The Importance of Feedback for Object Hand-Overs Between Human and Robot

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Abstract. Robot systems will soon be able to hand over objects to humans as well as receive objects from humans in a robust way. From an ergonomics point of view, it is required to evaluate those robot systems and their interactions with humans based on appropriate parameters and design them accordingly. Therefore, we conducted an experiment with human-to-human hand-overs. The aim was to analyze different conditions of hand-overs that occur in our daily life such as different spatial direction, cups with varying filling quantities and varying states of perception of the receiving person. It was shown that cups with a higher filling level lead to a significantly higher duration of the interaction phase than cups with a lower filling level. Additionally, perceptual impairment of the receiver and thereby a lack of feedback led to a higher duration of the interaction phase.

Keywords: Human-robot interaction · Object handover · Classification of phases · Perceptual impairment · Feedback

1 Introduction

Based on the current development in the field of robotics more and more people will make direct contact with robot systems in the next years. The industry has already successfully implemented robots in order to increase productivity and execute dangerous tasks [8]. Out of security reasons, the majority of robots used in industry is working in separate spaces without direct contact with humans. Latest progress in robotic intelligence and technology allows for increasingly safe and reliable interaction between robots and humans [4, 7]. Rehabilitation programs based on robotic support show that robotic systems can benefit patients, nursing staff and relatives. For a variety of people with physical impairments, assisting robots could significantly improve their quality of life. Robots that are able to assist humans both at home and in the working environment in a safe and smooth way, must be able to carry and hand over common objects, such as tools or dishes [4]. Usually, we use a wide variety of subtle and

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unconscious signals to express our intention to hand over something. Posture, hand and arm position, gaze behavior and grip force, as well as their respective change over the course of action are used to code the intention and as well as the when and where [1, 3, 6, 9]. A better understanding of human-human hand-overs leads to well-founded decisions in the development of designing human-robot interaction, which in turn leads to safer and more reliable human-robot interaction [5]. Having the current technical development of robotics in mind, the evaluation and design of robots and their interactions with humans will be more and more important in the near future. From a human factors and ergonomics point of view, appropriate parameters are necessary to do so. To gain a better understanding of how humans hand over objects, an experiment was conducted. During the experiment, objects with varying difficulty, from different directions and with varying states of perception of the receiving person were given from one subject to the other. The goal of the study is to identify phases in the motions of the handover process. Based on qualified motion phases, the effects of different spatial directions, varying difficulties in handing over the objects and distinct perceptual impairments are to be analyzed.

2 Materials and Methods

2.1 Subjects

In this study 20 adults participated which, according to their own statements, were healthy. The participants were between 20 and 32 years old and right-handed (Age: 24, 2 ± 3 years, Height: 176 ± 8 cm; Weight: 74 ± 12 kg). All people participated voluntarily and were explicitly informed about the procedure of the study, possible risks, their rights and the anonymity of the data before the experiment. For this purpose, they signed a statement of agreement. All participants had normal, or corrected-to-normal vision. All participants showed normal anticipation of time and movement (tested with ZBA [2]).

2.2 Experimental Setup

With the intention of studying the influence of the spatial direction on the hand-over movement, the area of recording was shaped like a circle around a chair in the middle as seen in Fig. 1. Six wooden columns were positioned on that circle with cups on top to which reflecting markers were attached. In order to study the implication of varying difficulties in the handover process the cups had different filling quantities. Six cups were not filled at all, six cups were filled with 50% water and another six cups were filled with 90% water. The influence of variety in perceptual impairment on the handover process was studied by having the receiving person wear black painted ski goggles and ear protection (3M Peltor X5A, SNR = 37 dB).

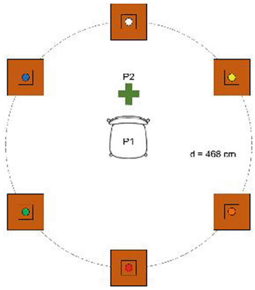

Fig. 1. Experimental setup.

2.3 Experimental Procedure

In the beginning of each recording Subject 1 (P1) is sitting on the chair while Subject 2 (P2) is standing on the green mark behind P1. The order in which the cups had to be picked up and handed over was pseudorandom. In each run, every cup and therefore every possible direction occurred once. All participants had the same order of cups. All 20 participants had to perform 42 handovers divided upon six scenarios from a passing and a receiving perspective, see Fig. 2.

