Perception of Multimodal Feedback Inconsistency in an Interactive Tracking Task

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Abstract

The presented study estimates the impact of inconsistency in proprioceptive and visual feedback which can be a side effect of interaction in shared virtual environment. An important factor for interaction in virtual reality is the perception of a partner's input as communication, not as disturbance. Therefore, the effects of disturbances correlated with a partner's pre-recorded input are contrasted to several conditions of more or less predictable perturbations. As generalizable scenario a tracking task is used. The root mean square error and the percentage of correct performance in time are analyzed in a multivariate analysis of variance. Results indicate that people adapt to a partner's input in timing patterns even though they ignore the magnitude of the disturbance. This indicates that the perception of Co-Presence is more depending on time factors as well.

Keywords: **Tracking Task, Co-Presence, Interaction, Disturbance, Visual Feedback, Proprioceptive Feedback**

1. Introduction

Questions that arise when humans collaboratively manipulate an object in virtual reality are: How do they perceive a partner? Which strategies do they use for interaction? And how is their performance and sense of Co-Presence (the term Social-Presence is used equivalent here) influenced? As a first step to solve this problem, the current study examines the consequences of interaction with a standardized partner.

Social Presence or Co-Presence is a topic related to collaborative virtual tasks, first defined in [2] as "the salience of the other in a mediated communication and the consequent salience of their interpersonal interactions". Various definitions exist by now. In our approach to quantify interaction, we relate on definitions which emphasize reactions of a partner e.g. Heeter who defines Social Presence as "the extent to which other beings in the world appear to exist and react to us" [3] and Biocca's description of this definition as "the self is defined by the generalized other's reaction to the self" [4].

When two persons collaborate in virtual reality they often share the same visual environment which presents both partners' haptic input to the scene. This becomes even more interesting when the partners are either directly connected or manipulate an object together [5]. In case of a rigid connection between the two participants the individual kinesthetic input and proprioceptive feedback of the scenario corresponds directly to the visual feedback. Nevertheless, if there is no haptic feedback provided [6] or if the connection between the partners is formed by another model (e.g. spring-damper [7]) the kinesthetic input and proprioceptive feedback are no longer consistent with the visual feedback [5, 8]. In a particular example of two people interacting without haptic feedback in a shared visual virtual environment, the following scenario is possible: partner A moves to the left side and partner B to the right - they both gain proprioceptive feedback of a movement but the visual scene would not change correlating or even not change at all.

Feedback discrepancies through visual rearrangements are a well studied issue but refer to static and therefore predictable changes in the perceived environment [9, 10, 11] or pointing tasks [12, 13]. Several studies successfully showed that people tend to integrate the input of the sensory modalities involved in the perception process [14, 15, 16]. This leads to the conclusion that if perturbation affected by feedback discrepancy is constant, integration takes place. It is questionable if results from these studies can be generated to the disturbances that arise from a collaboration task. In virtual collaborative tasks the inconsistence of proprioceptive and visual feedback is time-variant and therefore not as predictable as constant disturbances. Existing theories on feedback in time-variant environments have not taken into consideration the modalities of interest in the present research on interaction [17, 18].

This study aims to further the understanding of the perception of a partner's input in collaborative tasks; a step which seems to be necessary before studying more complex scenarios on Co-Presence. We try to identify fundamental properties of the adaptation to inconsistent proprioceptive and visual feedback due to interaction tasks. We would like to know how performance is influenced by different kinds of disturbances of the congruence of feedback modalities, which is likely to happen in interaction tasks without haptic feedback or with non-rigid haptic feedback. We assume that for high performance, a model of the partner is necessary to predict his or her behavior and the correlated feedback discrepancy. This is closely related to Biocca's statement that a mental model is activated "upon behavior that suggests the presence of another intelligence" [4]. The author adds that within this modeling among others the intentions of a partner can be modeled. Sallnäs as well connects the concept of Social Presence inter alia with the measure "to what extent persons understood the other person's intentions" and "to what extend they felt that the reactions were perceived by other persons" [20].

