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The Effect of Steady Dyadic Opposition Forces on a Cooperative Point-Following Task

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Abstract— **Previous papers have investigated human-human cooperative point-following, bimanual tasks, and human-robotic interactions on cooperative tasks. In this paper, we investigate human-human cooperative point-following with an additional component of matching set forces through a variety of paths. We wanted to find out how this additional component affected users' ability to follow the target, while also determining new challenges caused by this additional component. The results showed that the force requirement made it more difficult than expected to follow slower, simpler paths. Faster paths were affected less. We also found that higher forces were found to be more difficult and that it took time for subjects to adjust to new target forces.**

I. INTRODUCTION

Humans often find themselves physically cooperating to achieve shared goals. For instance, physical cooperation is necessary for moving furniture, using a two-handed saw, or ballroom dancing. In each of these scenarios, information about each participant's intent is conveyed to the other both visually and through forces and motions, either applied directly or via a mutually grasped object. Gentry [1] showed that dancing couples performed equally well while blindfolded, suggesting that a significant proportion of the information exchange takes place through haptic channels. Each participant must utilize the haptic information that they receive in order to plan their own motions and forces in such a way that the shared objective is reached.

Although human-human cooperative interaction is a part of everyday life, we still know relatively little about the behavioral and neural processes that underlie these activities.

As robotics technology improves, human-robot interaction will become more common. In cases of rehabilitation, task-instruction and task-assistance, this human-robot interaction will involve collaboration, whereby the robot is seen less as a tool, and more as a partner. Green et al. [2] defines collaboration as "working jointly with others or together especially in an intellectual endeavor". These robots will need to be programmed to be proactive and adaptive, and to generate the types of forces and motions that a human would produce in similar cooperative scenarios. How do cooperative pairs of people respond when there are multiple methods available to reach the desired outcome? How are forces and roles divided when two people cooperate? Such information can only be gathered by investigating the forces and motions produced by a human-human team working cooperatively.

Some cooperative tasks require the participants to physically oppose each other, while still working toward a common goal. For instance, when two people place a sheet on a bed, they must introduce tension into the sheet, in order to flatten it out, by pulling in opposite directions, while at the same time cooperatively positioning the sheet in the correct location. In order to create robust cooperative robotics, we must study more complicated tasks, such as those with multiple complimentary goals.

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II. BACKGROUND

One might expect that an individual would perform better on accuracy-based tasks than a team of individuals performing the same task, due to the increased complexity in the multi-user case, but previous research has shown the opposite to be the case. Wegner and Zeaman [3] showed that teams of two and four performed better than individuals on a basic pursuit rotor task. In that experiment, the goal was to guide a stylus to follow a target as it travels around a circular path. In the case of multi-user teams, the individual participants were physically linked by grasping a single object, the stylus.

Reed et al. showed that haptically-linked dyads perform better than individuals in a one-degree-of-freedom target acquisition task, even when each participant reported feeling as though their partner was a hindrance [4]. This result was later reproduced by Feth et al. [5].

Reed et al. also observed that participants in a cooperative crank-rotor task produce equal and opposite steady dyadic opposition forces when at rest [6]. This steady dyadic opposition force can be likened to the muscular co-contraction exhibited in an individual holding a limb stationary against outside perturbations [7][8]. Gribble [9] showed that the magnitude of the co-contraction force in an individual varies with the inverse of the target size in a Fitts-like task. Similar co-contraction forces are used in parallel robotics and human bimanual control [10][11].

van der Wel et al. observed that dyads produce much more overlapping forces than individuals, especially when performing tasks with higher coordination requirements [12].

Groten et al. found that, although reciprocal haptic feedback in cooperative tasks increased the participants' performance, it did not improve efficiency, since they need to provide greater effort to perform the task with the addition of the physical connection between them [13].

Extending their previous research on the division of roles among dyads in a crank-rotor task, Reed et al. experimented with replacing one of the humans with a robot programmed to fulfill one of the two roles previously observed [14]. The results of the study showed that human-robot dyads failed to achieve the level of results obtained by human-human dyads, even when the robot was programmed to fulfill one of the specialized roles as seen in the human-human pairs.

Jarrasse et al. wrote a review summarizing recent research in the field of role assignment in cooperative tasks, as it relates to human-robot interactions [15].

