Audio-Visual Communication in a Two Person Gross Manipulation Task

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Introduction

In order to design robots suited to engage in cooperative manipulation tasks with humans, we study human-human teams as they work together to move a heavy object across a room. We are interested in several questions. First, do two person, gross motion tasks follow the same sinusoidal pattern, one person fine motion tasks do? Does performance improve when audio or visual communication is permitted? How does performance correlate with an individual's perception of performance?

Non-physiological, or performance based, studies of human-human cooperation can be divided into two categories: Haptic and Non-Haptic (audio, visual, etc). The first category, involves physical interaction through the object being manipulated via force, pressure, and tactile sensations (Jones and Sarter 2008), (Reed and Peshkin 2008). Most of the non-haptic experiments are virtual setups where individuals are moving an object together on a computer screen via two controllers (Basdogan, Ho, and Srinivasan 2000), (Sallnas and Zhai 2003). A survey on the role of communication between people appears in (Whitaker, 2003). The novelty of our work is to investigate non-haptic communication in haptic manipulation tasks.

Experimental Setup and Data Analysis

We study a task where two individuals move a table (0.75m X 1.2m, 18 kg) to specific targets in a room (Fig. 1 Left). There is a black circle (0.15m diameter) placed at the center of the table which represents the target. Four laser pointers are mounted on the ceiling and aimed down to four locations on the floor. The goal of the participants is to move the table such that the laser is inside the black circle (not necessarily centered) as quickly as possible. The researchers select target sequences to study *cyclic* Fitts tasks (e.g. Target 1 to Target 2 to Target 1, etc.) with low difficulty indices as in (Bootsma et al 2004). The table is tagged with reflective markers so that it can be tracked via 8 infra-red cameras placed around the room. The participants fill out a post-experimental survey that assesses the individual's perception of teamwork, physical demand, frustration, stress, and their own performance. Several steps were taken to mitigate learning effects including randomizing the targets and order of the experiments and using placebo (non-cyclic) trials.

In all the trials, one individual is consistently designated the *leader*, which allows him full use of his visual senses and knowledge of the target location. The other individual is designated the *follower* and is never told of the target location by the experimenters. The follower has various communication limitations:

Type 1: Follower blindfolded, no partners can speak.
Type 2: Follower blindfolded, both partners can speak.
Type 3: Follower not blindfold, both partners can speak.

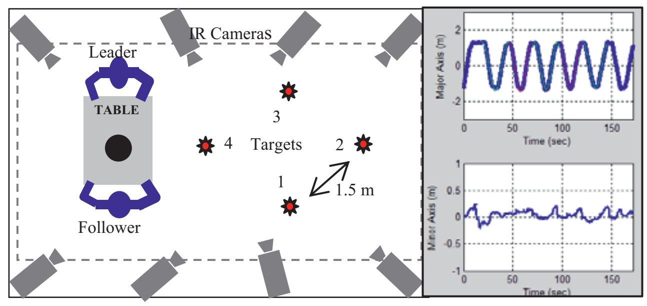

Figure 1: (L) Experimental setup. (R) Sample trajectory.

The data acquisition takes place in real time at 20 Hz with a precision of 8 mm (95% confidence). The position vs. time data is translated so that Y represents the major axis of motion; while the minor axis, X, is perpendicular. Ideal target-to-target straight line motions should not deviate from the major axis. Fig. 1 (Right) shows an example of the transformed motion between targets 1 and 2. The data is then partitioned into intervals corresponding to cycles (to determine the effect of learning) giving us 130 data sets.

Results

We investigated three, of many possible, quantitative measures of a team's performance – explained below.

1. Goodness of fit to a sinusoid (r^2)
2. Time to complete a target cycle (T sec)
3. Deviation from straight line (E_{rms} in meters)

To separate the affect of communication type from any confounding factors such as group number, ordering and trial number, an N-way Analysis of Variance (ANOVA) was performed for each performance measure (a.k.a. response variable). Cumulative Cycle Number was considered a continuous variable; Group Number was considered a random variable; Communication Type (1, 2, or 3) was a categorical variable; and alpha is set to 0.05. In the tables that follow a small p-value implies the predictor had significant effect on the mean.

