Haptics in Between-Person Object Transfer

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Abstract. Although object handover between people is a commonly performed task, little about underlying control mechanisms is known. The present study examined haptic contributions in object handover. On each trial one participant held an object and passed it to the other participant at self-selected, fixed or randomly varied positions. In some trials, the receiver wore a glove to attenuate tactile information. The results showed that the passer's time of grip release relative to contact was later when the transfer location randomly varied or when the receiver wore the glove. On the other hand, forces at contact dropped across trials with negligible effects of glove or transfer location. In conclusion, the present study demonstrated that the dyad reduced redundant forces at contact by forming a stereotypical handover movement in a feedforward manner, while the sensory feedback modulates timing of object handover to avoid premature release of grip by the passer.

Keywords: Joint action, Cooperation, Motor control, Object Manipulation.

1 Introduction

People hand over objects to one another smoothly and effortlessly as part of daily life. Coordinating action with another person is not a trivial task, however. In one-person lifting of an object using precision grip (opposed index finger and thumb), grip force normal to each contact surface allows the development of frictional resistance against the vertical load force tangential to the contact surface. In order to prevent the object from slipping, the product of the grip force and the coefficient of friction between the digits and the object must exceed the load force with a small safety margin [1]. In two-person object transfer, in addition, position and time of handover is not certain, and there is a risk of the receiver dropping the object if the passer releases the object too soon. On the other hand, if the passer hesitates in releasing the grip at the appropriate time, the receiver's grip may slip due to unexpected drag from the passer. Despite such complexities in coordinating action with another, casual observation suggests that people are easily able to hand over an object. How do humans perform an object handover when there is uncertainty in the partner's action? One possibility is that people learn the spatio-temporal cues of object handover to prevent miscommunication

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between the partners. When a person singly manipulates an object, his/her gaze position proceeds the actual action, reflecting unfolding of the motor plan [2]. A study has shown that people also predictively orient their gaze towards the other person's grasping behaviour as though the observer is performing that action by him/herself [3]. Thus, it is plausible that humans learn and predict movement characteristics of their cooperative partner in order to perform object handover.

Thus, the present study investigated the effects of uncertainly about the partner's movement on grip forces during transfer of object possession between a passer and receiver. In this study, participants were asked to pass an object from one to the other while uncertainty in the task was manipulated. In order to examine tactile effects, we reduced tactile sensitivity for the receiver in grasping object, by the receiver wore a glove on the receiving hand. The predictability of the passer's movement was varied by instructing the passer to transfer the object to a fixed location repetitively or to varying locations in a random order. It was hypothesised that partial loss of haptic feedback about the object or increased uncertainty about the partner's movement would result in higher interaction force, higher grip force at contact and increased contact period of the dyad.

2 Method

2.1 Participants

10 right handed participants were recruited at the University of Birmingham. The average age of the participants was 31.4 years (SD = 5.6 years) and five were female. The participants were randomly paired and assigned to the roles of Passer or Receiver for the duration of the task. The Passer was defined as the person who brought the object from a starting location to a transfer location. The Receiver then took the object out of the Passer's hand at this transfer location and placed it on the final location.

2.2 Apparatus

The object was a custom-made 3D printed symmetric plastic structure in which were mounted three 6 DoF force/torque (FT) sensors (see Fig. 1a). The object was 13 cm in length, 6 cm in height and 2.5 cm in width at the ends and its total weight was 150 g. Pairs of participants were asked to use precision grip (thumb pad opposing pads of index and middle fingers) to grasp the sides at each end of the object indicated by a 3 cm x 3 cm square. Two FT sensors (ATI Nano17, USA) mounted under the grip surfaces at each end recorded grip force of each partner. A third FT sensor (ATI Nano43, USA) was placed in the middle of the object to record the interaction force between the two partners. The data from the FT sensors were sampled at 1000 Hz. A 12 camera Oqus motion-tracking system (Qualisys, Sweden) tracked three light-weight spherical markers (3mm in diameter) placed on the object surface at 200 Hz to record the position and orientation of the object. Markers were also placed on the wrist of the Passer and Receiver to track their motions.

Pairs of participants sat facing each other across a table (Figure 1b). The table surface measured 70 cm x 70 cm and on it three lines (midway between the dyad and 10 cm on either side) were drawn each indicating a possible object transfer location. These transfer locations were chosen from a pilot study which revealed that people were likely to pass an object around the midpoint of the workspace with SD of less than 5.0 cm. Thus, the 10 cm shift of a transfer location was expected to be perceptible to both partners. The transfer locations were indexed with the number ascending from the closest to the furthest from the Passer in order to indicate to him/her the transfer location for each trial. There were also two lines used as start and transfer locations for the object 5 cm from either edge of the table.