The presented experiment measures performance in a tracking task, where the cursor is influenced by two inputs. One is the participant's movement and the second either a prerecorded partner or three different control conditions. If the participant is able to adapt to the disturbances in feedback discrepancy caused by the second input to the cursor position, this should result in a higher tracking performance. This would be a first step to correlate performance measures with Co-Presence. As Durlach & Slater point out "the relation of presence to task performance" is "one of the unresolved issues concerning presence" [1]. In the first contrasting condition, the second input to the cursor position is a guiding control condition which is consistent with the tracking path itself. The second one is a constant time delay. The disturbance reflects again the tracking path but with a temporal offset. This represents a constant disturbance which we assume predictable. The third contrasting condition is random perturbation which is not consistent with the path. The comparison of the prerecorded partner as second input to the cursor position with those control conditions clarifies to which extend the input of an interaction partner is predictable for the participants. A simple tracking scenario can serve as a basis for more complex scenarios of virtual collaboration such as medical training tasks, collaborative object manipulation or dancing. A shared trajectory can be seen as a principle component of all these scenarios. A tracking task with a changing path was chosen in contrast to a regular movement task [21, 22].

The remainder of this paper is organized as follows: In Section 2 the hypotheses are presented followed by the method in Section 3. The experimental results are given in Section 4 and discussed in Section 5.

2. Hypotheses

In the experimental setup, the visual feedback was reflected by a cursor position and was influenced by the participants' input to a haptic interface. To identify the consequences of the discrepancy between proprioceptive and visual feedback, the cursor position was additionally defined by four kinds of perturbations: For the first condition, the disturbance was identical to the reference path, i.e. it aided the participant in tracking the path (*control* condition). The second condition consisted of a constant *time delay* in replaying the reference path as second input. This disturbance is therefore resulting in a constant position offset. The third condition included *human input* recorded from an interaction partner and the fourth condition added a *random disturbance* as second input.

Building on the presented theoretical background we analyzed the following hypotheses:

H1: Performance is better in the *control* condition because here the position of the cursor is partly determined by the external input which already follows the reference path.

H2: Performance in the *time delay* condition is increased compared to the *random* disturbance and the *human input* condition due to the invariance of the time delay and inherent predictability.

H3: Even though in the *human input* condition the disturbance is not constant, it is predictable and thus performance is better than in the *random disturbance* condition. The participants can see the next section of the path and might know where the partner has difficulties.

3. Method

We decided to choose a design in which the human input as well as the other perturbations is allocated online instead of a real interaction between two partners to gain a higher standardization of the setup. Of course, in this way the interaction partner is highly dominant, since participants adapt to the programmed partner input but not vice versa. However, to understand the basics of interaction this reduction of influencing factors to the experimental design is reasonable.

Figure 1. Screenshot of tracking task scenario.

To keep the four conditions comparable, the horizontal root mean square (RMS) error was kept in a similar range between 1.8 and 1.9 units[1] across all conditions accept for the

[1] One unit corresponds to 6 mm.

control condition. This was calculated for the total of all trials of each condition. To achieve comparability of the four conditions, the human input was recorded beforehand in order to obtain a reference disturbance for the design of the artificial conditions. We recorded three participants during seven trials of the tracking task and calculated the mean of their discrepancies from the reference paths. The RMS error for this condition was calculated and the other conditions were fitted to a similar amount in this measure.

The adaptation to the RMS error resulted in a constant time delay of 150 ms. The random disturbance condition was constructed by low-pass filtering a uniformly distributed random signal with a cut-off frequency of 1 Hz.

3.1. Participants

13 PhD candidates (3 females, 10 males; aged 25 to 35, mean 26.6 years) participated in the task. Participation was voluntary. All participants had normal or corrected-to-normal vision.

3.2. Procedure

One condition consisted of seven identical trials, where one trial is defined as the passage of the reference path on the screen. The transition from one trial to the next was contiguous, i.e. the participants followed one continuous path per condition. One trial took 36 seconds, so one condition lasted for three minutes and 36 seconds. A trial consisted of three different types of curves: a triangle and two types of parabolas. Each type was given in two different sizes and directed to the right or to the left of the center of the screen.

The four experimental conditions were presented to each participant in random order. First, the participants performed a warm-up-trial under the control condition. Between the four experimental conditions, participants had to perform a short single trial under the control condition. This procedure was introduced to eliminate possible transfer effects from the previous condition.

The only instruction was to follow the tracking path with the cursor using the human system interface. Participants were informed of the dependence of the cursor position on their input and the prerecorded input. Before each condition the type of disturbance was explained.

3.3. Experimental Setup

A thin white tracking path with a maximum overall width of 40 units was presented on the black screen of a monitor. This reference path continuously scrolled down with a constant velocity of 15 mm/s. Participants were instructed to track this line with a 6 mm sized red ball (one internal unit) serving as the cursor. A screenshot of the scenario can be seen in Figure 1. The position of the red ball was not only influenced by the participants' input to the haptic device, but also by the predefined disturbances. As a consequence, the position of the cursor was calculated as the mean of the participant's input and the disturbance signal.

