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Exploring Haptic Force Feedback for Jumping in Virtual Reality Using Ankle Joint Robotic Interface

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***Abstract*— This work investigates the effect of haptic force feedback on jump performance and muscle activation using a custom-designed seated virtual reality foot platform. Four participants performed 20 jumps per condition (with haptic force feedback and without haptic force feedback). Muscle activation and jumping kinematics was recorded and analysed. The results show that the presence of force feedback increased jump height and muscle activation. This pioneering work on using seated haptic interface for virtual jumping task demonstrates significant potential to enhance VR-based physical training, gamification and lower limb rehabilitation.**

I. Introduction

Prior studies on walk-in-place haptic platforms have shown promise for VR locomotion [1], yet jumping remains underexplored. Seated haptic VR platforms have the advantages of being more accessible to impaired users [2] and more portable [3]. However, they lack the level of feedback that walking using motion capture VR devices provides. This can be mitigated by adding haptic feedback to platforms. This research aims to investigate how a haptic platform can repeatably simulate a high jump in VR while producing similar lower-leg muscle activation to real-world jumps. Two haptic feedback conditions were tested to evaluate platform usability and motor learning. The hypothesis is that force feedback can also improve the users' learning, i.e. the higher the user's muscular effort the more repeatable and reliable the user's performance.

II. Design And Methods

The setup, shown in Fig. 1, consists of a single DC-motor driven dual-foot seated platform that can swivel enabling a user's ankle joint flexion with a 1:20 transmission module [4]. The ankle-foot platform is used to control a standing VR humanoid avatar's ankle joints to perform vertical jumping movements. The virtual floor and foot collisions are fully inelastic, i.e. all energy is transferred from the avatar to the floor when landing.

A. Haptic feedback conditions

These represent the rules on how the haptic feedback is rendered. Since information flows between the virtual and the real world in both directions, the haptics have to be rendered both in the Real World and the VR World.

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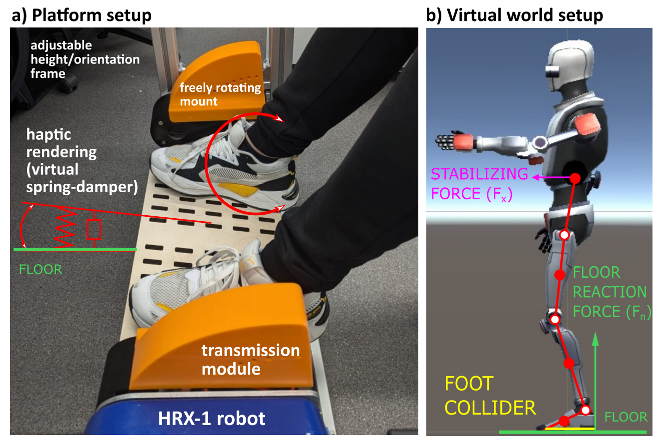

Fig. 1. Haptic setup. **a)** The haptic platform, composed of the HRX-1 robot with the BLDC motor, the 1:20 step down direct drive cable transmission module, and the two foot platform. The freely rotating mount is only used for support. The setup is fully adjustable. The haptic force rendering is completely electronic, there are no passive mechanical components. **b)** Virtual Model setup. The red circles represent the ceter of mass, the segments are the chain links and the white and red circles are the 2D PD controlled revolute joints

For each environment, we investigate two rules on how the haptics are rendered:

- "Force Feedback" (1) and (3)
- "No-Force Feedback" (2) and (4)

For platform rendering, the haptics are shown as in (1), where θ_p is the angle of the platform with respect to the floor, τ_{out} is the haptic force feedback of the platform, θ_a is the ankle angle of the virtual avatar, k is a constant, Z_g is the gravity compensation factor, B is the viscous friction or virtual damping. The damping is applied on negative platform angles as a resistive torque, while the $k\theta_a$ factor is applied only on positive avatar ankle angles as an assistive torque to transfer the user's crouching effort. The non-force feedback system defined by (2), and the only difference is that the damping element is not used to calculate the motor torque.

$$B\dot{\theta}_p + Z_g(\theta_p) - k(\theta_a) = \tau_{out} \tag{1}$$

$$Z_g(\theta_p) - k(\theta_a) = \tau_{out} \tag{2}$$

In the Virtual World, the avatar's movement is rendered by flexing the 3 joints down proportionally with the user's foot dorsiflexion as shown in (3). To initiate the jump, the platform torque τ_p is sampled, summed and averaged over a 200 ms window $W = \{t_1 = -200ms, t_2, \ldots, t_n = 0\}$. To make it platform-agnostic, the torque is divided by the

