Handing Over a Cube

Spatial Features of Physical Joint-Action

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Even though joint action is highly developed in humans, not much is known about motor control in physical joint-action tasks. Here we investigated a physical handover task: one subject sequentially passed wooden cubes to another without communicating verbally. Temporal parameters such as reaction time decreased on a trial-to-trial basis, showing that the efficiency of the task is optimized on-line by implicit negotiation between the partners. In contrast, the spatial position of the handover was found to be invariant and trial-independent. Thus, our results suggest that physical joint-action is guided by on-line adaptation and a priori assumptions.

Key words: **joint action; motor control; grasping**

Introduction

One of the remarkable human capabilities is to effectively join their actions to achieve a goal, which would not be possible for an individual. Humans are experts in safe and efficient cooperation. The details of how humans coordinate their cooperation are nowadays very important for the field of robotics. High-level joint action strategies between humans are investigated to integrate them in competitive robot systems.[1] In our studies we focus on repetitive handover tasks between humans. Single arm and hand movements as well as grasping have been studied well,[2] and various mathematical models have been developed.[3] However, studies about physical joint-action are relatively rare.[4,5]

Here we report results on the handover of objects, a basic physical joint-action task. Even though the subjects know the overall task of passing over a fixed number of objects in a common workspace, specific parameters are not known in advance. Such parameters, for example, the timing and the position of the handover, have to be negotiated by the subjects during the experiment. We therefore investigated which parameters are adapted over trials to achieve a maximum in comfort and efficiency.

Methods

We measured hand movements of human subjects during a handover task using the magnetic field–based motion tracking system Polhemus Liberty (sampling rate 120 Hz). The two test subjects sat opposite each other at a table (width 75 cm). During the experiment the hand and body positions were tracked. Six wooden cubes (3 × 3 × 3 cm) were handed over by one subject to the other. The size of the cubes required a precision grip. The cubes were placed in one row on predefined marks at the table.

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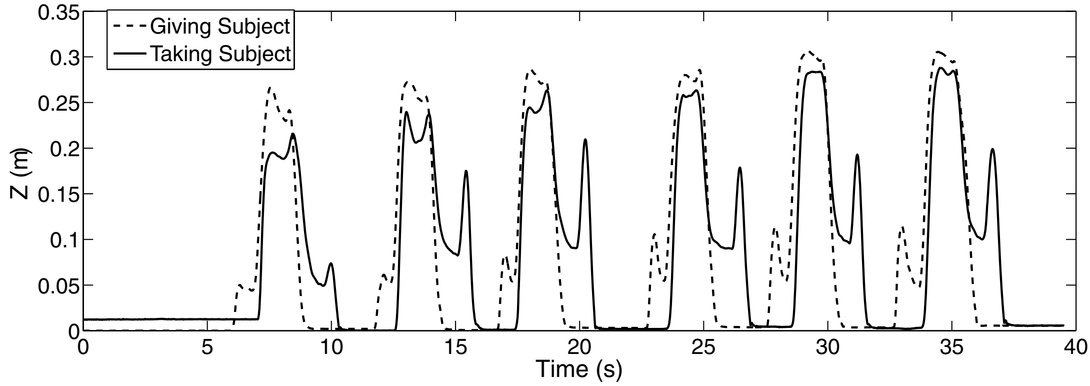

Figure 1. A typical set of data for one pair of subjects. The height of the hands above the table (Z) is shown over time. The giving subject (*dashed line*) first lifted his hand to reach out and grab the first cube (*small peak*), then moved it to the handover position. The taking subject (*solid line*) reacted and started movement toward the handover position while the hand of the giving subject was still in motion. After the transfer of the object, both subjects lowered their hands, and the taking subject's hand shows an additionally short peak corresponding to cube placement on the table.

Sixteen pairs of subjects participated in the experiment. The subjects were instructed to hand over/take the cubes.

Results and Discussion

A typical set of human–human hand positions over time is shown in Figure 1. Due to space limitations, we refer to Ref. 6 for a detailed description of the timing behavior. In the following, we concentrate on the spatial properties of the handover. The spatial layout of the experimental setup and the recorded hand and body positions are depicted in Figure 2 (left). The average handingover position lies close to the middle of the experimental table. The mean is slightly shifted toward the taking subject (mean: X = 0.033 ± 0.072 m; Y = 0.060 ± 0.038 m; Z = 0.225 ± 0.040 m). Analyzing the standard deviation shows that all subjects preferred approximately the same height and the same distance for handover. Repeated measures of ANOVA show significant dependence of the lateral (X) position of the handover on the cube sequence ($F(5,75) = 8.671$; $P = 1.597e{-}06$). The relatively large standard deviation of the X-position thus results from the predefined cube positions in our experiment setup.