The experiment was performed using a 1 DoF linear actuator equipped with a position encoder (width approx. 500 mm) as human system interface. The setup is shown in Figure 2. A standard PC running Linux and the Real-Time Application Interface (RTAI) processed all data. The sequence control and the tracking of the user's position were implemented via MATLAB/Simulink which generates real-time capable executables. The sampling rate was chosen at 1000 Hz. An admittance control with a virtual mass of 1.5 kg compensated the friction of the device, especially the stick-slip phenomenon. The current positions of the track and the cursor were sent through a local network to a second PC. A 19" TFT monitor (visible area 380 x 305 mm) displayed the scene to the participant. It was positioned 350 mm behind the linear actuator.

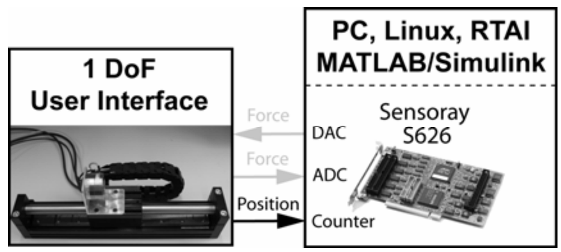

Figure 2. Human system interface for position tracking.

3.4. Data Analysis

The error is defined as the horizontal displacement between the cursor position and the reference path (Figure 3). A difference of 0.5 internal units (3 mm) between the path and the cursor center is tolerated as correct tracking behavior. The cursor position presents the mean of the disturbance input and the participant's input. By calculating the error in dependence of this measure, the amount of displacement in addition to the participant's reaction in this particular position is taken into account.

Trials between conditions and the warm-up-trial are not analyzed.

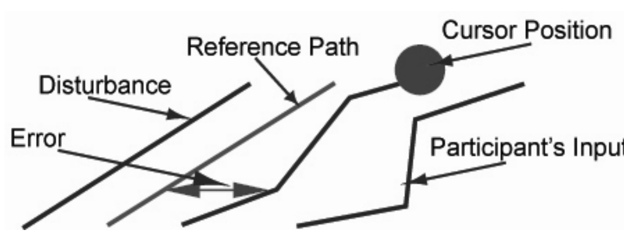

Figure 3. Error calculation: the error is calculated as the horizontal displacement in both directions between the reference path and the cursor position, which derives from the participant's input and the disturbance.

Data analysis includes two measures of participants' error: The first is the ratio of correct time, which is the time the tracking path is followed correctly, divided by the total amount of time per trial (= error ratio). The second is the RMS error of cursor displacement per trial. In this way the results reflect the amount of errors made as well as the percentage of time in which errors occurred.

A 4 x 6 within-subject multivariate analysis of variance (MANOVA) was performed on two dependent variables because it cannot be assumed that the error ratio and RMS error are independent. In addition to the factor "condition" (four levels) the factorial design was extended to the factor "trial number within one condition" (six levels) so possible practice effects are taken into account. The multiple comparisons between the factorial levels are Bonferroni adjusted.

4. Results

Descriptive results for the factor "condition" are illustrated in Figure 4 and 5. Each condition represents the performance of 13 participants in seven trials per condition (N=91). When analyzing the error ratio, participants did best in the control condition and performance decreased in the time delay condition. Worst performance can be found in the human input and the random condition; here participants did better in the human input condition. A similar picture can be found for the analysis of the RMS error except that the difference between the human input and random condition is not as strong.

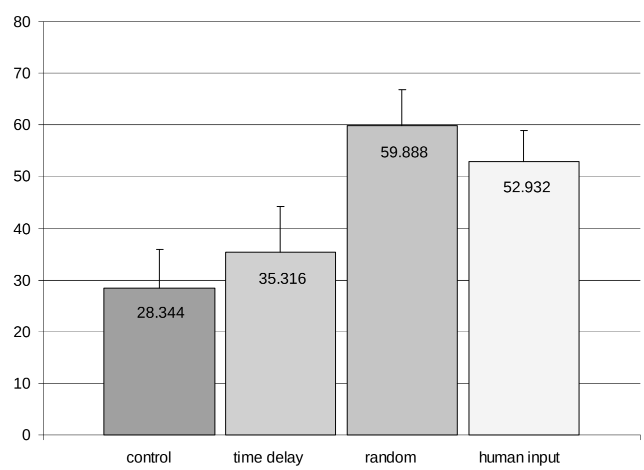

Figure 4. Mean error ratio (error time/total time) and standard error across conditions (in percent).