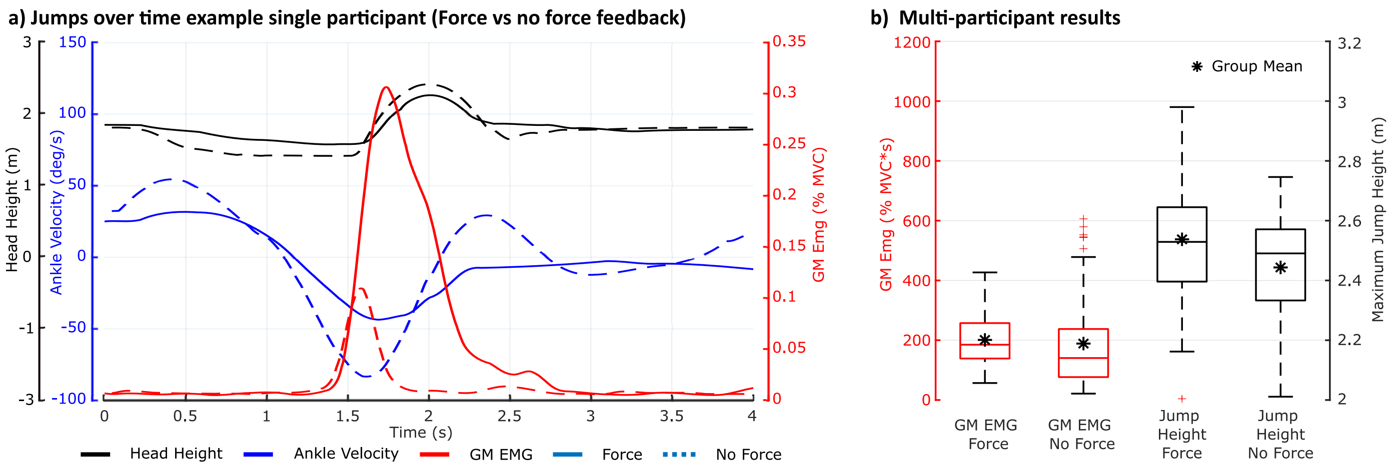

Fig. 2. Preliminary Results. **a)** Time results. This shows the jump characteristics Gastrocnemius Medialis (GM), Ankle velocity and Avatar Jump Height, over time between the two haptic regimes (Force, No Force) **b)** Results with 4 participants. These show the statistical distribution of the results over 20 jump per participants. For each jump the integrated Gastrocnemius Medialis (GM) activation has been calculated, along the maximum avatar jump height achieved. It seems that the No Force condition leads to lower EMG activations and jump heights.

platform mass m_p and multiplied by a constant C and the Avatar mass m_a. The resulting impulse is sent as a continuous torque to the Avatar's ankle joint τ_a. In the no force feedback regime, the same equation is used, but the system is sampling the platform's acceleration $\ddot{\theta}_p$ instead of the platform motor's torque that is disabled.

$$\tau_a = \left(\sum_{t \in W} \tau_p(t) \Delta t - \frac{1}{N} \sum_{i=1}^{N} \tau_p(t) \right) \cdot \frac{C \cdot m_a}{m_p} \tag{3}$$

$$\tau_a = \left(\sum_{t \in W} \ddot{\theta}_p(t) \Delta t - \frac{1}{N} \sum_{i=1}^{N} \ddot{\theta}_p(t) \right) \cdot \frac{C \cdot m_a}{m_p} \tag{4}$$

B. Data Collection Methods

Four participants, all male, aged between 21-31, agreed to test these haptic regimes. Each participant was briefly coached and shown by the experimenter how to perform a jump using the platform. Consequently, they were asked to do 20 real full body jumps, 20 with force feedback and then 20 without. Everyone was asked to make the avatar jump up to a specific height of 2.5 meters (avatar's height 1.8 m), visualized by a green sphere on a screen. The participants were not told what the difference would be between the two force feedback conditions. EMG electrodes were placed on the Tibialis Anterior and Gastrocnemius Medialis to record the muscular activation while jumping.

III. Results and Future Work

As shown in Fig. 2, preliminary results suggest a measurable difference between the two haptic regimes. The "No-Force" regime revealed that the muscular activation of the Gastrocnemius Medialis is lower and the maximum jump height showed greater variability compared to the "Force" regime. The integrated GM EMG and jump heights for the "Force" regime look normally distributed with more consistent quartile shapes compared to the "No-Force" regime, this could suggest that the "No-Force" jump haptic pattern is more repeatable. If users can reach the target height more repeatably, the evidence supports that users can learn more effectively with force-feedback haptics. Across time, the achieved jump height of the avatar and the start time of the jump are similar, they both occur at the minimum ankle velocity, proving that both haptic regimes can seamlessly initiate a jump. The difference between the two haptic regimes is as expected: muscular activation is higher with the "Force" regime while the ankle speed is higher with the "No-Force" regime. The "No-Force" regime results in a lower minimum ankle velocity and muscular activation compared to the "Force" regime. However, it is still unclear whether the difference in results is caused by a more repeatable haptic algorithm, or genuinely improved learning by the users.

Overall, the results are promising in showing that force feedback yields better haptic jump repeatability. However, to confirm the hypothesis that it can improve learning, more participants are needed to produce stronger statistical results. Additional tasks such as obstacle jumping, will be used to check if learning is affected by haptic regimes. Further analysis such as PCA or clustering may help reveal patterns between variables and haptic regimes. Additionally, user experience surveys and comparisons with real jumps will also be investigated.

References

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