In each trial, the transfer location was communicated to the Passer via a computer monitor which displayed the location number. The monitor was placed behind the Receiver so as to be only visible to the Passer. The object handover was paced using a metronome which played eight tones at 1 s intervals. The first four tones were for preparation, and on the fifth tone the Passer grasped the object and initiated the transfer. On the sixth tone, the Passer handed the object to the Receiver at a designated location. On the seventh tone, the Receiver placed the object on the final location. The

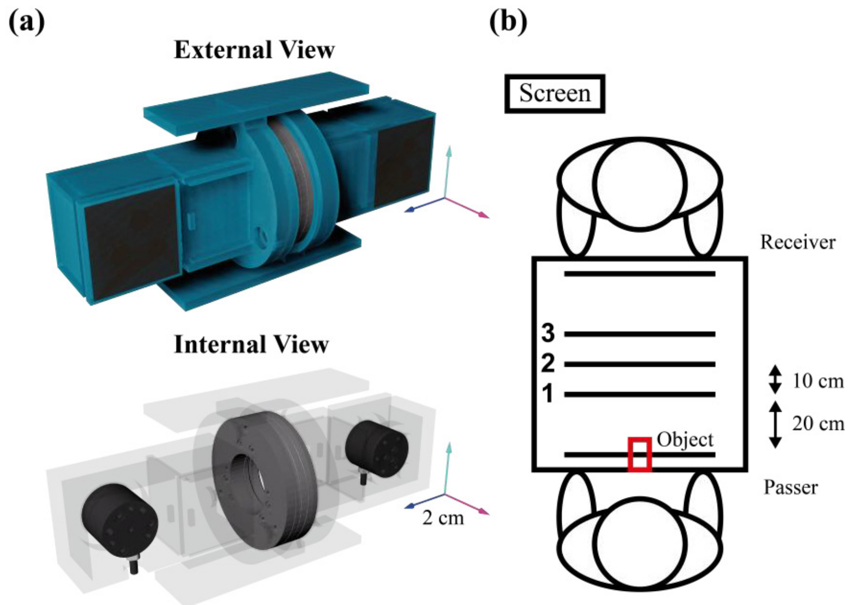

Fig. 1. (a) Drawing of the device. Each participant grasped the object on the square pads at each end. **(b)** Workspace viewed from the above. On a table, there were three lines indicated possible transfer locations with the designated number written next to these lines. A line at each end of the table indicated a starting/final location.

eighth and final tone indicated the end of trial. The metronome was generated using a custom-made program in MATLAB (MathWorks, USA).

2.3 Procedure

Pairs of participants sat on height-adjustable chairs and faced each other across the table. Instructions were given to both partners at the same time, however conversation or other explicit interaction between the partners was discouraged. The participants were instructed to transfer the object from a starting location to a final location in time with a metronome (see Design for detail). To begin each trial, the experimenter placed the test object on the starting location in front of the Passer. The object was centered at the longitudinal axis on the centre of the starting location. At the beginning of each trial, the Passer placed thumb and index finger of the right hand near the grasping surfaces so as to perform a tripod grip (thumb opposing the index and middle fingers) and waited for the metronome tones. The Receiver rested the right hand on the final location. The participants were allowed to practice with a small hollow cube (5 cm x 5 cm x 5 cm) until they felt comfortable with the keeping their movements in time with the metronome. When the participants were ready, a transfer location was displayed on a monitor and the metronome started. At the end of the trial, the experimenter returned the object to the starting location for another trial. The experiment took approximately 1h.

2.4 Design and Analyses

This study was a 2 x 3 within-subject design. The dependent variables comprised the peak interaction force applied on the longitudinal axis of the object during dyad contact (see Fig. 2). The first contact time of the Receiver was detected from the first moment of grip force increase by this person. The release of the grip by the Passer was defined as the first frame at which the force became zero after the contact.

For the analyses, the first factor was Use of Glove (by the Receiver) which was expected to affect his/her haptic sensitivity to the object. The second factor was Transfer location indicated to the Passer. In the first level of this factor, the Passer was instructed to transfer an object repetitively to the same location (Fixed transfer). A dyad performed 10 trials for each of three transfer locations 3 separate blocks of trials. In the second level, the transfer location pseudo-randomly changed between trials so that the total number of location occurrences was the same as for the Fixed transfer but the order of locationss was random (Random transfer). The total of 30 trials in this level was also separated into 3 blocks of 10 trials. In the third level, the participants performed the task naturally without the transfer location being specified (Natural transfer). This condition was run first to prevent any carryover effect from the conditions which instructs the Passer about the specific transfer location. The order of the bare hand and glove conditions was counterbalanced and presented as two separate blocks. The remaining blocks were randomly administered subsequently. In total, a dyad performed 140 trials administered over 14 blocks.