In this study, we investigate the effect of intentional steady dyadic opposition forces on the accuracy of a cooperative point-following task. By investigating this relationship, we hope to provide insights that could be used in the development of human-robot collaborative interactions.

III. METHOD

We created a cooperative point-following task, where two users are haptically linked via two Phantom Omnis arranged in a position-exchange schema, utilizing position and derivative control, whereby motion in one device is felt in both devices as a spring-like force drawing the two together. The shared goal point representing the average of the participants' locations is depicted as a purple sphere on the screen; the actual positions of each user's haptic interaction point is not displayed, making it necessary for each of them to interpret the other's position based only on the haptic forces felt.

In each trial, one of six path confgurations was randomly selected for the target point to follow. Each of the six path confgurations was generated by alternating between a sinusoidal path, a parabolic path, and a zig-zag path made up of 45 degree slopes in a random order. We added a visualization of the opposition force between the two users in the form of a force-meter that hovers just above the target to be followed. By specifying a particular opposition force on the force-meter, displayed by the green line that goes through the meter, we added a second goal to the basic point-following task. This, as well as the target point and the shared goal point, is displayed in Figure 1.

The experiment was conducted in a noisy environment with many people around. The two Omnis were positioned on either side of the shared display, with the participants seated in front of them, as shown in Figure 2.

All participants who took part were in attendance at a demonstration, which included this experiment as well as many other experiment and projects from others. Attendees who expressed interest in our experiment were asked if they would like to volunteer to participate in it. They were under no obligation to participate in our experiment or any other experiment. All tests were done over a two and a half hour period.

Each subject was instructed to use their dominant hand. They were also instructed not to communicate with each other regarding any aspect of the experiment to ensure that adjustments by the subjects during the experiment were due to haptic feedback, not verbal communication. The users were instructed to cooperatively follow the target point while maintaining a constant opposition force with their partner, with a magnitude as indicated by the goal force.

After having the mechanics of the system explained to them, the users were allowed to practice with their partner, using a target following a straight line path, so that they could get a feel for the system before beginning the experiment. They were given as much time to practice as they wanted, but most pairs only remained in practice mode for about a minute to a minute and a half.

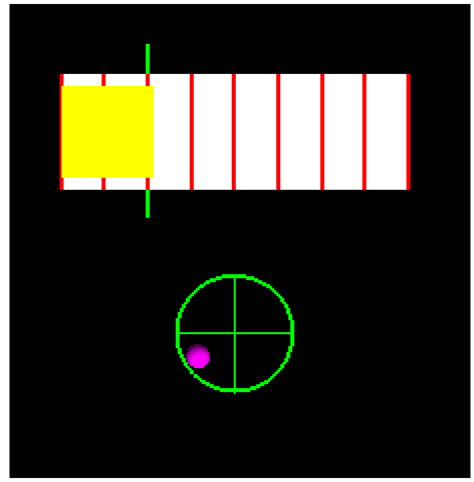

Fig. 1. A basic diagram of the point-following task with force-meter

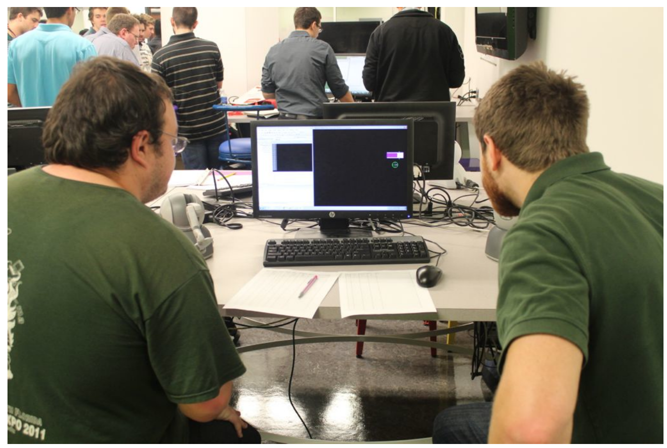

Fig. 2. The experimental setup consisted of two Omnis on either side of a computer monitor

Each trial started with a five second countdown, during which users were asked to get to the target and try to match the force to start the experiment. The target was stationary and no results were collected during the countdown.