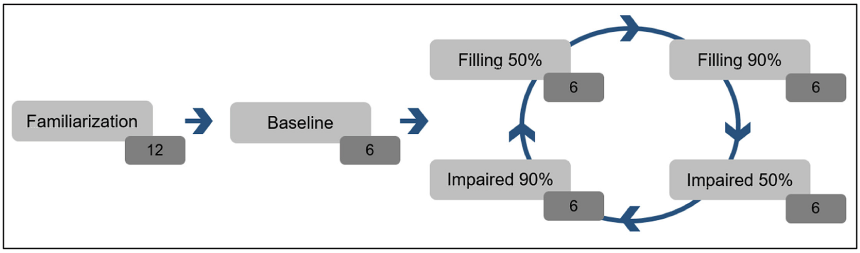

Fig. 2. Experimental design.

2.4 Data Processing and Statistics

The kinematic data were recorded by an optoelectronic system (Vicon Motion Systems; Oxford Metrics Group, Oxford, UK). The passively reflecting markers, which were attached to the participants' skin, recorded the motion using an infrared camera. The accuracy of the 3D position of each marker is calculated with a deviation under 1.0 mm. In the presented work the coordinates of the markers were recorded by 11 infrared cameras. Motion data was recorded and processed with the software Vicon Nexus 1.8.5. further data processing was conducted using the software MATLAB (R2019b) and the statistical calculations were made using the software JASP (Version 0.11.1).

The quantification of the differences between different spatial directions, different percentages of filling and the varying perceptual impairment was accomplished by comparing the duration needed in the phase of interaction during the handover. There, we focused on the three markers of the transferring persons hand, the cup and the receiving persons hand.

A one-way ANOVA with repeated measurement and a two-way ANOVA with repeated measurement was used for calculations because of the experiments repeated measurement design. The results were checked post hoc by a Bonferroni test.

3 Results

For better understanding, the handover process has been split up into different phases based on events. The phases were identified using the markers on the transferring hand, receiving hand and cup. Based on the velocity profiles in Fig. 3 the following phases were determined.

The *getting phase* starts with the initial movement of the transferring person towards the object and ends with the firm grip on the object. The *transport phase* begins with the transferring person's firm grip on the object and ends with the receiving person's firm grip on the object. From the receiving person's firm grip on the object onwards, the whole handover process is in the *interaction phase*, which ends with the transferring person letting go of the object. Therefore, the interaction phase is the period between the start and the end of interaction.

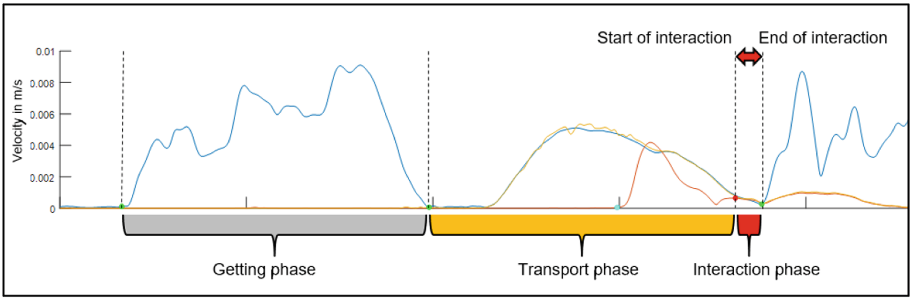

Fig. 3. Classification of phases based on velocity profiles of the transferring hand (blue), the receiving hand (orange) and the cup (yellow).

In the following, the influence of the independent variables spatial direction, percentage of cups' filling and perceptual impairment of the receiver on the interaction phase is going to be analysed. The statistical comparison of the duration of the interaction phase shows no significant differences between the different spatial directions ($F(5) = 1.148$, $p = 0.344$, $\eta^2 = 0.004$). On the other hand, the statistical comparison of the duration of the interaction phase shows significant differences between the different filling conditions of the cup ($F(2) = 129.877$, $p < .001$, $\eta^2 = 0.416$) as well as between the two conditions of perceptual impairment ($F(1) = 77.504$, $p < .001$, $\eta^2 = 0.196$).

