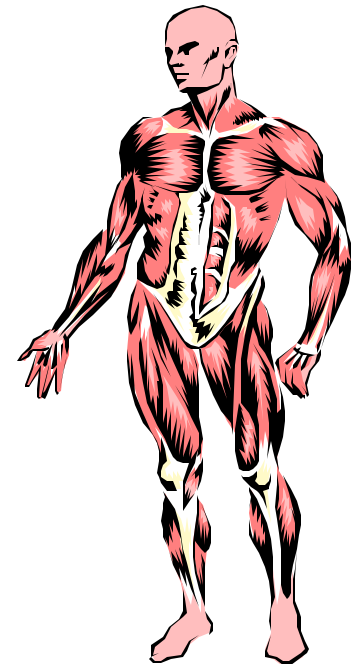
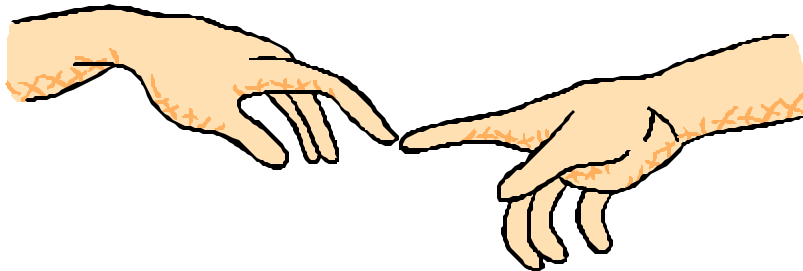


Human Factors and Haptic Interfaces

Lynette Jones,
Department of Mechanical Engineering,
Massachusetts Institute of Technology.



Human skin

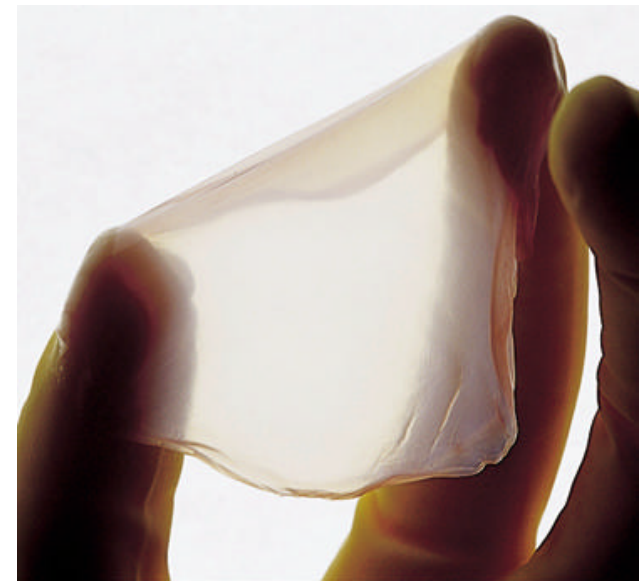
**Surface of average sized adult human: 1.8 m²
(1000 times that of retinae)**

Density: 1250 kg/m³

Weight: 5 kg

Total number of axons converging on CNS: 1.1*10⁶

**Retina: 10⁶ axons,
Cochlea: 6*10⁴ axons**



Haptics and Vision

	Information capacity (bits/sec)	Temporal acuity
Fingertip	10^2	5 ms
Ear	10^4	0.01 ms
Eye	10^6 - 10^9	25 ms