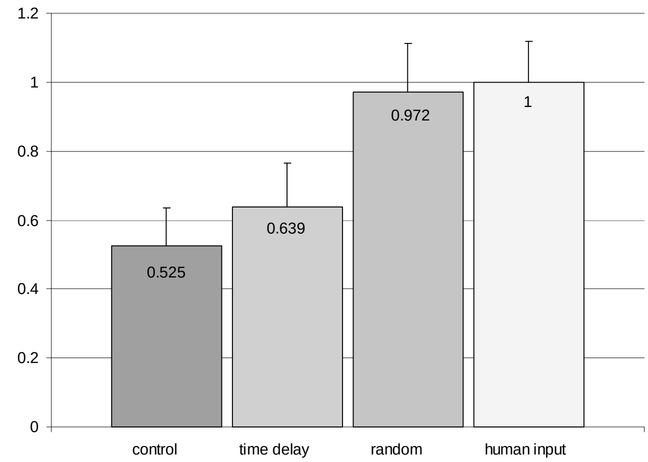

Figure 5. Mean displacement calculated as root mean square error across conditions (in internal units).

The MANOVA leads to the following results: With the use of Wilks' criterion the combined dependent variables are significantly affected by "condition" ($F(6, 70)=133.93$, $p<0.05$, $\eta^2=0.907$) and "trial" ($F(10, 118)=3.22$, $p<0.05$, $\eta^2=0.215$). Interaction reached significance as well ($F(30, 358)=3.68$, $p<0.05$, $\eta^2=0.236$). The univariate test which are all Greenhouse-Geisser corrected are reported in Table 1.

Effect	Error Ratio	Root Mean Square Error
Condition	$F(1.6, 19.6)=296.060$, $p>0.05$, $\eta^2=0.961$	$F(1.8, 21.7)=311.309$, $p>0.05$, $\eta^2=0.963$
Trial	$F(3.3, 39.3)=5.288$, $p>0.05$, $\eta^2=0.306$	$F(2.7, 32.3)=5.585$, $p>0.05$, $\eta^2=0.318$
Interaction	$F(7.4, 89.3)=2.711$, $p>0.05$, $\eta^2=.184$	$F(6.1, 73.2)=5.484$, $p>0.05$, $\eta^2=.314$

Table 1. Results from univariate analysis of variance for the two factors and their interaction.

Each pairwise comparison in the condition factor reaches significance with one exception: a difference between human input and random error measured with the RMS error cannot be shown.

The factor condition explains nearly all variance in the dependent variables. Still, there is a slight linear trend across trials, which indicates some adaptation to the condition. The interaction reaches significance but does not explain a lot of variance. Interaction is caused by a stronger linear trend in the human input than in the other conditions whereas in the random condition there is no trend. The fact that pairwise comparisons in the "trial" factor did not reach significance, except for a few exceptions, even more supports the emphasis on the condition influence on the dependent variables.

To shed light on the processes during task performance, Figure 6 to 9 illustrate the behavior under the four conditions of an exemplary participant. It can be seen how a participant corrects disturbances by shifting her input to the opposite side of the reference path.

The factor “condition” has a significant effect on the performance in both measures. The pairwise comparison between the random condition and the human input condition does not gain significance in the RMS error but in the error ratio. This leads to the conclusion that people make fewer errors under the human input condition but when they do, errors are of equal magnitude as under the random condition.

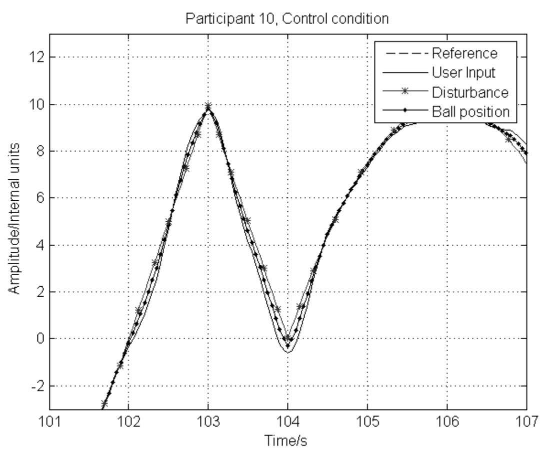

Figure 6. Adaptation to disturbance under control condition.