Moreover, the statistical comparison of the duration of the interaction phase shows significant interaction effects between the cups' filling and the receiving persons perceptual impairment ($F(2) = 62.600$, $p < .001$, $\eta^2 = 0.100$) (Fig. 4).

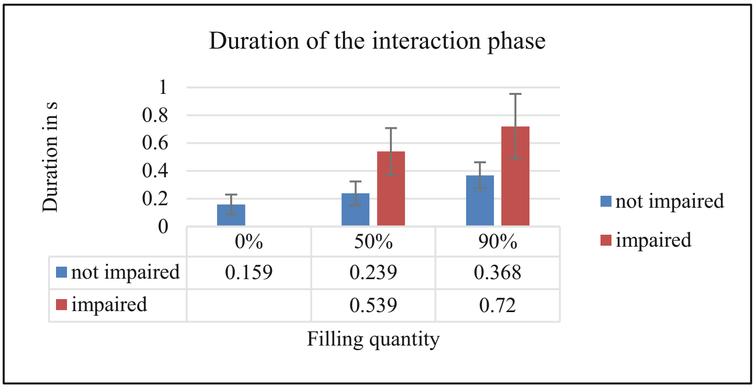

Fig. 4. Differences in duration of the interaction phase depending on cups' filling quantities and perceptual impairment.

In the following calculations, we take a closer look at the differences that appear in the different filling quantities and perceptual impairment of the receiver. In the first section, the different filling quantities without perceptual impairment are compared.

The mean duration of the interaction phase shows no significant difference between the 0% filling (0,159 ± 0,072 s) and the 50% filling condition (0,239 ± 0,085 s) without impairment respectively ($t(19) = -2.733$, $p_{bonf} = 0.120$). On the other hand the mean duration of the interaction phase shows significant difference between the 0% filling (0,159 ± 0,072 s) and the 90% filling condition (0,368 ± 0,095 s) without impairment respectively ($t(19) = -7.113$, $p_{bonf} < .001$). The mean duration of the interaction phase between the 50% filling (0,239 ± 0,085 s) and the 90% filling condition (0,368 ± 0,095 s) without impairment respectively also shows significant difference ($t(19) = -4.380$, $p_{bonf} < .001$).

In the second section, the same filling quantities are compared with and without impairment. The mean duration of the interaction phase shows significant difference between the 50% filling not impaired (0,239 ± 0,085 s) and 50% filling impaired condition (0,539 ± 0,168 s) ($t(19) = 9.520$, $p_{bonf} < .001$). The mean duration of the interaction phase also shows significant difference between the 90% filling not impaired (0,368 ± 0,095 s) and the 90% filling impaired condition (0,72 ± 0,233 s) ($t(19) = 11.162$, $p_{bonf} < .001$). The mean duration of the interaction phase shows significant difference between the 50% filling impaired (0,539 ± 0,168 s) and the 90% filling impaired condition (0,72 ± 0,233 s) ($t(19) = -6.137$, $p_{bonf} < .001$).

4 Discussion

It was shown that cups with a higher filling level lead to a significantly higher duration of the interaction phase than cups with a lower filling level. Additionally, the receivers' perceptual impairment led to higher duration of the interaction phases compared to when the receiver was fully sighted and able to hear. The direction from which the hand-over was conducted did not show a significant influence on the interaction phase.

In this study, 1200 hand-overs were observed. None of these hand-overs completely failed and the participants spilled no water. Therefore, we conclude that the participants tried to execute their hand-overs as safely and as reliably as possible. By increasing the level of water in the cups, the hand-overs became more difficult, due to the higher risk to spill water. To achieve the same safety and reliability of the hand-overs they needed to be performed slower and more carefully.

In the interaction phase of a hand-over, the transferring person as well as the receiving person send and receive feedback about the state of the hand-over. The transferring person will not release the object until he/she receives feedback that the receiving person has a save grasp on the object. By impairing the vision of the receiving person, he/she was neither able to send nor to receive feedback about the state of the hand-over. The receiving person was only able to rely on haptic feedback. This leads to the assumption that the lack of subtle communication of feedback leads to an increase of time in the interaction phase of a hand-over.

Based on these results robots should necessarily be able to send visible feedback about the state of the interaction to prevent the feeling of uncertainty both for the transferring person as well as for the receiving person to implement faster and smoother hand-overs from robot to human and vice versa.

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