Table 1: ANOVA Results: Performance r-squared					
Source	Sum Sq.	dof	Mean Sq.	F stat.	p
Comm.	0.00028	2	0.00014	5.67	0.0044
Cycles	0.00002	1	0.00002	0.73	0.393
Group	0.00155	6	0.00026	10.45	2.6e-9
Error	0.00296	120	0.00002		

Goodness of fit to a Sinusoid: In the case of a single person, upper body manipulation task, the motion follows a sinusoidal pattern (Bootsma, Fernandez, and Mottet 2004). The mean r^2 value of 0.99567 provides strong evidence that Fitts' law for cyclic motion also holds for two person gross motion tasks such as this one. Table 1 allows us to further conclude that there is a small but statistically significant effect of the communication type on how sinusoidal the motion is (p=0.0044). However, it can also be noted that there is large variation of all the performance measures between groups. Interestingly, the number of cycles (times a group performs the task) has very little influence (p=0.393).

Table 2: ANOVA Results: Time per Cycle (sec)					
Source	Sum Sq.	dof	Mean Sq.	F stat.	p
Comm.	199.2	2	99.56	10.61	0.0001
Cycles	80.5	1	80.50	8.58	0.0041
Group	1137.9	6	189.65	20.21	3e-16
Error	1125.9	120	9.38		

Time to complete a cycle corresponds to Fitts' original performance measure (Table 2). In this performance measure, there is a high correlation between cycle number and completion time – suggesting there is a learning effect (p=0.0041). Also, as in the earlier measurement, the groups have taken on personalities and some groups are fast while others move slowly. Communication type does have a statistically significant effect on this measure (p=0.0001).

Deviation from a straight line is one measure of efficiency. In this case, as in the r^2 measurement, the number of cycles does not affect how straight of a line the group walks in (Table 3). Thus, learning does not come into play in this measurement (p=0.52); but the communication type is highly significant (p=3.2e-5).

Table 3: ANOVA Results: E*rms* (meters)					
Source	Sum Sq.	Dof	Mean Sq.	F stat.	p
Comm.	0.04951	2	0.02475	11.32	3.2e-5
Cycles	0.0009	1	0.0009	0.41	0.5213
Group	0.04319	6	0.0072	3.29	0.0049
Error	0.26241	120	0.00219		

Survey At the conclusion of each trial, individuals were asked to rate his/her own performance. While the above data shows that performance is significantly correlated with the available channels of communication, individuals do not perceive any statistically significant disadvantage when their communication is limited.

Pair wise Comparisons and Conclusions

The only conclusive pair wise comparisons were:

Sinusoidal Fit (r^2)	Type 3 better than Type 1
Completion Time	Type 3 better than Type 1 & 2
Straight line	Types 3 & 2 better than 1

While Type 3 (audio and visual) communication generally outperforms Type 1 (no communication); neither Type 2 nor Type 3 consistently outperforms the other suggesting more trials are required. Other conclusions include:

- Repetitive two person gross motor manipulation tasks can be modeled sinusoidally.
- The effect of communication type on performance is extremely significant in all measures.
- The only measure which exhibits a learning effect is completion time.
- Performance varies significantly between the groups.
- There is no correlation between actual and perceived performance.

Finally, we are developing new experiments to determine if these results can be generalized to other two person gross motion tasks.

References

Basdogan, C., Ho, C.H., and Srinivasan, M.A. 2000. An experimental study on the role of touch in shared virtual environments. *ACM Transactions on Computer-Human Interaction* 7: 443-460.

Bootsma, R.J., Fernandez, L., and Mottet, D. 2004. Behind Fitts' law: kinematic patterns in goal-directed movements. *International Journal of Human-Computer Studies* 61: 811-821.

Jones, L.A. and Sarter, N.B. 2008. Tactile displays: guidance for their design and application. *Human Factors* 50 (1): 90-111.

Reed, K.B. and Peshkin, M.A. 2008. Physical collaboration of human-human and human-robot teams. *IEEE Transactions on Haptics* 1 (2): 108-120.

Sallnas, E.L. and Zhai, S. 2003. Collaboration meets Fitts' law: passing virtual objects with and without haptic force feedback. *Proceedings of INTERACT*, 97-104.

Whittaker, S. (2003). Theories and methods in mediated communication. In A. Graesser, M. Gernsbacher & S. Goldman (Eds.), Handbook of Discourse Processes (pp. 243-286).