Time delays differ for hand and eye – hand is quicker than the eye

Information Channels in Human Hand

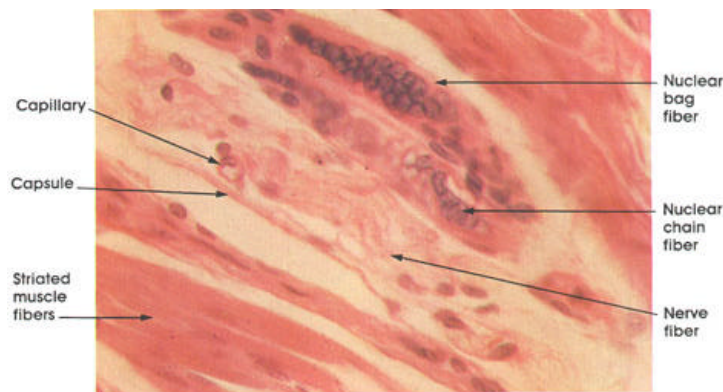
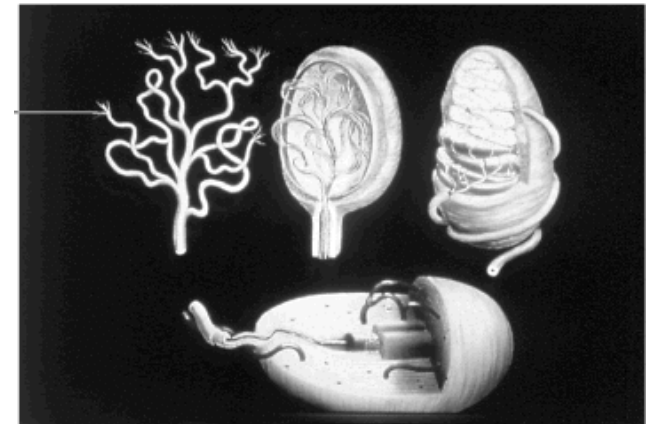
SENSORY

7 classes of **Mechanoreceptor**
(17,000 – glabrous skin)

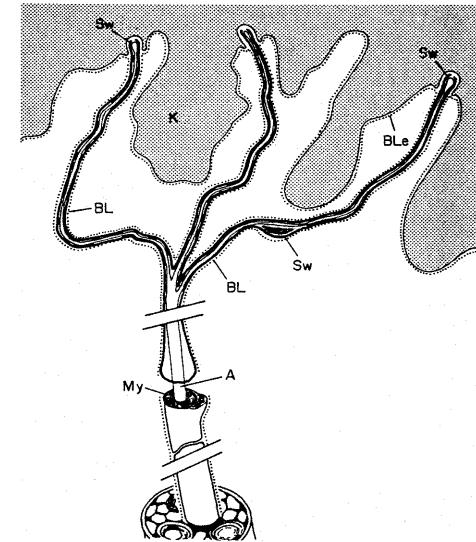
2 classes of **Thermoreceptor**

4 classes of **Nocioceptors**

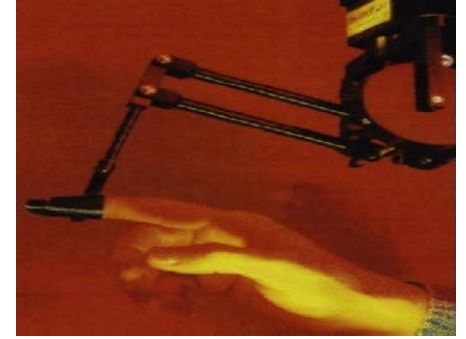
3 classes of **Proprioceptor**
(0-300 in different muscles)



