Cooperative Cooking: A Novel Virtual Environment for Upper Limb Rehabilitation*

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***Abstract*— Motor rehabilitation technologies commonly include virtual environments that motivate patients to exercise more often or more intensely. In this paper, we present a novel virtual rehabilitation environment in which two people work together to prepare meals. The players' roles can be fixed or undefined, and optional challenges can be added in the form of flies that must be swatted away. A preliminary evaluation with 12 pairs of unimpaired participants showed that participants prefer cooperating over exercising alone and feel less pressured when cooperating. Furthermore, participants enjoyed the addition of flies and preferred not to have defined roles. Finally, no significant decrease in exercise intensity was observed as a result of cooperation. These results indicate that cooperation could improve motor rehabilitation by increasing motivation, though the virtual environment needs to be evaluated with participants with motor impairment.**

I. Introduction

Home rehabilitation technologies are becoming increasingly popular for recovery of motor function after neurological injuries such as stroke and traumatic brain injury. By combining motion tracking devices such as the Microsoft Kinect [1] with virtual environments (VEs) [2], [3], these technologies allow people with motor disabilities to train motions at home, without therapist supervision, and receive feedback about their motion through the VE. Furthermore, to improve engagement and increase the intensity of exercise, rehabilitation VEs commonly include game-like elements such as entertaining graphics, automated difficulty adaptation, and in-game rewards [4]–[6].

In recent years, designers of motor rehabilitation systems have experimented with VEs that allow two or more people to compete or cooperate with each other. Both competition and cooperation have been shown to increase motivation in rehabilitation compared to exercising alone [7]–[12], with competition also increasing exercise intensity [11], [12]. Though these studies were limited to 1-4 sessions, both motivation and exercise intensity are correlated with positive rehabilitation outcome [13], [14], and the observed short-term benefits of competition and cooperation may thus translate to better long-term rehabilitation outcome. While rehabilitation VEs involving competition have received more attention than those involving cooperation, studies have emphasized that competition is not suitable for everyone, and may in fact evoke strong negative reactions in some participants [9], [11], [15]. Thus, designers of rehabilitation VEs should not neglect cooperative exercises, which could provide a less stressful experience even if they do not increase exercise intensity.

To date, only one cooperative rehabilitation VE has been evaluated with more than one or two people with disabilities: a game where the two players must hold a long beam (one player on each end) and balance it so that the object atop the beam does not fall off [10]. In this VE, both participants are thus performing the same task, and are essentially "linked" through the virtual plank. In contrast, we propose a different design of cooperative VE: a VE where multiple tasks must be performed to achieve the overall goal, but each individual task is only performed by a single person. To make this exercise more relatable to real-world activities, the VE has been designed as a "virtual kitchen" where two players must prepare dishes together. Such virtual cooking tasks are common in rehabilitation VEs for solo exercise [16].

This paper presents the design of our cooperative cooking VE as well as first evaluations with unimpaired subjects. The goal of these evaluations was to determine whether cooperative exercise is more motivational and/or intense than exercising alone, as well as to examine how different role assignments in the cooperative exercise affect motivation and exercise intensity. By obtaining this information, the paper lays the foundation for future studies that will include participants with chronic limb impairment.

II. Methods and Materials

A. Arm Rehabilitation Device

Our rehabilitation VE is designed to be controlled via wrist and forearm motions, which were tracked using the Bimeo arm rehabilitation system (Kinestica d.o.o., Slovenia). The system consists of three inertial sensors placed on the upper arm, on the forearm, and inside a handheld module that sits on a table. To interact with the rehabilitation VE, the participant tilts the handheld module forward, backward, left or right, similarly to a joystick. The required range of motion is 20° from the center position in each direction. The same setup was used in our previous research [11], [12], and is shown in Fig. 1.

Cooperative exercises in the rehabilitation VE are performed by two participants simultaneously. However, as we did not have access to two Bimeo systems, the second participant in a pair used a commercial Logitech joystick as the input to the VE.

B. Cooperative Food Preparation Scenario

The cooperative rehabilitation VE requires the two participants to work together to prepare different dishes. Three graphically distinct "levels" of the VE were designed:

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Fig. 1. The Bimeo arm rehabilitation system, which consists of two inertial sensors on the arm as well as an inertial sensor inside a handheld module.

