Grip Force Dynamics during Exoskeleton-Assisted and Virtual Grasping

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Motivation and Scientific Background

The analysis of grip forces during grasping and lifting diversely weighted objects is highly informative about an individual's level of sensorimotor control and potential neurological condition [1]. Thus, it provides a powerful tool to design and assess neurorehabilitation therapy.

Main Research Question

Are the natural characteristics of the grip force dynamics preserved during modern hand rehabilitation methods such as exoskeleton-assisted grasping and grasping of virtual reality objects?

Methods

Experimental Setup

Six healthy participants are instructed to perform three sets of repeatedly pinch grasping and lifting an object with varying weight under different conditions:

- Normal Grasping
- Exoskeleton-Assisted Grasping: The participants adjust the grasping force using a turn knob.
- Virtual Load Grasping: The virtual object in a video game can only be lifted if a specific force threshold is reached ("virtual load").

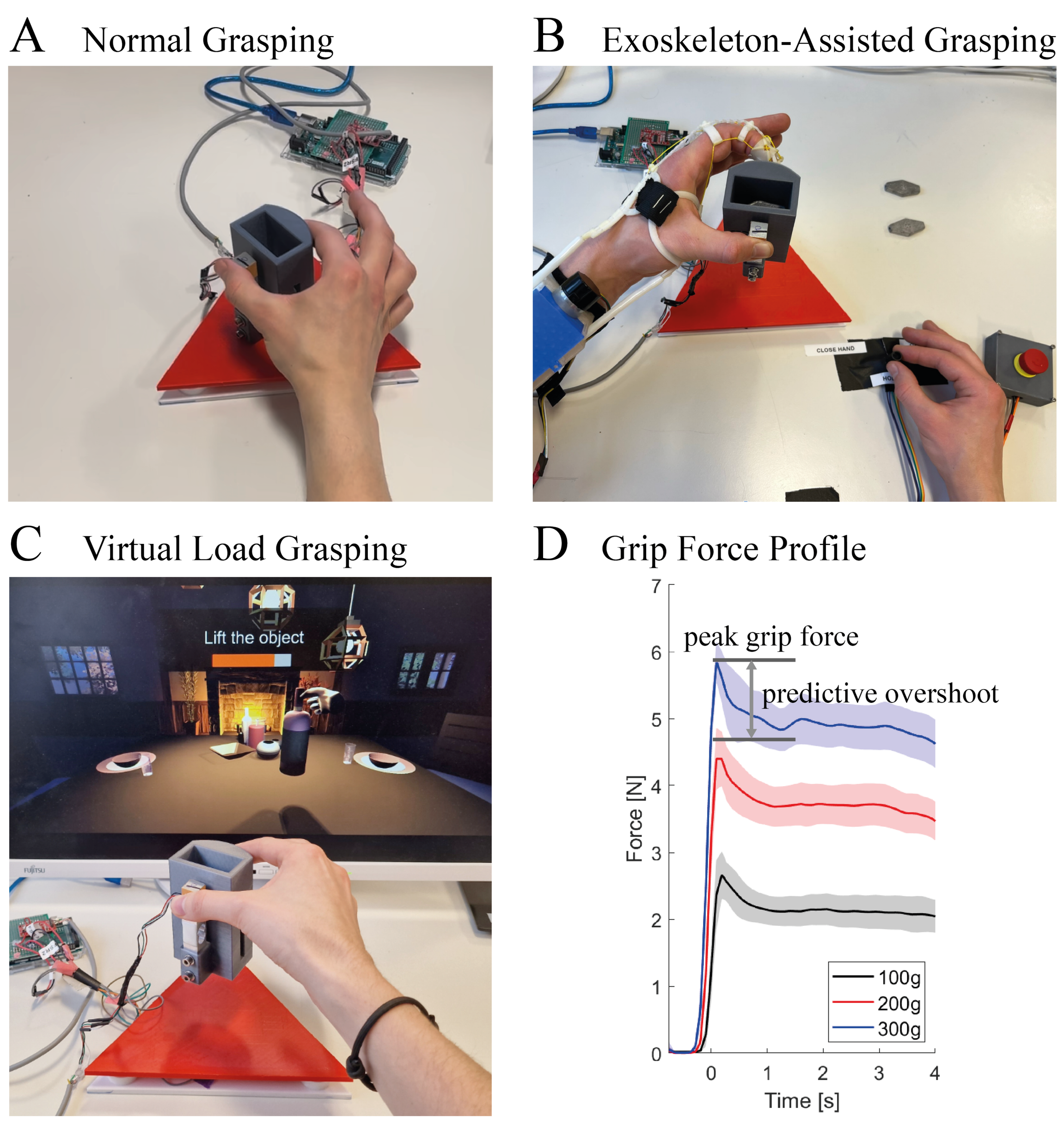

Figure 1: A-C) The grasping interface is lifted in three different experimental settings, while the grip force and ground contact are measured. D) A characteristic grip force profile of a healthy subject during normal grasping of different weights.

Technical Design

A soft, 3D-printed and tendon-driven exoskeleton actuates the index finger. As grasping interface we use a 3D-printed box that can be filled with different weights. This box is placed on a pressure plate (see Fig. 1).

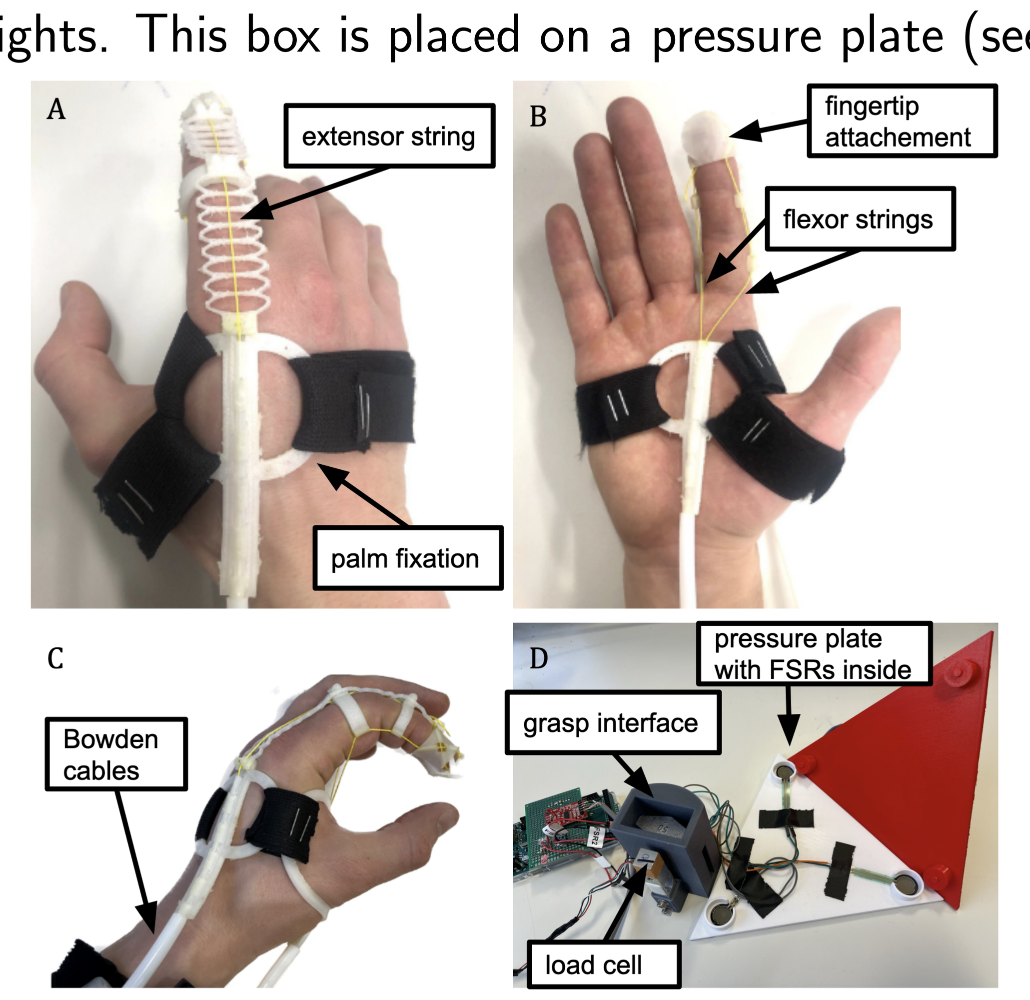

Figure 2: A-C) Minimalistic design of the index finger exoskeleton from different perspectives. D) A load cell is attached to the weight box to measure the grip force and force sensing resistors (FSRs) underneath the pressure plate inform about the timing of lifting and putting the object down.

