Adaptation of grasping behavior to 3D printed surface textures

Maria F Pena Prieto[1] , Ying Lu[2], Seda Bilaloglu[3,4], Chelsea Tymms[5], Megan Caughey[3], Matthew Bird[1], Manuel A. Anaya[1], Esther Gardner[6], Preeti Raghavan[1,3]

1. Department of Physical Medicine and Rehabilitation, Johns Hopkins University School of Medicine, Baltimore, MD; 2. Department of Applied Statistics, Social Science and Humanities, NYU Steinhardt, New York, NY; 3. Department of Rehabilitation Medicine, New York University School of Medicine, New York, NY; 4. Center for Data Science, New York University, New York, NY; 5. Department of Computer Science, New York University, New York, NY; 6. Department of Neuroscience and Physiology, and NYU Neuroscience Institute, New York School of Medicine, New York, NY.

Introduction

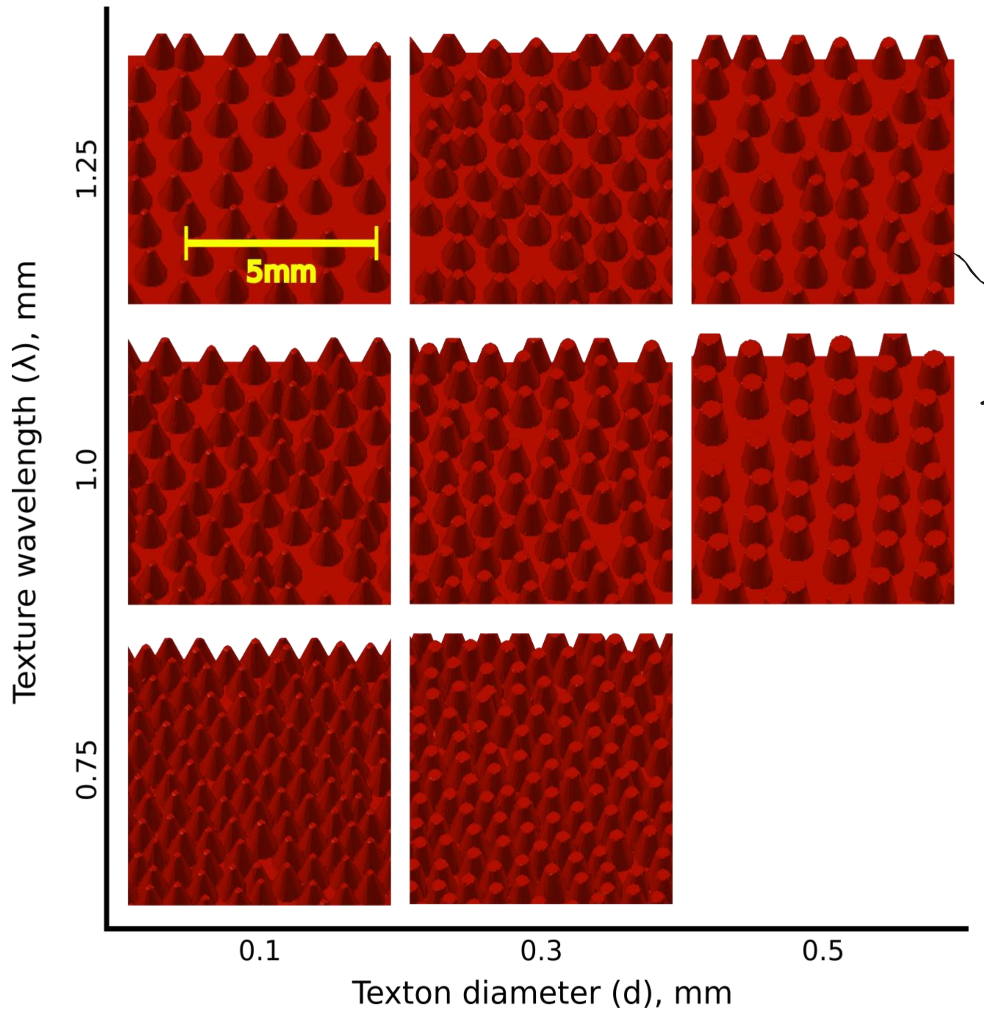
Surface texture is important for haptic perception to adapt fingertip forces and prevent use of inadequate or excessive forces during object manipulation.[1,2] Previous work has used surfaces that do not have quantifiable tactile features limiting our understanding of texture perception.[3] In this study, we used 3-D printed textures of precise surface geometry to examine the mechanisms of tactile roughness perception and grasping behavior. The 3-D printed textures were affixed to the grasping surface of a precision grip instrument which measured grip and load forces applied during a grasp and lift manual dexterity task, to permit quantitative analyses of grasping behavior.