Further analysis indicates that humans rely more on the partner's spatial position than on the spatial layout of the experimental setup (e.g., table center). This becomes evident after transformation of the handover positions in a coordinate system, with the point of origin being the midposition between the subjects' bodies (Fig. 2, right). The average handover position is closer to the middle between the subjects than to the middle of the experimental setup (mean: X = 0.022 ± 0.055 m; Y = 0.039 ± 0.035 m; Z = 0.062 ± 0.030 m). The standard deviation of all components is smaller than in the table-centered coordinate system. The smaller variance in the lateral X-direction shows that part of the correlation between cube position and handover position is due to translation of the body. Accordingly, the significance of the dependence between cube position and handover position is reduced ($F(5,75) = 5.335$; $P = .0003$).

The present investigation of physical joint-action is a first attempt to better understand the mechanisms of coordinating sequences of actions between human subjects. We found that temporal and spatial parameters of the

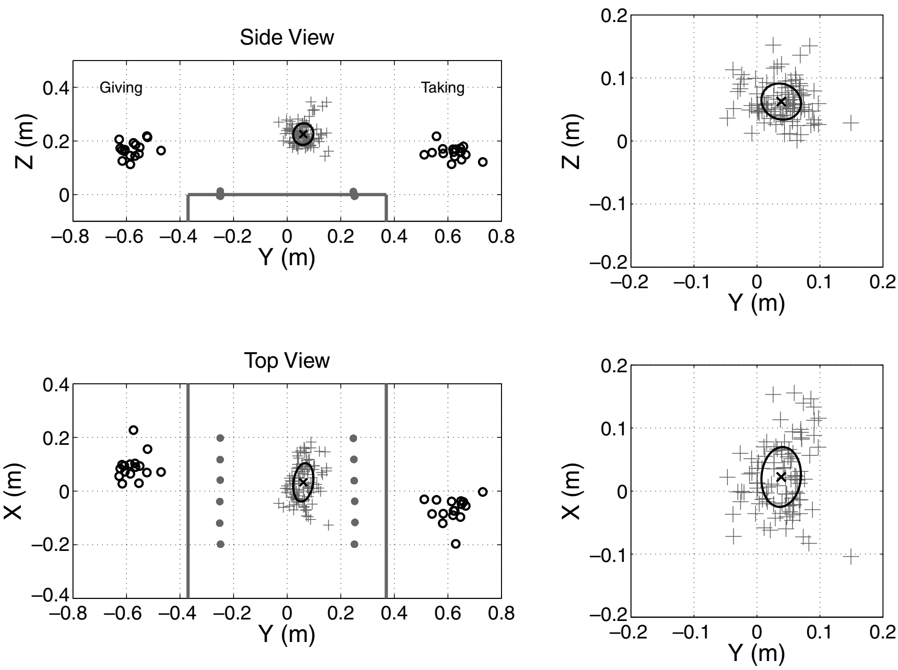

Figure 2. (**Left**) Experimental setup with the cube positions (*filled gray circles*) and the outlines of the table (*gray lines*) in side view (*top*) and top view (*bottom*). The handover positions of all subjects are shown as *gray crosses*. The middle of the subjects' chest is shown as *circles* (left: giving subject; right: taking subject). The mean and the standard deviation of the handover position are shown as *black crosses* and *circles*. (**Right**) The handover positions after transformation to a coordinate system, where the point of origin is the middle between the subjects' chests. Again, mean and the standard deviation of the handover are shown as *crosess* and *circles*.

handover behave differently over repetitions. two kinds of parameters behaving differently. Temporal parameters are slightly adapting to achieve a maximum in efficiency.[6] In contrast, the spatial handover position is trial- and subject-independent, coinciding approximately with the midposition between partners. This suggests that the handover position is predetermined by prior assumptions. However, it depends on the task-specific spatial layout, that is, the initial cube positions and the partner's body position.

Conflicts of Interest

The authors declare no conflicts of interest.

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