- Salad: The screen displays a bowl on one side of the screen as well as multiple salad ingredients on the other side of the screen. All ingredients must be picked up, carried to the bowl, and dropped into it. Each participant's arm position is shown as a pointer on the screen. When using the Bimeo, an ingredient is picked up by briefly pushing the handheld module downward (against the table), then released by pushing the module downward again. A screenshot of this level is shown in Fig. 2 (top).
- Pizza: The screen displays a pizza base on one side of the screen as well as multiple pizza ingredients on the other side of the screen. Participants are instructed to prepare the pizza by adding only the ingredients that they want to have on it. When the participants are satisfied with the pizza, they can press the 'enter' button on the keyboard to complete the task. This provides participants with a feeling of freedom and control. A screenshot of this level is shown in Fig. 2 (bottom).
- Buffet: The screen displays an empty tray on one side of the screen as well as multiple smaller dishes on the other side of the screen. A list on the screen gives the dishes that must be picked up and carried to the tray. This list includes less than a third of the displayed dishes, thus requiring participants to locate the correct dishes rather than place everything onto the tray.

All three levels also include an optional challenge that can be switched on or off: flies that appear at the edge of the screen and fly in a straight line toward the target object (salad bowl, pizza or buffet tray). If a fly reaches the target object, the same level restarts from the beginning. However, if the fly collides with a player-controlled pointer, it flies back off the screen, then reappears on the edge of the screen and starts moving toward the target object again. Thus, when flies are enabled, participants must divide their attention between preparing the food (primary task) and swatting the flies away (secondary task).

All three levels can be played either cooperatively or solo (single-player). In the single-player setting, only the Bimeo is used to interact with the VE. Furthermore, when flies are enabled, the cooperative VE can be set so that the two players' roles are undefined (allowing both players to contribute to meal preparation and fly-swatting) or so that the players' roles are fixed (in which case the Bimeo player can only swat flies and the joystick player can only prepare the meal). Due to time constraints, we did not test the opposite version of role assignments (Bimeo prepares meal, joystick swats flies).

C. Study Goals

As the first evaluation, we primarily wished to compare the cooperative version of the VE to the single-player version. We hypothesized that the cooperative version would be more motivating, justifying its use in motor rehabilitation.

To inform future design of cooperative rehabilitation VEs, we also wished to compare the VE with flies to the VE without flies and to compare the VE with fixed roles to the VE with undefined roles. Different role assignments are known to have major effects on human-human cooperation [17], though we were unsure of how they would affect participant experience in this scenario - providing fixed roles may reduce mental demand, but may also be less motivating since it reduces the interaction between participants. Similarly, providing a secondary task (flies) may motivate participants by providing additional game variety, but may also be considered stressful since it requires participants to divide their attention and adds a timed element.

D. Study Participants

The cooperative rehabilitation VE was evaluated with 12 pairs of healthy participants recruited among students and staff of the University of Wyoming. The study procedure was approved by the university's Institutional Review Board. In the study advertisement, participants were asked to volunteer for the study with a self-selected partner, and all pairs thus consisted of two friends or at least acquaintances. Within each pair, one participant was randomly assigned to the Bimeo while the other used the joystick to interact with the VE.

For this evaluation, only data from the Bimeo participants were analyzed. These 12 participants consisted of 5 men and 7 women, who were 27.8 ± 11.3 years old.

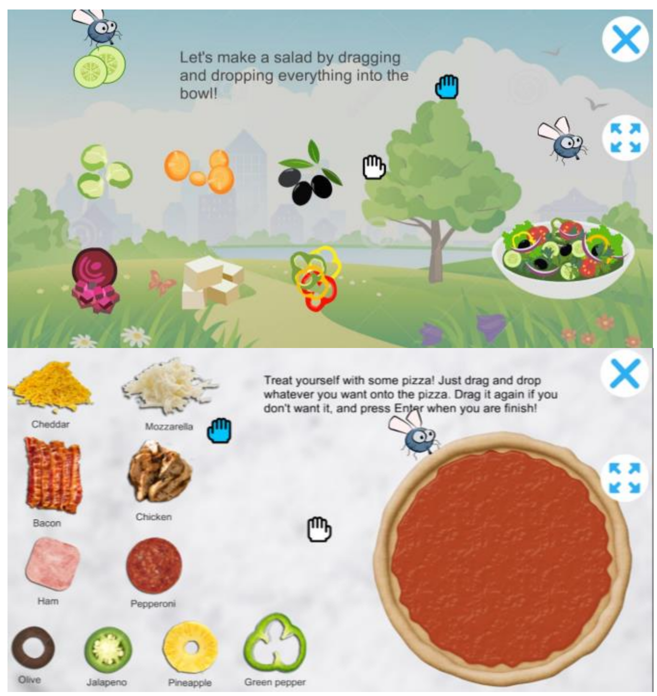

Fig. 2. Two levels of the cooperative cooking scenario: salad preparation (top) and pizza preparation (bottom). Each player's hand position is represented by a pointer (blue for Bimeo, white for joystick). Flies appear from the edges of the screen and fly in a direct line toward the salad or pizza.