Results

Characteristic Grip Force Profiles

- The positive correlation between grip force and object weight shows force efficient grasping, also during exoskeleton assistance.
- Inertial effects are compensated by an initial force overshoot at lift-off, even during exoskeleton assistance, where some participants contributed with their own muscle force. (Especially Participants 1 and 3.)
- The magnitude of this overshoot scales with the object weight.
- During virtual grasping the overshoot does not scale with the physical but virtual weight.
- The absence of time delay of the force adaption indicates that inertial effects are predicted instead of only perceived by sensory feedback [2].

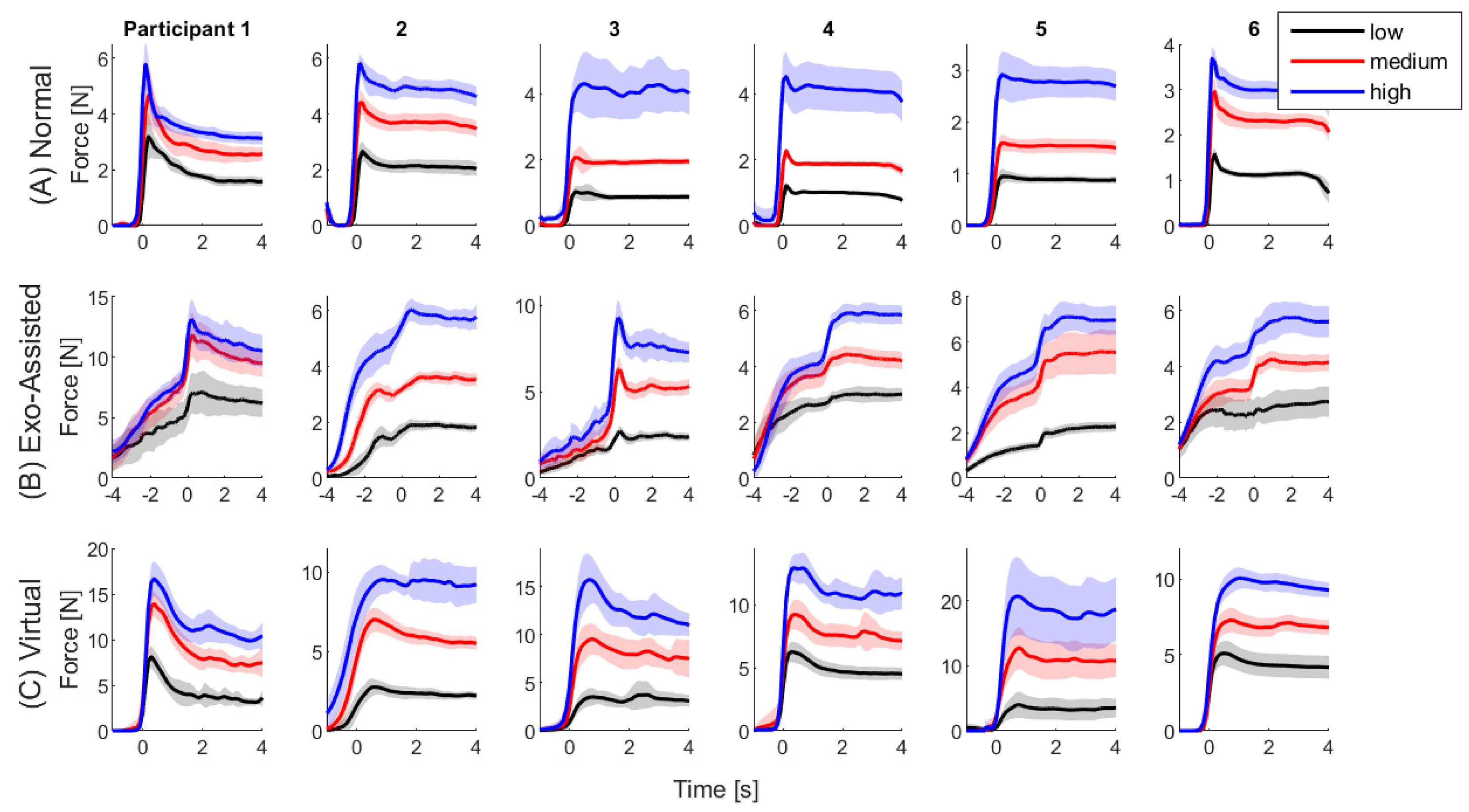

Figure 3: Average grip force and standard deviation of six participants under three different conditions: normal, exoskeleton-assisted and virtual load grasping. The grasps are aligned at the time of lift-off (0s). For conditions (A) and (B), weights of 100g, 200g and 300g are used.

