Interpretation of Results in Experimental Haptic Interaction Research

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***Abstract*— This paper summarizes a talk, given at the "Workshop on Haptic Human-Robot Interaction". After a general introduction on haptic collaboration, we focus on aspects which influence the conclusions which can be drawn from experimental results. These aspects are also of major importance when transferring experimental results to real applications. These aspects involve factors in relation to the experimental design as well as the statistical analysis. Therein, we concentrate on challenges related to interaction data.**

I. INTRODUCTION

As artificial partners and assistance functions can provide physical support due to recent developments in robotics, haptic human-robot interaction needs to be addressed experimentally to design these partners with high usability, in a safe environment. Before going into detail here, the following definition of haptic collaboration is given:

Interaction is defined as "relationship between two or more systems [...] that results in mutual or reciprocal influence" [28]. Interaction relates to physical signals which are exchanged.

Collaboration is a specific type of interaction. Different interactions are distinguished in dependence on the *intentions* of the two partners (systems). If intentions are shared and communicated, the interaction is called collaboration. In literature collaboration is also called cooperation [12] or joint action [27].

Haptic Collaboration is based on the exchange of force and velocity signals between partners, either in direct contact (guidance) or via an object. As long as there is physical contact between the two partners, haptic collaboration is simultaneous because we perceive our partners dynamics in the same moment as we are acting. This direct feedback is the main difference to other forms of communication and collaboration where mostly sequential cooperation (i.e. turn-taking in talking) takes place. In addition to the haptic feedback of the partner and the object, in most haptic collaboration additional feedback is involved: the parties hereto can visually perceive the environmental changes which are caused by their haptic interaction. The physical coupling leads to a constant signal flow between partners. However, not all of these signals will have a symbolic character, meaning that they are meant to transport individual intentions to the partner. Therefore, the biggest challenge in haptic collaboration research is to find out how partners communicate via signals and how the shared action plans are developed.

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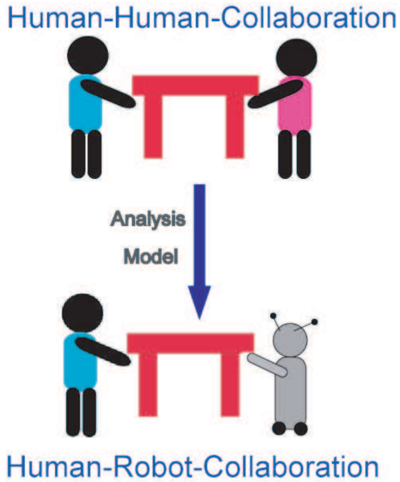

Fig. 1. Generating a model for a technical partner by substituting one human partner of the interacting dyad

In [12] it is emphasized that a collaborative system should overcome an artificial way of communication (e.g. typing in coordinates when moving a table with a robotic partner) but instead offer *intention recognition*. In haptic collaboration, this also involves to overcome the master-slave interaction which is up to now a common form of haptic human-robot interaction but does not involve intention recognition: either the robot is replaying a fixed trajectory [3](master) or is programmed as a passive follower [21], [1]. To allow real collaboration between partners cognitive models for the technical system are needed. Therefore, new research in haptic collaboration is studying **human-human** haptic collaboration as a reference [24], [6], [14] when designing technical partners, see Figure 1. The so gained behavior-models of interactive individuals are supposed to allow intuitive interaction, based on dynamic intention recognition, with a robot.

Given the overall-goal to develop models of individual humans within an interactive dyad in kinesthetic tasks, experimental studies are a prerequisite to gain the necessary information. This is above all due to the fact that the human behavior is hard to predict and shows low consistency in dependence of external and internal influencing factors. Therefore, case studies as they are appropriate to investigate the behavior of technical systems have low validity in human behavior studies. However, to setup experiments and analyze data from those experiments contains some challenges which especially have impact on the generalizability from such studies to real applications. The following section summarizes problems of comparability and statistical results in relation to this knowledge transfer.

II. Generalizability of Experimental Results

It has to be mentioned, that the state-of-the-art on haptic interaction is still far from an interactive model which can be implemented on a technical partner. First studies in this research area focus mainly on the effect of mutual haptic feedback on
1) the implications of executing a kinesthetic task alone compared to an interactive condition [25], [7]
2) performance compared to visual feedback only [26], [15]
3) dominance distributions between partners [23], [20], [6], [14]
In the following overview on generalizability of results we therefore focus on such studies.