E. Study Protocol

All participant pairs took part in a single session in our laboratory at the University of Wyoming. At the start of the session, the study purpose and procedure were explained to both participants. After participants signed an informed consent form, they interacted with the VE for five 3-minute periods. These five periods were:

- single-player, without flies,
- single-player, with flies,
- cooperation, without flies,
- cooperation, with flies and undefined roles,
- cooperation, with flies and fixed roles.

The five periods were performed in random order, with half the pairs starting with a single-player period and half the pairs starting with a cooperative period. Only the Bimeo player interacted with the VE in the single-player periods; the joystick player was asked to leave the room during those periods. All data were thus analyzed only for the Bimeo player.

In each period, participant went through all three levels of the cooking VE one after another. When the task in one level was completed, the VE automatically advanced to the next one; if all three levels were completed before the 3-minute period was over, the VE returned to the first level. Throughout each period, exercise intensity was measured using the Bimeo's inertial sensors as the root-mean-square value of the angular velocity of the handheld module; this is an accepted measure of exercise intensity that was also used in our previous studies with the Bimeo [11], [12].

After each 3-minute period, participants filled out the Intrinsic Motivation Inventory (IMI), a questionnaire that measures four aspects of motivation: enjoyment/interest, effort/importance, perceived competence, and pressure/tension. While many versions of the IMI exist, we used the same 8-item version used in our previous papers [12], [18], which has two 7-point Likert items per motivation aspect. Finally, after completing all five periods, participants were asked the following questions:

- What were your favorite and least favorite of the five 3-minute periods?
- Did you prefer playing alone or cooperating?
- In single-player, did you prefer having flies or no flies?
- In cooperation, did you prefer having flies or no flies?
- In cooperation with flies, did you prefer fixed or undefined roles?

For the last four of these questions, participants chose among five possible answers: strongly preferred option A, weakly preferred option A, no preference, weakly preferred option B, and strongly preferred option B.

III. Results

A. Game Preferences

When asked about their favorite 3-minute period, 8 of the 12 participants chose cooperation with flies and undefined roles, 2 chose cooperation without flies, and 2 chose cooperation with flies and fixed roles. No participant chose either of the two single-player periods as their favorite. When asked about their least favorite period, 5 participants chose single-player without flies, 2 chose single-player with flies, and 5 chose cooperation with flies and fixed roles.

When asked whether they preferred cooperation or playing alone, 9 participants strongly preferred cooperation, 1 weakly preferred cooperation, and 2 had no preference. No participant preferred playing alone.

When asked about flies in the single-player game, 3 participants strongly preferred playing with flies, 3 weakly preferred playing with flies, 1 had no preference, 2 weakly preferred playing without flies, and 3 strongly preferred playing without flies. However, when asked about flies in the cooperative game, 9 participants strongly preferred playing with flies, 1 weakly preferred playing with flies, and 2 had no preference.

Finally, when asked about roles in the cooperative game, 4 participants strongly preferred undefined roles, 6 weakly preferred undefined roles, 1 had no preference, and 1 strongly preferred fixed roles.

B. Intrinsic Motivation and Exercise Intensity

Results of the IMI and measurements of exercise intensity are presented in Table 1. Enjoyment/interest, effort/importance, and perceived competence did not significantly differ between study periods. However, a one-way repeated-measures analysis of variance did find significant differences in pressure/tension and exercise intensity between study periods. Pressure/tension was higher in both single-player periods than in any of the three cooperative periods ($p < 0.05$ in post-hoc Holm-Sidak tests for all six comparisons). Furthermore, in the cooperative game, exercise intensity was higher in the two periods with flies than in the period without flies ($p < 0.05$ for both comparisons).