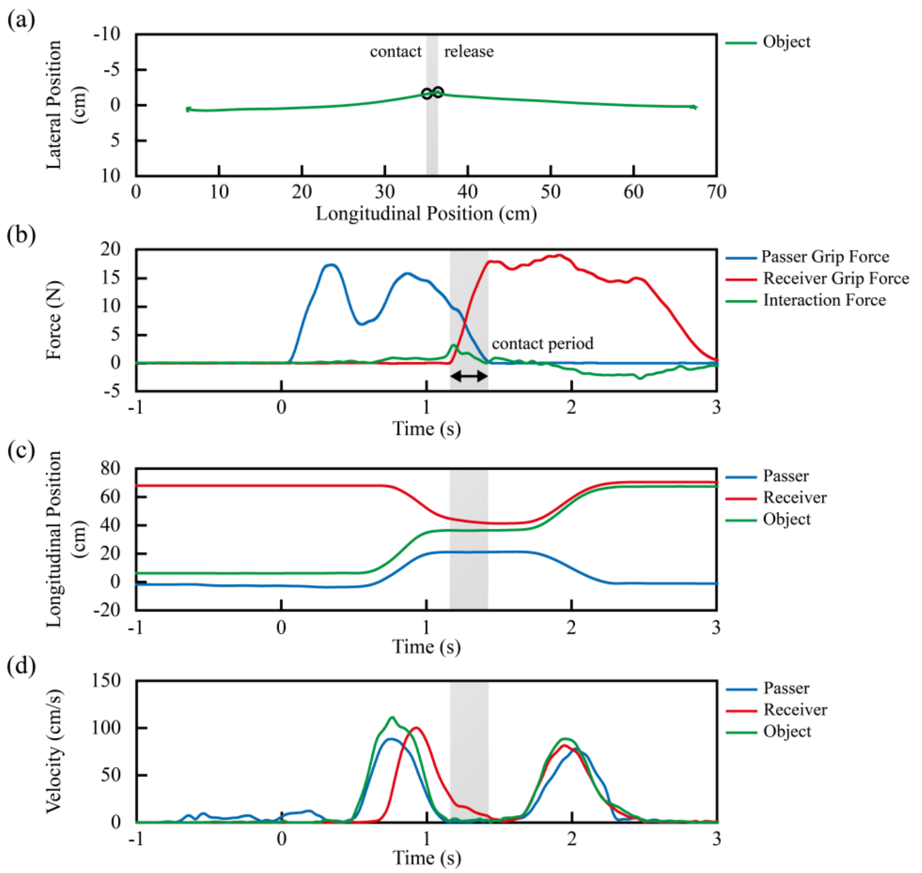

Fig. 2. (a) A single trial example of the workspace as viewed from above. Shaded areas indicate the contact period of the dyad which was defined as the time between the grip force increase by the Receiver and full grip release by the Passer. Values are set to the edge and center of the table for the longitudinal and lateral axis, respectively. **(b)** Grip forces and interaction force profiles over time. Positive force traces indicates compression. **(c-d)** Positions and velocities of the Passer, Receiver and object.

3 Results

3.1 Grip Force Modulation and Release Time of the Passer

Fig. 3 depicts average grip force of the Passer and Receiver at around the time of the initial contact. A start of grip force descent was observed 168.1 ms (SD = 39.3 ms) after the initial contact with the Receiver. During the contact period, the partners maintained the net grip force of 16.6 N (within trial SD = 2.8 N) between the partners.

A difference between the experimental manipulations was found in the variance of the grip force profile (shaded area in Fig. 3). A careful inspection shows that in each condition there is an increase in variability shortly before the grip was fully released by the Passer. This is greatest in the Random transfer and likely reflects variability in the release time of the Passer, given that the standard deviation of the release time was larger with the Random transfer (SD = 198.4 ms) compared to the Fixed transfer (SD = 172.8 ms). Passing an object naturally was found to be least variable (SD = 141.5 ms). Friedman's test indicate a trend in the sizes of standard deviations ($p = .07$). On the other hand, there was no difference in release time variability due to Use of Glove ($p = .66$).