For each trial, a goal force of 0, 1, 2, or 3 Newtons was randomly chosen, until each of the four target forces was attempted. By varying the goal force from trial to trial, we hoped to be able to study what effects, if any, varying magnitudes of steady dyadic opposition force would have on the team's accuracy on the point-following task.

Each trial took about a minute. The entire test for each pair took about seven or eight minutes, including instructions, practice time, and all four target forces.

IV. RESULTS

The experiment was completed by 10 pairs of subjects. The subjects' ages ranged from 21 to 36. There were five pairs in which both subjects were male and five pairs in which one subject was male and the other was female. Two ANOVAs were done with the factors of subject pair, iteration of target force, path, target force, and path iteration. The post-hoc tests used throughout follow Tukey's honestly significant difference criterion.

The first ANOVA was done with distance from the target set as the response variable. This showed that the null hypothesis could be rejected for the factors subject pair ($F_{2,100}$ = 6.09, p $<$ 0.001), path ($F_{2,100}$ = 4.79, p = 0.01), and target force ($F_{3,100}$ = 2.86, p = 0.041). That the null hypothesis for pairs was rejected was an expected result. As for path differences, a post-hoc test showed it was the zig-zagging path and the parabola path that differed significantly (Fig. 3).

The post-hoc test for target force (Fig. 4) revealed that the results when the target force is one Newton differs from the results when the target force is three Newtons.

The second ANOVA used a response variable of the average absolute value of the difference between force and target force, or average absolute force error. Statistically significant results for the factors target force ($F_{3,100}$ = 4.17, p = 0.008) and path order ($F_{2,100}$ = 131.53, p $<$ 0.001) were found. The post-hoc test for path iteration (Fig. 5) showed that the first path, no matter which path it was, gave subjects the most trouble in attempting to match the target force. The post-hoc test for the target force when force error is the response variable (Fig. 6) shows a similar trend as the results in Fig. 4, where distance is the response variable. Beyond that, as with the distance test, the statistically significant results are those for target forces of one Newton and three Newtons.

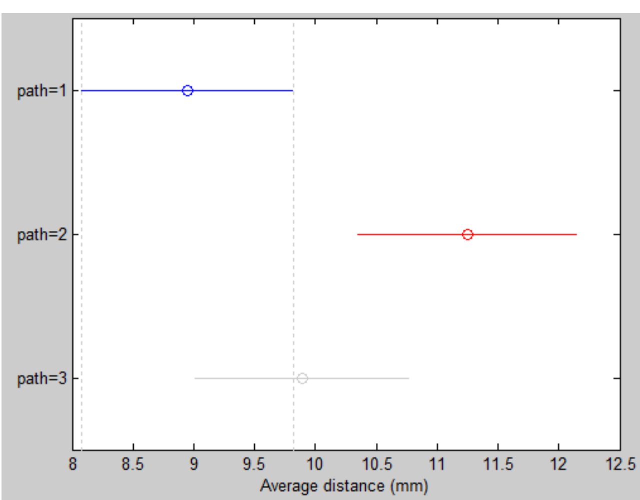

Fig. 3. The post-hoc test with path as an independent variable and distance from the target as the dependent variable. Path=1 is a zig-zagging path. Path=2 is a parabola path. Path=3 is a sine wave. The difference between the zig-zag and parabola paths was statistically significant.

Any other tested factor not mentioned above for either ANOVA were factors in which the null hypothesis was not rejected.

V. DISCUSSION

Based on the observation of the steady dyadic opposition force by Reed et al, our initial expectation was that introducing opposition forces into the cooperative point-following task would act as a stabilizing influence and would result in better accuracies, up to a point; while relatively small opposition forces were expected to improve performance, large opposition forces were expected to overwhelm the point-following aspect of the task, thus decreasing performance.

While the post-hoc analysis showed that only the one Newton and three Newton target forces had a statistically significant difference in accuracy for both distance and absolute force error, the trend shown in figures 4 and 6 show that when a target force is introduced into the point-following task, the difficulty of both remaining close to the target point and maintaining the target force become more difficult as the target force is increased. This is in agreement with our hypothesis. It should be noted that a target force of zero did not fall in line with this trend. This is expected, too, as perfect synchrony is required to not produce a force.