TABLE I. INTRINSIC MOTIVATION (MEASURED VIA QUESTIONNAIRE, RANGE FROM 2 TO 14) AND EXERCISE INTENSITY (MEASURED AS THE ROOT-MEAN-SQUARE VALUE OF ANGULAR VELOCITY OF THE BIMEO'S HANDHELD MODULE). UR = UNDEFINED ROLES, FR = FIXED ROLES.

Measure	Study period				
	Single-player		***Cooperative***		
	No flies	***Flies***	***No flies***	***Flies, UR***	***Flies, FR***
Enjoyment/ Interest	8.9 ± 2.1	9.2 ± 2.2	10.2 ± 1.5	10.2 ± 1.6	10.0 ± 2.2
Effort/ Importance	9.0 ± 2.8	10.5 ± 2.7	9.8 ± 2.7	9.6 ± 2.6	8.3 ± 3.5
Perceived competence	10.0 ± 1.4	9.2 ± 2.7	10.2 ± 2.2	10.4 ± 1.9	10.2 ± 3.2
Pressure/ Tension	7.8 ± 1.1	7.0 ± 3.0	5.3 ± 2.7	5.3 ± 2.4	4.9 ± 2.7
Exercise intensity (rad/s)	0.382 ± 0.063	0.456 ± 0.124	0.351 ± 0.067	0.444 ± 0.104	0.592 ± 0.373

IV. Discussion

A. Differences between Cooperation and Exercising Alone

The cooperative version of the game was more motivating than the single-player version; almost all participants preferred cooperation to playing alone, pressure/tension was lower in the cooperative study periods, and enjoyment/interest was higher (though not significantly) in the cooperative periods. We believe that, with a larger sample, we would have also obtained significant differences in enjoyment/interest. We can thus conclude that cooperative exercises have potential motivational advantages over exercising alone.

Exercise intensity was slightly lower in cooperative periods than in equivalent single-player periods, but the difference was not significant. We had previously worried that cooperation would lead to decreased exercise intensity for both players, which would be problematic for motor rehabilitation [11], but this does not appear to be a major issue in this study. Still, the effect of cooperation on exercise intensity should be verified with a larger sample of participants.

B. Effects of Flies and Role Assignments

Though we had initially worried that adding flies would be too stressful for participants, this was not the case. In the cooperative game, participants largely enjoyed playing with flies enabled, and the addition of flies increased exercise intensity (which would be beneficial for rehabilitation). The participants also preferred undefined roles, and stated that this gave them more freedom, allowing them to choose how to coordinate their actions. In future versions of the cooperative VE, we will thus use flies and undefined roles by default, and can fix the roles or turn the flies off if preferred by participants.

One unexpected result was observed with regard to role assignments: while participants self-reported lower effort in the "fixed roles" period, exercise intensity (measured using the Bimeo's sensors) was higher. This can be attributed to the experiment design - in the "fixed roles" period, all Bimeo participants were assigned to swatting flies, which required them to constantly move around the screen (as opposed to picking up and carrying food, which requires frequent stops).

C. Limitations and Future Work

The main limitation of the current study is that it was mainly conducted with young unimpaired participants rather than actual participants with neurological injuries. Thus, we cannot guarantee that the observed results (preference for cooperation, preference for undefined roles, no decrease in exercise intensity) would apply to patients in need of motor rehabilitation. We nonetheless believe that our results are important, especially as many results regarding competition and cooperation do transfer from unimpaired people to patients [9]. Still, we will begin conducting tests with participants with neurological injuries in the near future.

The second limitation of the study is that all exercises were performed at a constant difficulty level that did not change between participants or over time. Previous studies have emphasized that the difficulty of rehabilitation exercises should be dynamically tailored to each participant [4]. Prior to conducting tests with participants with neurological injuries, we will thus first upgrade our VE with automated difficulty adaptation algorithms that will tailor the exercise to suit two players with potentially different skills and motor abilities. This can be done by, e. g., changing the range of motion required for each player, increasing or decreasing the number of flies, introducing time constraints, or only allowing each player to perform a certain percentage of total subtasks. Such adaptation algorithms have already been developed for competitive rehabilitation VEs, with positive effects on both motivation and exercise intensity [8], [18].

V. Conclusion

Our cooperative game has the potential to improve motivation in upper limb rehabilitation, as our participants preferred cooperation over exercising alone and found it less stressful. In the near future, we will augment the cooperative game with intelligent difficulty adaptation algorithms, then evaluate it with participants with neurological injuries such as stroke and traumatic brain injury.

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