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MESSPa: Multi-modal Embodiment Stimulation Shoulder Pad

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I. Introduction

In recent years, wearable robotics have emerged as a transformative technology with the potential to significantly enhance human capabilities and performance. A critical factor in their effectiveness is the user's degree of embodiment, encompassing the sense of agency and ownership, which influence how naturally a user interacts with the device.

Despite advancements, a significant challenge remains: maintaining a high sense of agency and ownership across different states of wear. Users typically experience strong control and connection when the robotic arm is attached, but this diminishes when it is detached, reducing effectiveness and satisfaction. This study explores the following questions:

- How can we maintain a consistent sense of agency regardless the robotic arm is or not attached?
- Can we enhance the sense of embodiment to improve task performance with wearable device?

We propose a system integrating motion transfer and innovative balloon-based haptic feedback to enhance the sense of embodiment and agency.

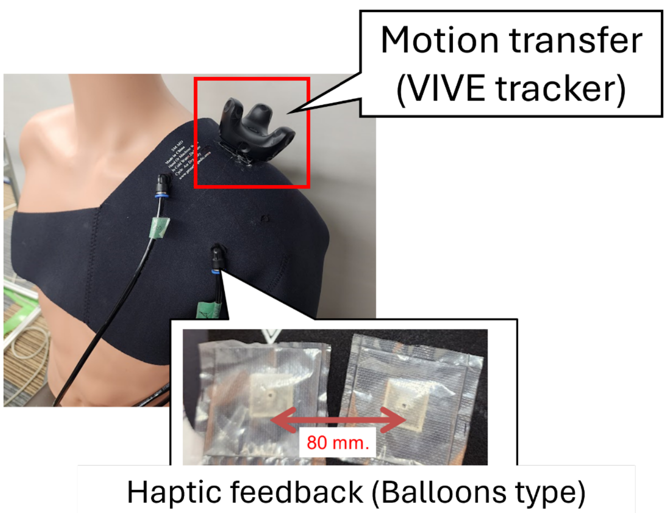

Fig. 1. MESSPa that consisted of motion transfer and haptic feedback (4 balloons)

II. System Design

A. Implementing Motion Transfer

We integrated the HTC VIVE motion tracker, allowing users to control the robotic arm with their body movements. The motion tracker captures real-time user movements and translates them into commands for the robotic arm.

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B. Balloon-based Haptic Feedback

To enrich user experience and strengthen the sense of ownership, we are exploring balloon based feedback technology. Traditional vibration feedback can become uncomfortable or desensitizing over time [1]. Balloon based feedback involves air-filled compartments that expand or contract in response to user interactions, providing more natural and intuitive haptic feedback [2], [3].

Balloons are positioned on the shoulder area, near the main points of contact and control with the robotic arm, ensuring immediate and relevant feedback. Four balloons are used to provide comprehensive coverage, simulating various types of feedback, such as direction and pressure.

Each balloon measures 50x50 mm, providing a noticeable tactile response without being cumbersome. The spacing between balloons is 80mm, ensuring distinct perception of each balloon's feedback, based on the two-point discrimination threshold. Also, The spacing between each balloon is set at 80 mm, a decision informed by studies on the two-point discrimination threshold, which ranges from 31-44 mm in humans [4].

The pneumatic system provides air pressure to the balloons and collects feedback based on user input. It operates with a compressor generating initial air pressure, regulated by a proportional valve to maintain 0.05 MPa. Solenoid valves are connected to the balloons for precise control.

Finally, Fig. 1 shows the MESSPa, which transfers user motions to the robotic arm using the motion tracker and provides feedback regarding the arm's position through balloon feedback.

III. Experiment design

The experiment is defined with 2 conditions, with MESSpa and without MESSPa. Fig. 2(a), shows the condition without MESSPa. Consequently, the experiment procedure will be as follow:

1) The task screen displays a green circle in the center (Fig.2(b)).
2) The participant moves a laser pointer on the robot arm to the green circle and presses "Enter" on a small keyboard. Unity records the laser pointer's position and logs the time in a CSV file.
3) After pressing "Enter," the task screen reverts to the center position, prompting the participant to repeat step 2. This sequence is repeated for 5 minutes.