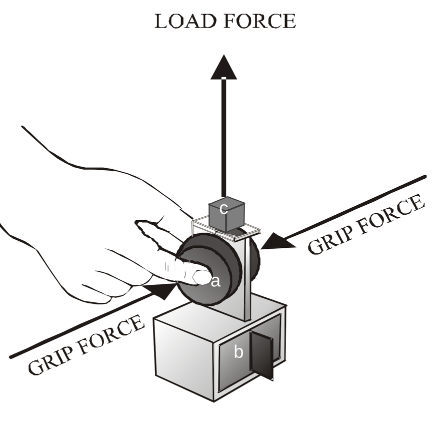
Objectives

The objective of the study was to examine the extent to which object weight and texture parameters - texton size and wavelength - explain adaptation and execution of fingertip grip and load forces.

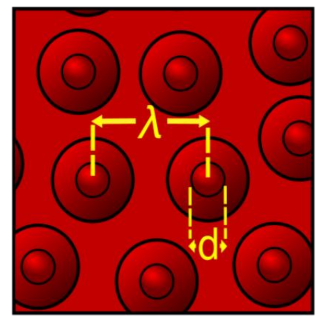
Materials and Methods

We created 8 different 3-D surface textures, where the texture elements, Textons, were truncated cones with texton diameters *(d)* of 0.1, 0.3, or 0.5 mm, spaced at wavelengths (λ), the center-to-center distance between the texton tip diameters, of 0.75, 1.0, or 1.25 mm apart. Ten healthy adult subjects grasped the instrument grip device using bare hands. The eight different textures were used with the grip device weighing 250 g, 450 g, and 650 g. The grip and load forces were measured at a sampling rate of 400 Hz, and the grip force rates and load force rates were computed.



