Weight perception in exoskeleton-supported teleoperation

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Abstract

Despite advances and research in the area of teleoperation (e.g. (1-3)) over the last decades and the development of active exoskeletons that provide force feedback to the human for a transparent and intuitive interaction (4), it is still challenging to measure the subjective transparency of a teleoperation system. But this information is of high interest to be able to define the sensibility of the system and to optimize the interfaces used (5). To address the question of transparency, we measure the ability of a teleoperator to distinguish weights in two different conditions: weights added to the exoskeleton ("teleoperation OFF") or to a robot under teleoperation ("teleoperation ON", see Fig. 1a and 1b). In the latter case, weight information was transferred using force feedback between two different robot platforms, i.e., RH5 Manus humanoid [6] and Recupera-Reha exoskeleton [7]. The implemented teleoperation framework utilizes the force control available in the exoskeleton and kinematic control on the humanoid. The movement intention of the human inside the exoskeleton is transferred to the humanoid robot using workspace scaling. On the other hand, forces and torques felt by the end-effector of the humanoid are scaled and transferred as additional end-effector forces in the exoskeleton's inverse dynamic model using HyRoDyn [8] to enable force feedback. Experiments were performed during a single-arm teleoperation setup without transferring movements from the human to the robot but only force feedback from the robot to the human via the exoskeleton. Both conditions, i.e., "teleoperation ON" condition (Fig. 1b) and "teleoperation OFF" condition (Fig. 1a) were compared when adding weights either to a basket attached to the robots end effector or to the end of the exoskeletons' hand interface structure. An adaptive procedure was used to determine the perception threshold to optimize sampling level.

14 participants, between 21 and 30 years old and right-handed, took part in this study. Prior to the experiments, the minimally perceptible weight during teleoperation was defined at 200g. During weight changes the position of the arm of the exoskeleton and of the humanoid were predefined. The exoskeleton was under force control and the controlled robot (used in the teleoperation condition) was under position control to only transmit forces caused by the weight added to a basked that was fixed to the end effector of the robot. To avoid visual and auditory cues the participants were blindfolded and wearing noise cancelling headphones. Each experiment starts with an empty box. After 30 seconds the start of the experiment is declared. 7 subjects started in teleoperation mode and 7 subjects with the non-teleoperation condition. Weights were changed every 10s. Weights were removed or added, depending on the participants' answers according to the weighted up-down staircase method (WUDM) by Kearnbach (9). If the participant perceived no gravitational

forces, weight was added until it was perceivable. If they perceived weight, it was reduced. In this procedure for each trial the size of the increasing steps is weighted according to the last three answers of the participant. The weight is decreased one step after each correct response and increased three steps after each incorrect one leading to a convergence level of 75%. A total of 20 trials were carried out per condition.

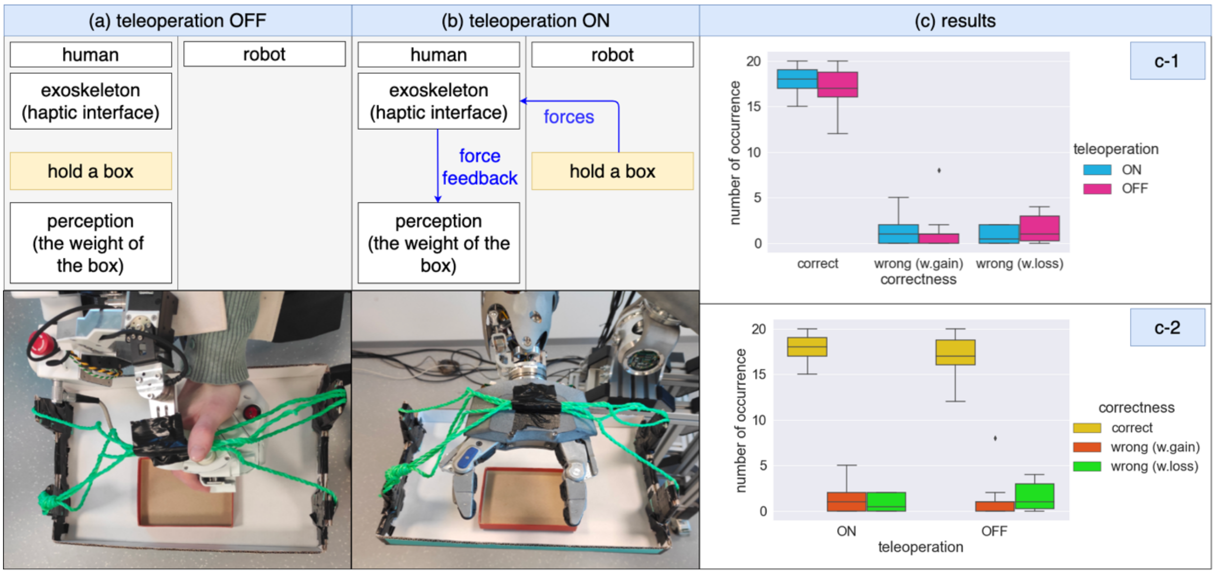

Figure 1 Experimental setup (a,b) and results (c)

For evaluation, we compared two teleoperation conditions (teleoperation ON and teleoperation OFF, see Fig. 1-c1). Further, we also compared two types of errors, which are distinguished according to whether errors occurred when the weight is decreased or increased (errors in w.gain and w. loss, see Fig. 1-c2). For statistical analysis, we performed Friedman test with two within subjects-factors (teleoperation and error type). Dunn's tests were performed as post-hoc analysis and Bonferroni correction was performed for multiple comparisons. We found no significant differences between both teleoperation conditions for both correct and erroneous responses [teleoperation ON vs. teleoperation OFF: $p = n.s.$, see Fig. 1c-1]. Further, we found high accuracy of weight estimation for both teleoperation modes [teleoperation ON in correct responses vs. teleoperation OFF in correct responses: $p = n.s.$, see Fig. 1c-2] and no significant differences between both error types [$p = n.s.$, see Fig. 1c-2].

In summary, we were able to show that our force feedback approach during teleoperation was able to transfer weight sensation comparably well as adding weights directly to the exoskeleton the user is wearing. In the future, we will conduct further experiments to measure the transfer of forces from a teleoperated system to a human via an exoskeleton while the human is teleoperating the robot, i.e., while both systems are under force control and the human is moving the robot via the exoskeleton. This will be a next step in evaluating the transparency of a teleoperation system.

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