Lawrence, M.A., Kitada, R., Klatzky, R.L. & **Lederman, S.J.** (2007). ***Haptic roughness perception of linear gratings via bare finger or rigid probe.*** Perception, 36, 547-557.

Abstract
The magnitude of perceived roughness was haptically estimated as subjects freely explored linear gratings with either the bare finger or a rigid stylus-shaped probe. A considerably expanded range of ridge and groove width was investigated, relative to the extant literature. The four experiments collectively indicate that, for both finger and probe-end effectors, the variance in the estimates of perceived roughness was predominantly predicted by a single parameter: groove width. The functions relating perceived roughness to groove width increased over a narrow band relative to the full range of values, then flattened. These data have archival values for models of roughness perception involving both direct and indirect touch.

Klatzky, R.L. & **Lederman, S.J.** (2006). ***The perceived roughness of resistive virtual textures: I. Rendering by a force-feedback mouse.*** ACM: Transactions of Applied Perception, 3 (1), 1-14.

Abstract
In previous work we demonstrated that people reliably perceive variations in surface roughness when textured surfaces are explored with a rigid link between the surface and the skin [e.g., Klatzky and Lederman, 1999; Klatzky et al. 2003]. Parallel experiments here investigated the potential of a force-feedback mouse to render surfaces varying in roughness. The stimuli were surfaces with alternating regions of high and low resistance to movement in the x dimension (called ridges and grooves, respectively). Experiment 1 showed that magnitude ratings of roughness varied systematically with the spatial period of the resistance variation. Experiments 2 and 3 used a factorial design to disentangle the contributions of ridge and groove width. The stimuli constituted eight values of groove width at each of five levels of ridge width (Experiment 2) or the reverse (Experiment 3). Roughness magnitude increased with ridge width while remaining essentially invariant over groove width. Kinematic variations in exploration were observed across the surfaces. The data point to the promise of using inexpensive devices to create virtual textural variations under conditions of unconstrained exploration.

Lederman, S.J., Klatzky, R.L., Tong, C. & Hamilton, C. (2006). ***The perceived roughness of resistive virtual textures: Effects of varying viscosity with a force-feedback device.*** ACM:Transactions of Applied Perception, 3 (1), 15-30.

Abstract
Klatzky and Lederman (2006) have shown that tangential resistive forces may be used to convey roughness of virtual textures using the Wingman force-feedback mouse. Modeling our experiment after that study, we directly examined the effect of viscous resistance on the perceived roughness magnitude of virtual gratings using a PHANTOM. For each virtual grating, the resistance level encountered at the ridges was varied by altering the viscosity coefficient. Perceived roughness increased with increasing viscosity coefficient. The ridge-to-groove ratio contributed a small additional effect. These results suggest that simple models of viscous resistance may be used to simulate varying levels of surface roughness.

Klatzky, R.L. & **Lederman, S.J.** (1999). ***Tactile roughness perception with a rigid link interposed between skin and surface.*** Perception & Psychophysics, 61(4), 591-607.

Abstract
Subjects made roughness judgments of textured surfaces made of raised elements, while holding stick-like probes or through a rigid sheath mounted on the fingertip. These rigid links, which impose vibratory coding of roughness, were compared with the finger (bare or covered with a compliant glove), using magnitude estimation and roughness differentiation tasks. All end effectors led to an increasing function relating subjective roughness magnitude to surface interelement spacing, and all produced above-chance roughness

discrimination. Although discrimination was best with the finger, rigid links produced greater perceived roughness for the smoothest stimuli. A peak in the magnitude-estimation functions for the small probe and a transition from calling more sparsely spaced surfaces rougher to calling them smoother were predictable from the size of the contact area. The results indicate the potential viability of vibratory coding of roughness through a rigid link and have implications for teleoperation and virtual-reality systems.