When point-following, it is expected that a slower moving point would be easier to follow than a faster moving point. For our experiment, the speed was constant in the x-direction. Therefore, paths that involved more movement in the y-direction resulted in a greater overall magnitude of velocity; of our three paths, the parabola is the slowest while the sine wave results in points of much higher velocity. Therefore, it is expected that the sine wave would be the most difficult to follow, while the parabola would be the easiest. This expectation is compounded by the fact that the parabola had the least amount of direction changes, while the sine wave had the most.

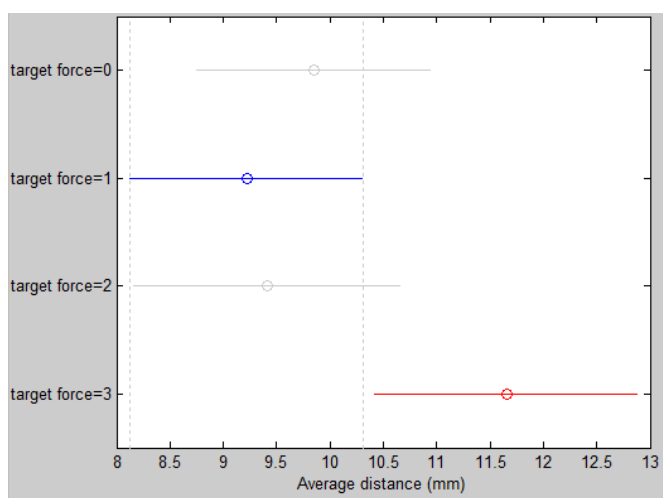

Fig. 4. The post-hoc test for target force showed only the 1 N and 3 N target forces were statistically significantly different. However, a slight trend can be seen.

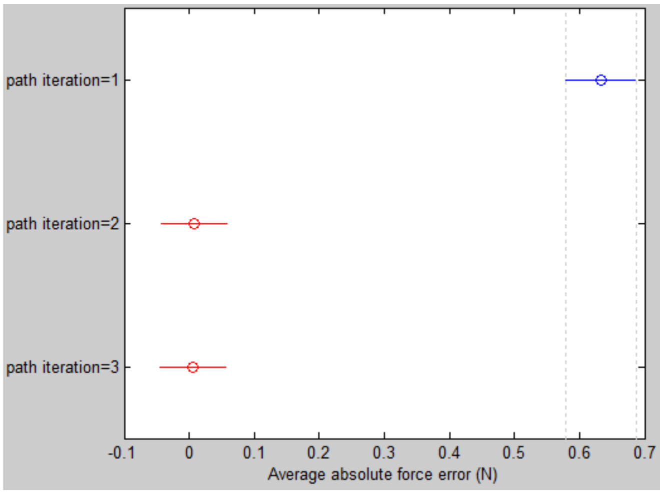

Fig. 5. The post-hoc test for path iteration, with force error as the dependent variable, showing that the users performed worst on the first path of each trial, in general.

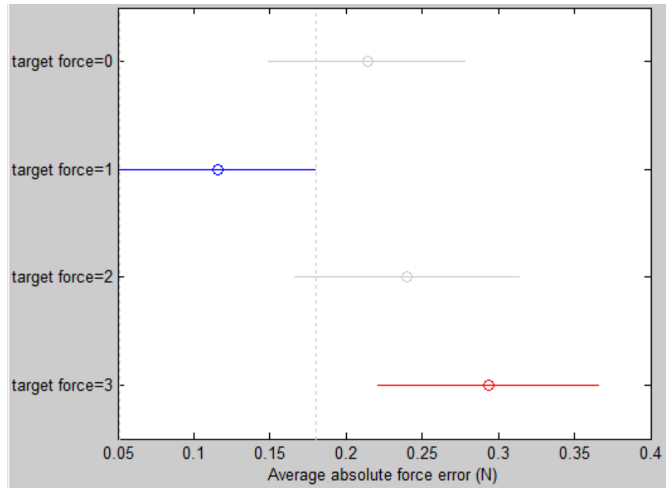

Fig. 6. The post-hoc test for target force, with force error as the dependent variable, shows very similar results as that in Fig. 4.