As Fig. 3 shows, there was a strong reciprocal relation between the grip forces of the partners such that the Passer's grip force reduced as the Receiver's increased to complete the object handover during the contact period ($r = -.97$). To understand the efficiency of the grip force modulations between the partners, this negative relationship of grip forces between the Passer and Receiver was evaluated using a simple linear regression. The slope coefficients were then analysed using a repeated-measures ANOVA. The statistical test indicated that there was a main effect for Use of Glove in slope size, $F(1, 4) = 7.43$, $p = .05$. The slope coefficient for with and without Gloves were -1.81 and -1.34, respectively, meaning that the Receiver was more responsive to grip force change of the Passer when he/she was wearing a glove.

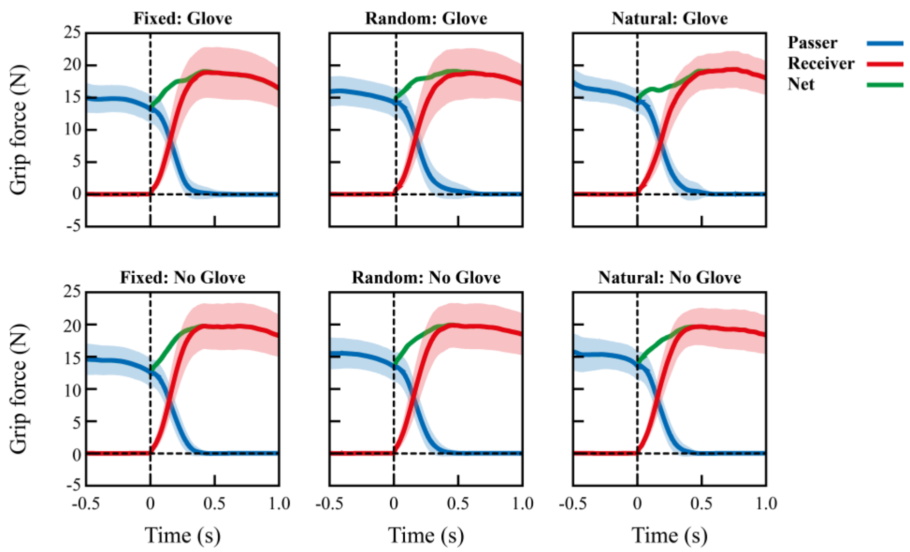

Fig. 3. Average grip force profiles of the Passer and Receiver during contact period. The grip force profiles are time-locked at the moment of a contact with the Receiver (Time = 0 seconds). Shaded areas indicate 1 standard error. The dotted lines are the summed grip force of the Passer and Receiver. Note there is a considerable larger variability before the Passer fully releases the grip when the transfer location was random (middle column) and when the Receiver was wearing a glove (top row).

3.2 Grip Force, Interaction Force and Contact Period

The grip force of passer at the moment of contact by the Receiver was analysed using a 2 x 3 repeated-measures ANOVA with Use of Glove and Transfer location as factors. This indicated that there was a trend towards a main effect ($p = .06$), with grip force during Natural transfer being highest (Fig. 4a). Use of Glove ($p = .17$) and Interaction effects ($p = .88$) were not statistically significant. Given that the Natural transfer was administered first in the experiment, we further investigated the order effect on the strength of the grip force. The total of 140 trials from each dyad was averaged to create 10 epochs of 14 trials each and analysed using one-way ANOVA. The results revealed a reliable practice effect over the course of experiment, $F(9, 36) = 2.71$, $p < .02$, such that the grip force gradually reduced across Epochs (Fig. 4b).

The peak interaction force change due to Transfer location and Use of Glove was analysed using a 2 x 3 repeated-measures ANOVA (see Fig. 4c). The statistical test indicated that there was a main effect of Transfer location, $F(2, 8) = 9.76$, $p < .01$. The interaction force was highest in Natural transfer (1.08 ± 0.26 N), and less during Random transfer (0.78 ± 0.26 N) and Fixed transfer (0.77 ± 0.9 N). A post-hoc test confirmed a difference between Natural and Fixed transfer ($p < .05$). No main effect for Use of Glove ($p = .24$) or interaction effect ($p = .48$) was observed. Similar to the grip

