160-180° region.

To access whether there was a difference in the phase regions, a 3 x 9 repeated measures ANOVA was performed with the within subject factors *start* (ZC, QC, HC) and *phase region* (0°-180°). A significant main effect was found for phase region, $F(8,56) = 3.23$, $p < .01$, see average curve in Figure 2. Post hoc contrasts show that this difference derives from a lower frequency of occurrence in the regions ranging from 120° to 180°. However, no peak for neither in-phase nor anti-phase synchronization can be found. The interaction also reached significance indicating a difference in the distribution of relative phase after different start delays, $F(16,112) = 3.36$, $p < .001$. Looking at the distribution after ZC delay in Figure 2, a peak at the 0-20° phase region can be observed. However, as human and robot had to start off at the same time in this condition, no delay was triggered and the human could move with no phase delay to the robot just by maintaining the original speed – and without synchronizing to the robot. After starting off with a QC or HC delay, no peak for in-phase or anti-phase synchronization can be observed. Post hoc observations show that the interaction derives from the higher percentage in the phase region 80-100° for the QC condition. During this condition, participants and the robot were triggered to start moving when the respective other was on half his way to the target. Thus, when performing in a constant velocity without adapting to the movements of one another, a phase shift of about 90° seems reasonable.

Summing up it was found, that with a non-adaptive robot, synchronization does not emerge naturally like it would during the interaction of two humans in a similar task (see [7], [11]). This is in line with a suggestion of [6], claiming that if the robot never changes its behavior, this could be uncomfortable and the human would stop adapting his/her behavior. Yet the question remains if robotic adaptation encourages humans to adapt to robotic movements during goal-directed tasks (bidirectonality) and if adaptive robotic movements would lead to successful human-robot movement synchronization and a subjectively pleasant sense of interaction.

IV. CONCLUSION AND OUTLOOK

With the work at hand it was shown that people do not synchronize to a robot in a repetitive, goal-directed task if the robot is non-adaptive. As a next step, an exploration of the appropriate adaptation would be required. The synchronization model presented in [11] has to be implemented onto a robotic platform which will allow to test human-robot synchronization behavior.

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