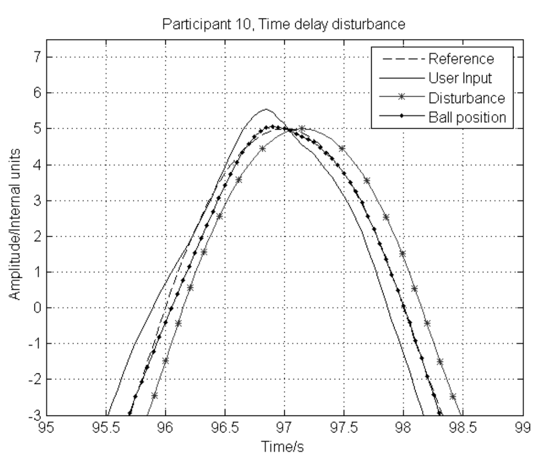

Figure 7. Adaptation to disturbance under the time-delay condition.

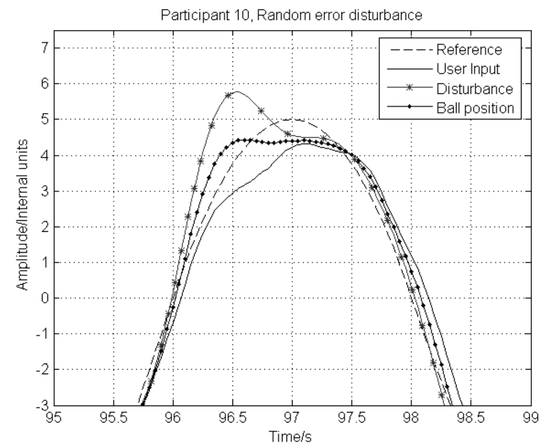

Figure 8. Adaptation to disturbance under random condition.

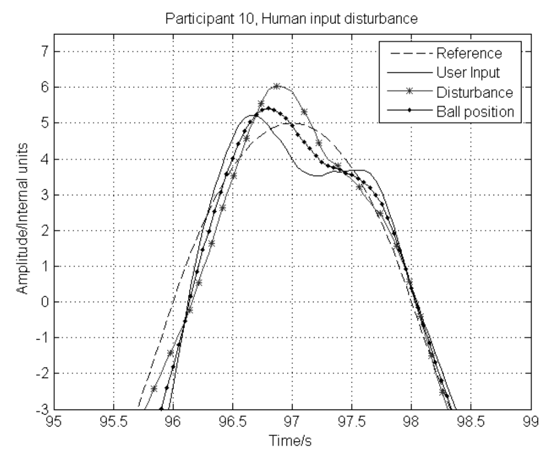

Figure 9. Adaptation to disturbance under human input condition.

5. Conclusion

One reason why most pairwise comparisons in the trial factor did not reach significance could be that other studies included repetitions over days in their research on adaptation [23, 24]. The question whether performance increases even more in the human input condition when the partners work together for a larger period of time will be part of a different study.

The fact that participants are capable of following the track is illustrated in Figure 6. It shows the performance related to the control condition and can be seen in comparison to the other conditions in terms of the error ratio as well as the RMS error. If disturbance is constant, the participants’ input is also constantly shifted in opposition to the disturbance as pointed out in the results of the time delay condition. This leads to the assumption that the irregular shifts in the other two conditions (random and human input) are produced as a response to the nature of the disturbing signal. Therefore, irregular shifts do not result from the challenge of the actual tracking task.

Results support the Hypotheses **H1**, **H2** and **H3** under the given circumstances: Participants seemed to be able to adapt to the human input better than to the random one in terms of the performance measured by the error ratio which represents timing patterns in interaction. As supposed in hypothesis **H3** this can be due to the fact that the human input is more predictable than the random one even though this prediction is not comparable to the one of a constant displacement as in the time delay condition. This predictability can be explained by the participants' ability to estimate where their dominant partner (presented by the human input condition) will have trouble in following the path. Another possible explanation is that future actions of the partner are somehow communicated in advance by the inconsistent feedback. Regardless of the cause of the predictability, the magnitude of the displacement of the upcoming disturbance cannot be estimated since the performance in terms of the RMS error is equal in the two conditions. Whether this modeling of the partner is a conscious process cannot be answered by this study. One could deduce that Co-Presence is more affected by asynchronous communication of signals between the two involved persons than by wrongly transmitted signal amplitude.

IJsselsteijn supports the idea that "the reactions of other actors […] to the user's presence […] provide an acknowledgement to the user […] of her existence in virtual space" [25]. After analyzing the perception of the user's influence on the virtual reality with a standardized partner a next step in this line of research is the communication between interacting partners. We would like to introduce direct partner. The results from interaction with a real partner in comparison to a pre-recorded standard-partner could allow further insights in interaction processes. In terms of Sallnäs already quoted statement that Co-Presence is connected to the extend of feeling that a partner perceives the user's reactions this could lead to a deeper understanding of Co-Presence.

Furthermore, we would like to examine the influence on different haptic feedback to the scenario.

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