Exoskeleton-Mediated Physical Teacher-Student Interaction for Gait Training: A Pilot Study

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Abstract. Recent advancements in physical human-robot-human interaction allow people to physically interact with each other through the robotic systems that they are in contact with. This preliminary study explores a potential experimental setup using exoskeleton-mediated interactions for gait training, where a teacher provides haptic guidance to a student. The experimental setup involves haptically coupling the hip and knee joints of pilot users wearing lower-limb exoskeletons, without visual feedback on the desired gait trajectory for the student. Initial observations suggest that while the student can potentially learn a new gait pattern through physical cues alone, several challenges were noted.

1 Introduction

In collaborative motor tasks, people physically interact by exchanging forces to coordinate their movements. This interaction is often seen in physical therapy, where therapists assist patients with sensorimotor deficits by supporting movements necessary for recovering motor skills, such as helping with foot placement in gait therapy for stroke survivors. Recent developments in human-robot interfaces have facilitated studies on complex physical interactions through robotic systems that render physical environments (e.g., spring-damper systems) between humans [1, 2]. In these systems, individuals interact with distinct robotic tools, moving freely within one or more degrees of freedom (DoF), and experience forces that reflect their positional or velocity changes relative to another person's movements.

Given the favorable results from assistive and resistive training methods [3], collaborative and competitive physical interactions between pairs hold substantial potential for enhancing task performance and individual motor learning [4]. Studies on upper limbs have demonstrated that individuals can more accurately follow sinusoidal trajectories when haptically connected with a partner. The extent of these improvements depends on the participant's skill level [5–7] and the characteristics of the virtual connection [8]. Furthermore, research indicates that training in a haptically coupled environment through a compliant connection can significantly enhance the speed of learning post-coupling, in scenarios involving 1-DoF position tracking [9] as well as adaptations in multi-DoF to visuomotor rotations [5].

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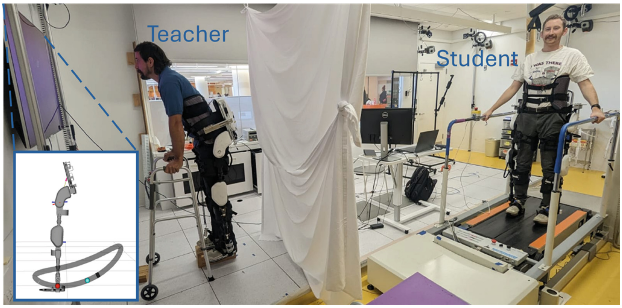

Fig. 1. Experimental setup.

In this preliminary work, we explore a potential experimental setup to be used for the investigation of motor learning with dyadic training in the context of gait rehabilitation. We tested a teacher-student interaction scheme on pilot users where the student train together with a teacher to learn a new gait trajectory.

2 Methods

Two lower-limb exoskeletons (ExoMotus-X2, Fourier Intelligence) were worn by two healthy pilot users, as shown in Fig. 1. Hip and knee joints of their non-dominant legs are haptically coupled to each other with virtual spring (49 Nm/rad) and damper elements (7 Nms/rad). Desired interaction torques for each joint are calculated based on the interaction medium and the states of the robots [1]. Calculated desired interaction torques are fed into a whole-exoskeleton closed-loop controller (WECC) [10] that compensates for the whole-body dynamics of the exoskeleton during the whole gait cycle and tracks the desired interaction in a closed-loop manner. The controllers were implemented on a ROS and C++ based open-source software stack called CANOpen Robot Controller (CORC) [11] and were run at 333 Hz on an external PC.

Distinct roles of teacher and student were given to the users. While the student walks on a treadmill, the teacher stands in front of a monitor. The teacher receives visual feedback of his own and the student's instantaneous state, together with a desired gait profile. While the student is aware that he is haptically connected to a teacher, he does not have any visual feedback of the desired trajectory, nor is he able to see the teacher. The desired gait trajectory is designed such that the range of motion of the hip and knees is scaled up by 20% from the normal gait of the teacher [12]. The teacher is instructed to correct the student's ankle trajectory towards the desired one by moving his leg to apply force. The student tries to learn the new gait trajectory with the physical feedback he is receiving from the teacher.

The following sessions are run to evaluate how well the student learns the new gait trajectory via physical interaction with the teacher.

a) *Rigid Demonstration (D):* The desired trajectory is briefly demonstrated to the student with a rigid position control on his non-dominant leg for twenty seconds.

b) *Baseline (B):* Student tries to replicate the desired trajectory that was demonstrated in the previous session. The exoskeleton is in haptic transparent mode; this session takes thirty seconds.
c) *Training (T):* Teacher and student are haptically coupled; teacher assists the student for 90 s.
d) *Retention (R):* Student tries to replicate the desired trajectory that he has trained on for thirty seconds. The exoskeleton is in haptic transparent mode.

Single sessions of demonstration and baseline are consecutively followed by six sessions of training and retention (DBTRTRTRTRTRTR) with a minute of break between each of them. The tracking error of the student is measured via the dynamic time warping algorithm [13] such that the actual trajectory is warped in a nonlinear fashion to match the desired one. This allows calculating the spatial error between two trajectories without a temporal reference.

3 Results and Discussion

The average deviation between the student's actual ankle trajectory and the desired one during the rigid demonstration, baseline, training, and retention sessions are presented in Fig. 2. Thanks to the stiff position controller, the desired target was successfully demonstrated to the student with a small mean error (8 mm). The average error during the training sessions was consistently around 2.2 cm. The baseline retention error was around 3.5 cm and dropped to 3 cm and 2.8 cm in the first and second retention sessions, respectively. This indicates some learning of the new gait trajectory with the first two dyadic training sessions. However, after the third retention session, the tracking error was increased to 3.5 cm. The student indicated the task was mentally and physically demanding, which might result in fatigue and deterioration in the performance after the third session. Another comment from the student user was that the lack of feedback on the performance during the retention sessions limits the learning significantly. The teacher reported that only following the desired trajectory was not enough, and he had to exaggerate the motion at specific points to better assist the student. This made the task quite challenging for the teacher and required high power to guide the student toward the desired gait trajectory.

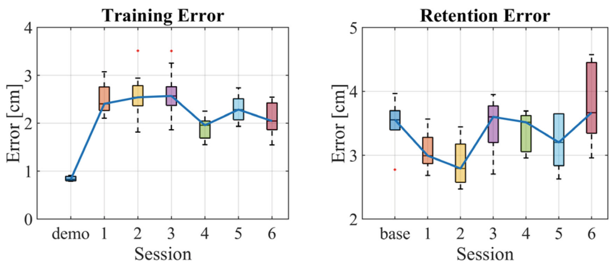

Fig. 2. Training and retention errors during different sessions.

4 Conclusion

In this pilot study, we explored an experimental setup of an exoskeleton-mediated physical teacher-student interaction for gait therapy. We observed that learning an unknown gait trajectory with only physical cues is a challenging task which makes it a good candidate for motor learning experiments to be conducted on healthy users. However, the lack of feedback during the retention sessions and the significant effort required by the teacher limits the feasibility of the tested experimental setup. In the future, we will investigate additional feedback types (e.g., visual, auditory) and haptic interaction mediums (e.g., asymmetrical) to overcome the observed drawbacks.

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