Learning and Adaptation

- Over time, participants improve the grasp efficiency by applying smaller grip forces. This learning curve is steepest in the virtual condition and less significant during exoskeleton-assisted grasping.
- When changing from a high to low weight, participants initially apply more force than they learned is needed but adapt quickly to the new weight. This *wash out* or *aftereffect* [3] becomes visible in grasp 2, 8 and 14.

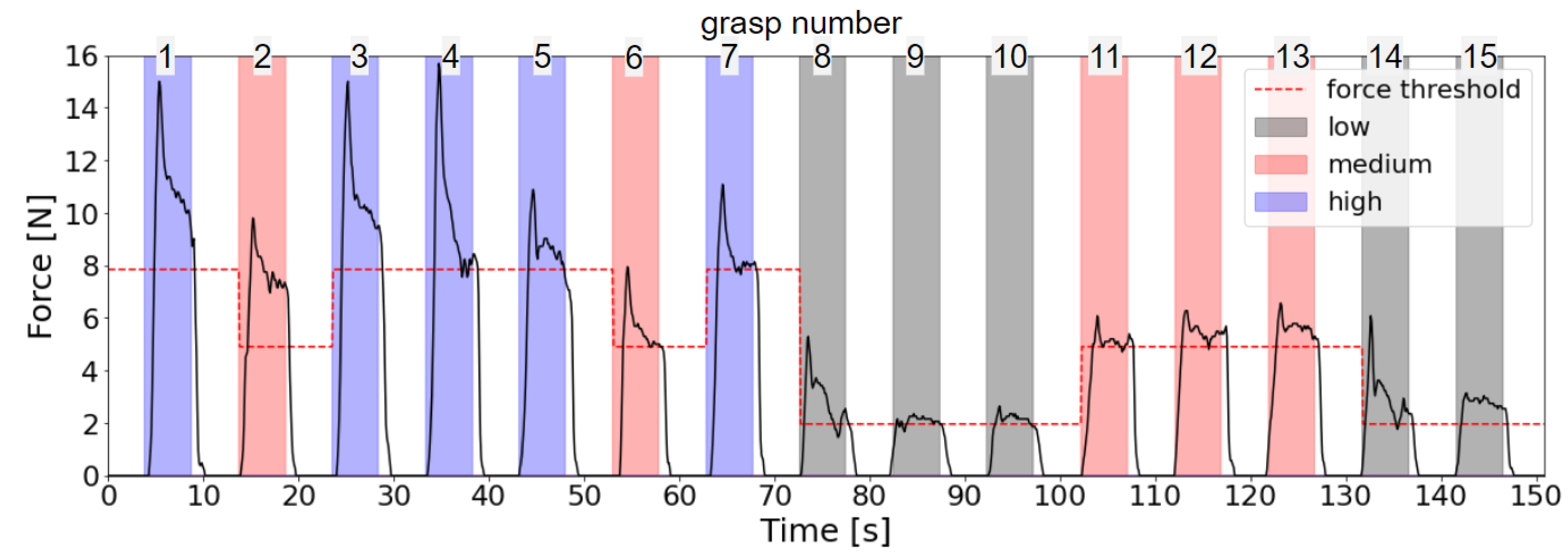

Figure 4: Grip forces of an exemplary sequence of grasping different virtual loads (low, medium and high) in random order. The filled sections indicate that the object is lifted.

Conclusion

- **The core characteristics of grip force dynamics are preserved under both rehabilitation settings exoskeleton-assisted and virtual load grasping in healthy participants.**
- Incorporating insights about grip force dynamics in the design of neurorehabilitation methods can improve their usability and rehabilitative function.
- For example: Designing compliant hand exoskeletons such that natural grip force dynamics are not disturbed allows to use grip force as bio-feedback signal.

References

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