Our results ran counter to our expectations about speed. The parabola was the most difficult for our subjects to follow, and significantly so when compared to the zig-zag path. This suggests that the additional condition of maintaining a constant dyadic force affected the ability of the subjects to stay on target. Possibly, the comparatively low speed of the parabola made it difficult to maintain the target force, if they were on target. If subjects weren't on target, adjusting the force may have caused them to move off of the point more easily because of low speed at which it was moving.

However, the results also suggest that the zig-zag path was the easiest for the subjects. This suggests that an increase in speed and direction changes doesn't necessarily make this task easier, as the zig-zag path was slower and had fewer direction changes than the sine wave path. It should be noted, though, that because the sine wave path was not statistically significant to either of the other two paths, it is possible that more extensive tests would show the sine wave as being either easier than the zig-zag path or more difficult than the parabola. Even if either of those scenarios were to occur, the actual results still would not match the expected results.

The results also show that subjects performed significantly worse at matching the target force on the first path given to them than they did during the following two (Fig 5). However, the order in which the target forces were presented did not significantly affect the results. These two results indicate that it took some time for each pair to adjust to each target force, but that their improvement wasn't simply caused by gained experience from using the device and previously doing the task with a different target force. When it comes to distance from the target, the order in which the paths were given did not significantly affect the results. This suggests that the target-following part of the experiment is more intuitive than matching the target opposition force.

Interestingly, there were significant differences for how different pairs varied in trying to stay on target, but there were not significant differences for the average absolute force error of different pairs. This suggests that while there were differences in how subjects tried to remain on the target, there were little differences in how subjects tried to reach and maintain the target force. However, as discussed previously, it is likely that the force portion of the experiment had some effect on the distance portion, so it is possible that some of the variation in the distance was caused by the subjects trying to stay at or match the target force.

VI. FUTURE WORK

There are many improvements and additions that can be made to this experiment in the future. With our setup each subject was asked not to communicate with each other, but each was able to see the other's Omni. It is possible that with their peripheral vision they could pick up visual cues from their partner. A future experiment could remove this potential and separate the subjects, or set up a wall so that they cannot see each other.

Another possible change would be to add more varied sets of paths. The paths could also be more unpredictable. In this experiment, the paths followed a continuous pattern and it quickly became obvious at what points the paths would change at.

More data could be added concerning the individual performance of each subject. This information could be compared to how the subjects performed in pairs. The experiment could also be done with some subjects redoing the experiment with different partners, some who had already done the experiment and some who hadn't and see how that affects the results.

In the future, the experiment could be redone with a higher range of target forces using devices capable of higher forces.

How the addition of a cursor that shows each subject's individual position affects the performance on the task could be investigated as well.

Future experiments could also include user feedback, such as what aspects they felt were easier or more difficult and how well they feel they did individually.

Given the increased complexity of the task studied here, as compared to the pursuit rotor task studied by Reed et al., it might be interesting to study the dyadic opposition force as a dependent variable, rather than as a goal of the task. This experiment could also be extended to compare the overall performance of dyads to the performance of a single participant working bimanually [16], to investigate whether the performance advantage seen in dyads performing a single degree-of-freedom task would carry over to a more complicated task. To further complicate the task, the point to be followed could move in three dimensions, instead of two; real-world cooperative tasks will often be in three dimensions, after all.

The experiment could be extended into a cooperative bimanual task, where each user manipulates two Omnis instead of one. Furthermore, it might be interesting to study cooperative tasks beyond dyads, using groups of three, four, or even more participants on a single task.

VII. CONCLUSION

For this study, we investigated the effect of adding a target force component to a cooperative two-dimensional point-following task. Using two Phantom Omnis programmed in a position-exchange schema, ten pairs of subjects completed four tests, one each where the target force was set to 0, 1, 2, and 3 Newtons in random order. For each test, they followed three different paths in random order. The results suggest that increasing the target force makes the dual-task of following the target and maintaining the intended force more difficult. Users also had difficulty in adjusting to new target forces as evidenced by the first path presented, no matter which path it was, averaging much higher absolute force errors than paths two and three, both of which averaged a force error of nearly zero. The path that was expected to be easiest when it comes to point-following, turned out to be the most difficult. This suggests the addition of a force component affected these results.

In conclusion, the additional goal of maintaining a steady dyadic opposition force appears to have simply complicated the task, generally reducing performance as the target force increases. The data obtained suggest that a more simplified approach might yield more meaningful results.

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