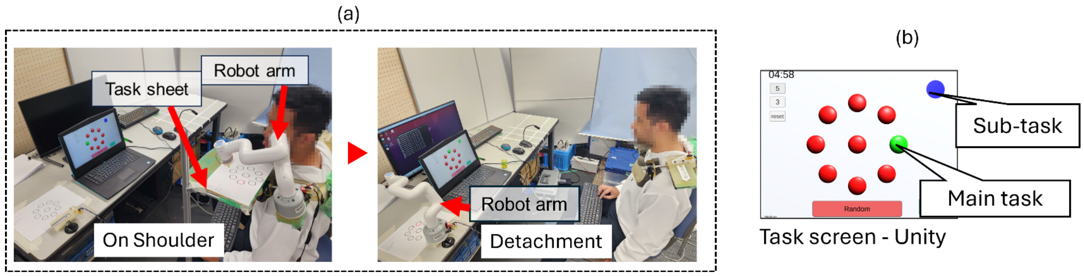

Fig. 2. (a) Experiment setup on shoulder condition and detachment without MESSpa, (b) Task Screen

IV. Result & Discussion

Data were collected from 12 participants(11 males, 1 female), aged 21-30(mean = 24.3, SD = 2.34)

A. Time to Finish Task

A comparison with a previous experiment (Fig.3) evaluated the device's impact on participant speed. One-way ANOVA showed significant differences among wearing conditions (with/without MESSPa and on shoulder/detachment) (F=35.881, df=3, $p < 0.001$). A post hoc t-test with Bonferroni adjustment revealed:

1) On shoulder vs. detachment without MESSPa: Task completion was significantly faster on the shoulder ($p < 0.001$).
2) On shoulder vs. detachment with MESSPa: No significant difference (p = 0.803).
3) Detachment with vs. without MESSPa: Task completion was significantly faster with MESSPa ($p < 0.001$).

These results suggest using MESSPa allows users to finish tasks faster and with greater consistency.

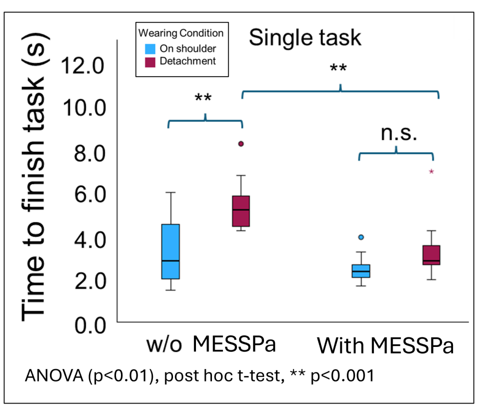

Fig. 3. Comparison of Time to Finish Task with and without haptic device in the detachment with wearing condition

1) Sense of Ownership and Agency: A comparison is made (Fig.4) evaluated improvements in participants' Sense of Embodiment (SoE) using the haptic device. A paired t-test in the detachment condition showed a significant improvement in Sense of Agency (t = 3.563, df = 11, p = 0.004). However, Sense of Ownership showed no significant difference (t = -0.507, df = 11, p = 0.311).

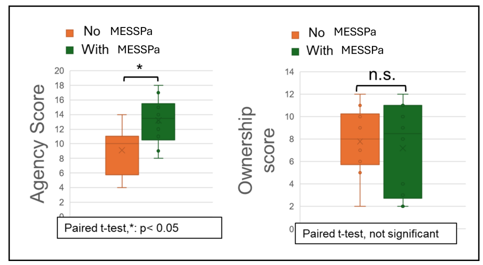

Fig. 4. Comparison of Agency and Ownership between with and without haptic device in the detachment with wearing condition

The study shows an improved sense of agency with the MESSPa, indicating that real-time, intuitive feedback enhances control over the robotic arm. However, the sense of ownership did not significantly change, highlighting the challenge of making the robotic arm feel like a part of the user's body. This suggests a need for further research to enhance both aspects of embodiment in system design.

References

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