A. Comparability: Control Conditions

Research questions related to the effect of working with a partner and the effect of providing reciprocal haptic feedback need to be studied by introducing control conditions where these conditions are not present (no partner, no haptic feedback). In dependence of the introduced control conditions, the conclusions which can be drawn from differences between the experimental conditions vary. Possible control conditions compared with an interactive condition with mutual haptic feedback have their advantages and disadvantages:
1) *Single-person control condition:* In this condition interaction does not take place. Mental models of the partner and motor-coordination are not necessary. Hence differences between the single-person condition and the haptic interaction condition can have several reasons, i.e. the effect of the haptic feedback, the interaction itself and the specific partner are confounded.
2) *Without-haptic-feedback control condition:* Here, interaction takes place as in the haptic condition on the motor-coordination level as well as on the cognitive level because mental models of the partner are required. However, there is no haptic feedback provided, meaning that in most cases only visual feedback is given. It is important to note, that visual feedback leads to inconsistencies when two persons jointly manipulate an object because the proprioceptive movement of the muscles and the so estimated object movement is not necessarily consistent with the real object movement, which is also influenced by the partner [13]. Therefore, this control condition confounds effects of the presented feedback with effects due to disturbances related to this feedback. In addition, two cases have to be separated: a) the haptic feedback of the object is still provided in this control condition [7], [14], [15] or b) no haptic feedback at all is given [2], [26]. In the latter case, the overall effect of haptic feedback cannot be separated from the effect of haptic feedback on the actual interaction, thus communication between partners.
3) *Single-person-dual-hand condition:* This control condition does not require mental models of a partner but still interaction takes place due to the fact that the two hands have to be coordinated. The dual-hand condition can be presented with and without haptic feedback and thus allows to study the effect of feedback separately from the effect of interaction in motor-coordination. The effect of shared mental models can be examined. The challenge here is that two participants may use their dominant hands, which disturbs the comparability with individuals.
4) *Technical partner:* comparing a technical partner with a human partner is foremost done to evaluate a model of an interactive haptic partner. Differences between the two conditions allow defining the quality of such a model. Because the model needs to be defined beforehand, this control condition is added for the sake of completeness but has only limited use as the state-of-the-art does not provide advanced technical partners.

B. Comparability: Environmental Conditions

It has to be noted that one goal of experimental studies is to allow direct causal inference between the measured behavior and the presented experimental conditions. This can only be done if the influence of confounding factors are controlled for (for details on the experimental control of disturbances see e.g. [9]). This, however, influences the transferability of the found results on real applications as here a lot of such confounding factors which where eliminated or controlled for in the experiment could gain influence on human behavior. To compare the results of different studies on haptic interaction it is therefore indispensable to take into account the environmental variables which are studied or eliminated. For haptic interaction research that means to check if the participants were for example allowed to talk [26] or not[25], [7].

C. Comparability: Participants

In studies on interaction it is also desirable to control influences related to different partners when studying other aspects of haptic interaction. There are several possibilities to do so:
1) The dyads taking part in the experiment are independent, i.e. no partner is part of more than one dyad. If the sample size is big enough, noise due to personal variables can be considered normally distributed for measures which represent the behavior of both partners together (dyadic level). Still, individuals within an interacting dyad cannot be analyzed this way.
2) Another approach which aims to examine individual behavior is to standardize one partner and assume it as constant. Then only the second partner is analysed. The drawback of this procedure is that interaction involves adaptation towards the partner. However, the trained partner cannot adapt naturally to the partner as his/her goal is to present a standardized partner.

3) A third possibility to deal with the question of how to examine the effect of the interaction partner is to directly address it. This can be done by using an experimental design which allows participants to interact with several partners (e.g. round robin design [18]). Though, if this approach is chosen, the dyadic behavior data is no longer independent and cannot be investigated with standard inference statistical methods (see also next section II-E).

D. Inference Statistics

In contrast to descriptive statistics which summarizes the data of a given sample, inference statistic analysis allows to generalize the found results to a larger population than the actual ample (most popular tests are t-test, analysis of variance and regression analysis). This does not mean that descriptive statistics is of minor importance, as the actual effect size is still determined by it, e.g. the difference between the means of two experimental conditions. However, if a found difference is significant can only be tested with inference statistic, meaning that with an a priori defined probability the same result can be found if the experiment is repeated or the scenario part of a practical application.

Inference statistic is based on representative samples. But this is not the only reason for demanding adequate sample sizes, in addition, the level of significance is directly influenced by the number of participants (via the standard error, for more information see e.g. [16]). As part of a new, exploratory field of research the samples in haptic interaction studies are rather small. However, it is obvious that samples of 1 to 6 participants can give hints of how to conduct experiments but that results cannot at all be considered representative.

E. Challenge: Interaction Data

One assumption of inference statistic tests is that the tested values are normally distributed and independent e.g.[8]. When studying any kind of interaction, this independence can not be assured due to a possible adaptation to the partner. This holds especially true for haptic interaction where the partners are coupled by a rigid connection. The individual behavior within a dyad is the data we are mostly interested in to find hints for intuitive models of technical partners. However, it is also the data most difficult to investigate as standard procedures of inference statistics cannot be applied, due to the dependent data.

In methods for social psychology, these problems are addressed and the knowledge can be transferred to haptic collaboration research [17], [11], [4], [22], [19], [5], [10], [18].

III. Conclusion

Human behavior studies are a prerequisite to model intuitive technical interaction partners for kinesthetic tasks. This makes experimental approaches necessary due to the variety in human behavior. The current paper gave a short introduction on the generalizability of results in haptic interaction experiments and the related challenges. Improving the quality of experimental studies in the context of human-robot interaction will lead to results with higher validity and hence improved prediction and modelling of human behavior, which is essential for intuitive technical partners.

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