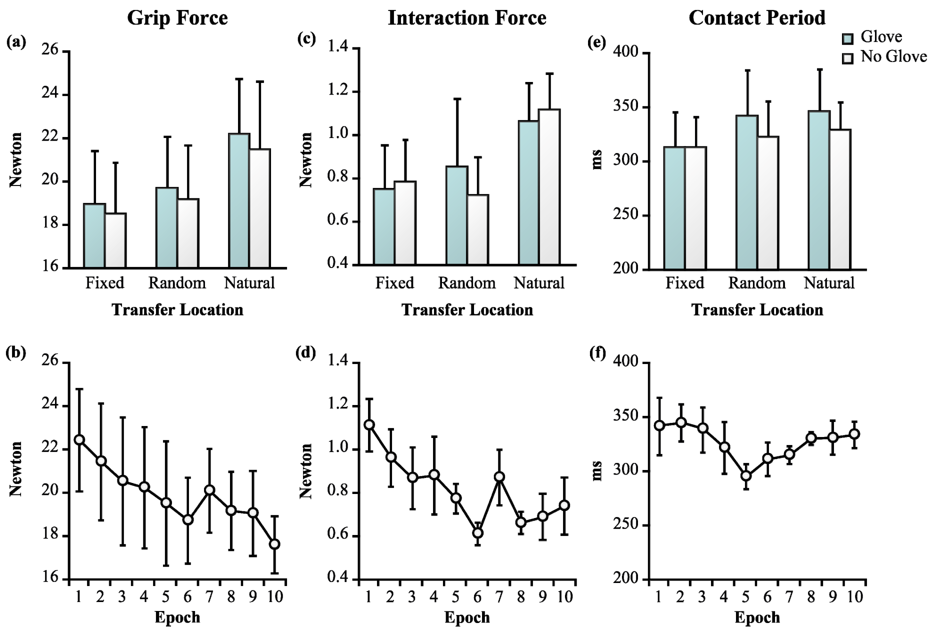

Fig. 4. (a) Grip force of the Passer at the moment of contact with the Receiver. **(b)** Grip force change over the course of the experiment when divided into 10 epochs. **(c)** Peak interaction force during contact period. **(d)** Change of peak interaction over 10 epochs. **(e)** Contact period of the partners. **(f)** Change of contact period over 10 epochs. All error bars indicate one standard error.

force measure, a reduction of the interaction force over the course of experiment was observed, $F(9, 36) = 4.597$, $p < .001$ (Fig. 4d).

Concerning the contact period, on average, the Passer fully released his/her grip 323.1 ms (SD = 24.1 ms) after the initial contact with the Receiver (Fig. 4e). A repeated-measures ANOVA showed that there was no main effect for Transfer location ($p = .52$). On the other hand, there was a main effect for Use of Glove ($p < .05$), such that the contact period was longer when performing the task the gloves (Glove: 334.3 ± 26.3 ms, No Glove: 324.0 ± 22.9 ms). In contrast to the force measures, no reliable change over the course of the experiment was observed ($p = .63$).

4 Discussion

The main objective of this study was to investigate role of tactile feedback and uncertainty about the passer's behavior for object handover. Our results showed a random change in a transfer location and the reduced haptic sensitivity influenced temporal aspects of grip force coordination during the direct contact of the dyad. In addition, we found learning effects on force profiles as their sizes gradually reduced over the time-course of the experiment when the object handover was repeated.

Previously, Mason and MacKenzie [4] studied grip force profiles of an object handover when the movement was initiated by passer or receiver. Their study showed that that the grip force of the passer was relatively insensitive to the experimental conditions. Thus, the contact grip force of the passer was similar whether the passer placed the object on a static receiver's hand or the receiver snatched the object from the static passer's hand. Our results may be seen as consistent with this study, in that neither change in quality of haptic feedback with the use of a glove, nor in transfer locations had a significant effect on the grip force of the passer at contact. However, our cross-trial grip force analysis showed a gradual reduction of the passer's grip force at contact as well as the peak interaction force during contact period over the time-course of the experiment regardless of these changes. These findings indicate that the passer used sensory feedback about the task dynamics to modulate the grip force safety margin in anticipation of collision with the receiver [5].

However, random change in transfer location and reduced haptic feedback due to the use of glove affected temporal aspects of grip force modulation at the end of the contact period of the dyad. One plausible interpretation of the present results is that aspects of initial contact are controlled in a feedforward manner by a passer who forms a stereotypic movement defined by temporal cues about task partner [6]. A larger degree of feedback control by the passer during the contact may have prolonged the contact period when the quality of the haptic feedback was reduced or when the location of handover unpredictably changed.

The detailed analyses of the passer's grip force profile highlighted a noticeable variance around the time when he/she released the grip depending on how the transfer location was specified. In particular, the random specification of transfer location impeded the performance in terms of grip release time variability of the passer, while the natural passing of object was associated with the least variability in release time.

Perhaps, a lack of coordination between the dyad affected the decision of timing at which the passer released the object. We believe that this moment of release is decided based on haptic feedback about the stiffness of the object-receiver linkage. Therefore, we aim to further investigate the force/torque profiles in more detail at the object passing moment to understand the nature of sensory feedback with which a passer perceives he/she can safely release an object in a receiver's hand.

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