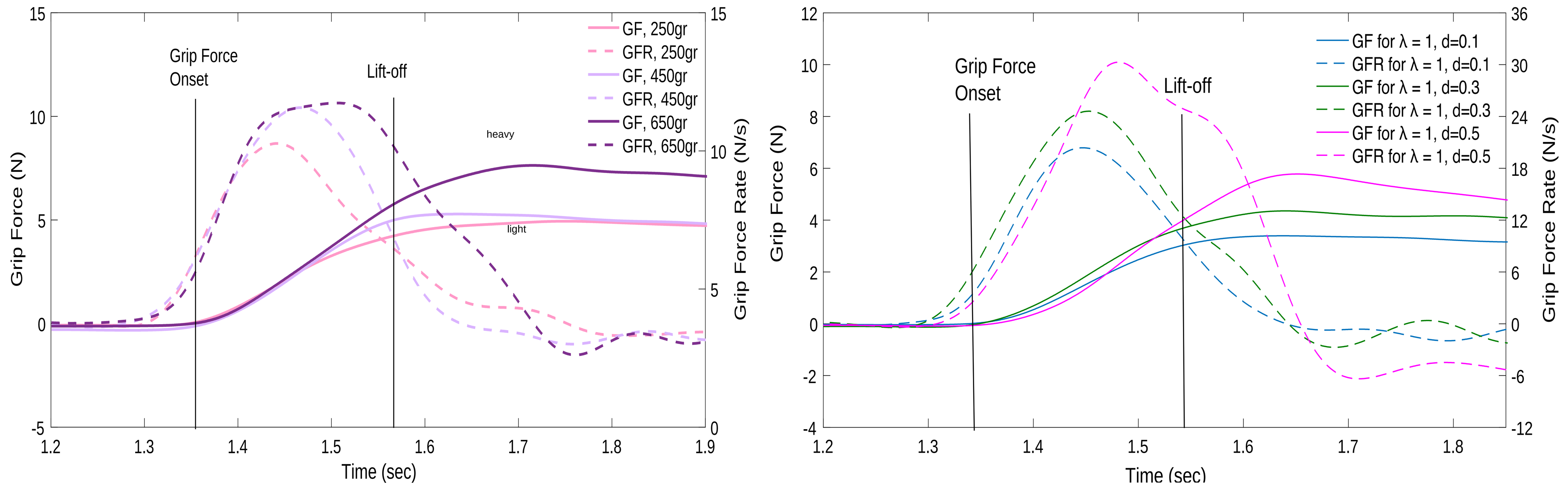


Grip instrument

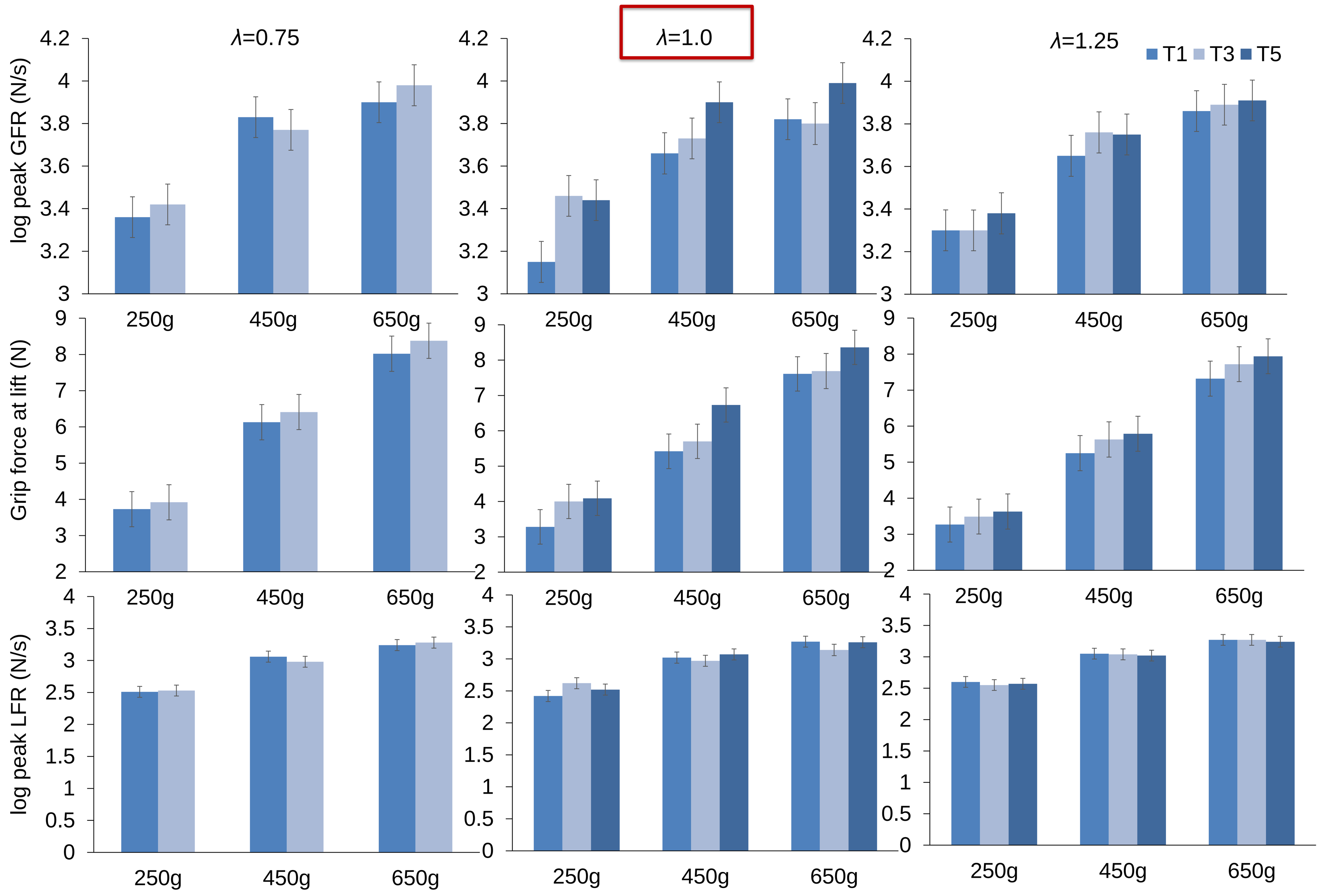


Results

Grip force rates scale to object load and texture before lift-off

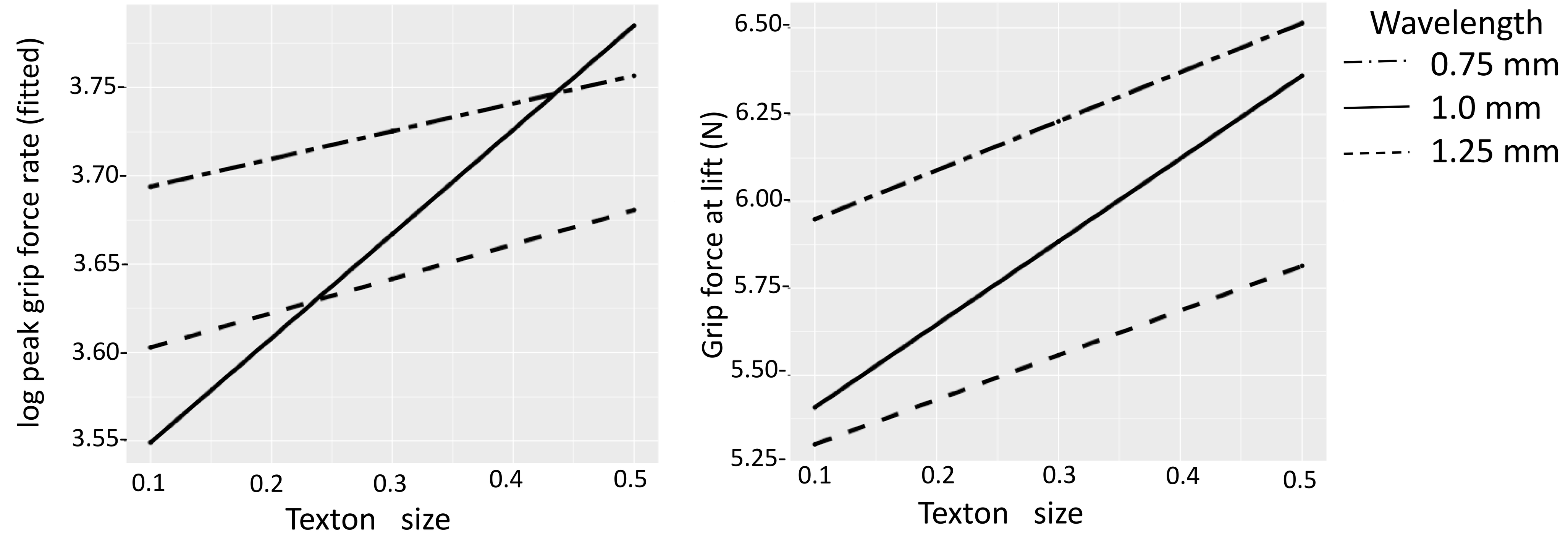


Representative data for λ=1 and d=0.3 from a single subject and single trial. The peak grip force-rates are higher for the heavier object weight. Representative data for λ=1 and weight=250g from a single subject and single trial. The peak grip force-rates are higher for textures with larger texton diameters (smoother textures).



Mean values of the variables representing grasping behavior across all subjects for the three weights and texton sizes (*d*=0.1, 0.3 and 0.5) arranged by wavelength (λ).
Note that load has a strong effect on all grasping variables. At a given load and wavelength, there is a general trend that as texton size increases, the log pGFR and grip force at lift increase. This effect appears to be strongest at a wavelength of 1 mm.

Linear relationship between grasping behavior strongest at λ=1



At a wavelength of 1, an increase in texton size increases the grip force rate by 12% as suggested by the slope (b=0.589, $p<0.001$). Similarly, there is linear relationship between texton size and grip force at lift-off, which is also the strongest when the wavelength of the surface texture is 1mm (b=2.387, $p<0.001$). These relationships are much weaker at wavelengths of 0.75 mm and 1.25 mm.

Conclusion

- Grip force rates scaled to object loads and the parameterized textures.
- Load has a strong effect on all grasping variables, but texton size shows a linear effect on grip force scaling and execution, which is strongest at a wavelength of 1 mm
- These results confirm that texture information from the fingertips is coded independently of load information for sensorimotor integration.
- Next steps will examine the relationship between texture properties and roughness perception on grasping behavior.

References

1. Johansson, R.S. and G. Westling, *Roles of glabrous skin receptors and sensorimotor memory in automatic control of precision grip when lifting rougher or more slippery objects.* Exp Brain Res, 1984. **56**(3): p. 550-64.

2. Westling, G. and R.S. Johansson, *Factors influencing the force control during precision grip.* Exp Brain Res, 1984. **53**(2): p. 277-84.

3. Bilaloglu, S., et al., *Effect of blocking tactile information from the fingertips on adaptation and execution of grip forces to friction at the grasping surface.* J Neurophysiol, 2016. **115**(3): p. 1122-31.

Funding acknowledgement: R01HD071978, R21AG064452

Email: Maria Pena (mpenapr1@jhmi.edu)