20 μ m



Sensory Receptor Properties and Haptic Display Design

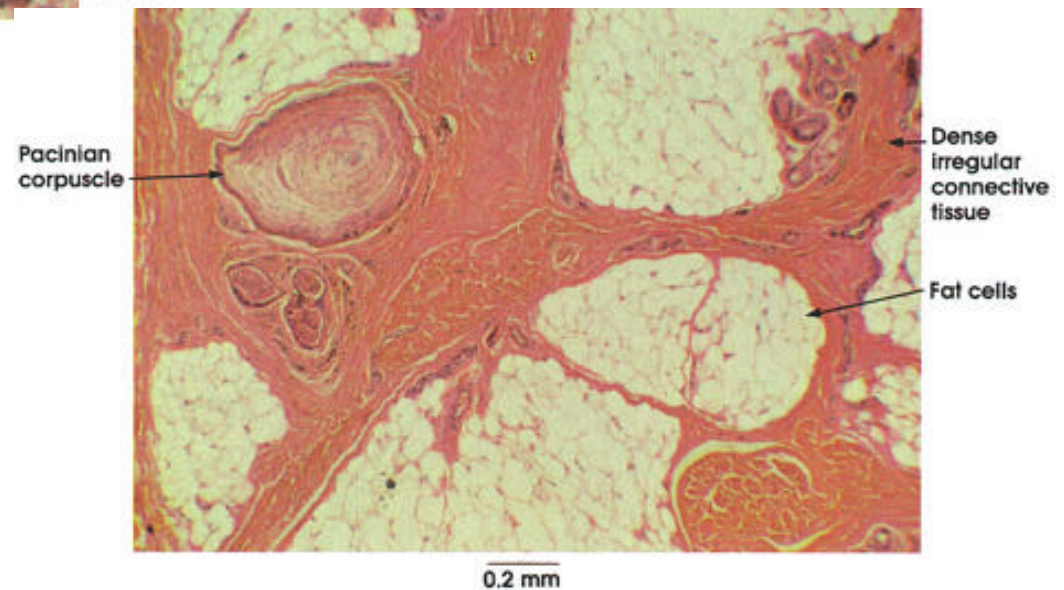
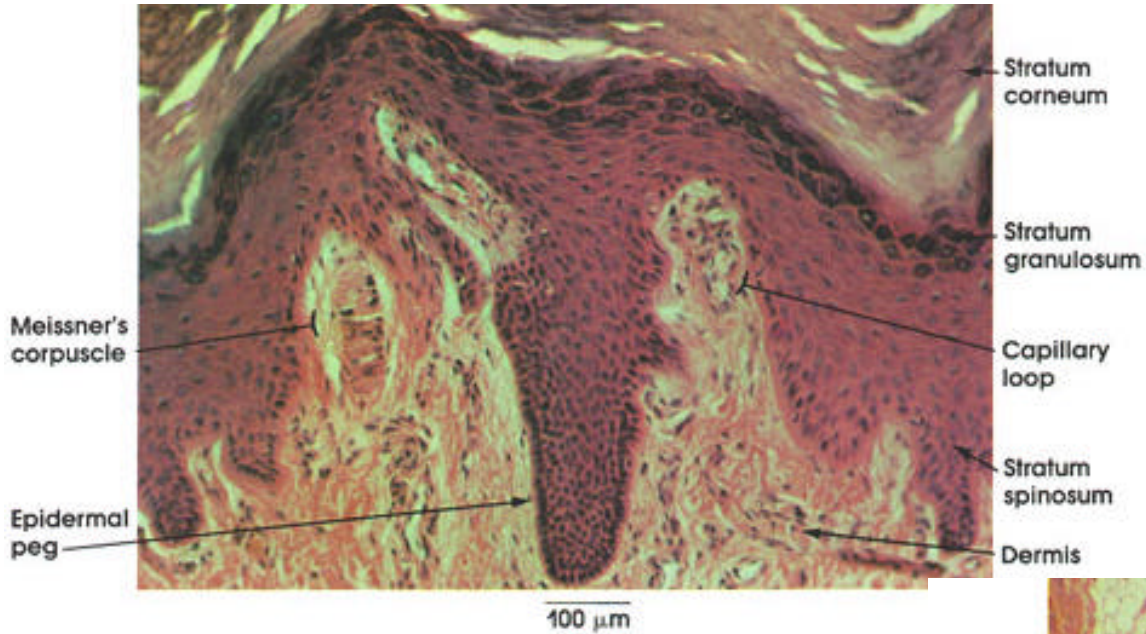


- ❑ Resolution and sensitivity of the sensors
- ❑ Temporal processing characteristics (adaptation, summation)
- ❑ Spatial features of processing
- ❑ Delays in processing information (0.4-120 m/s)

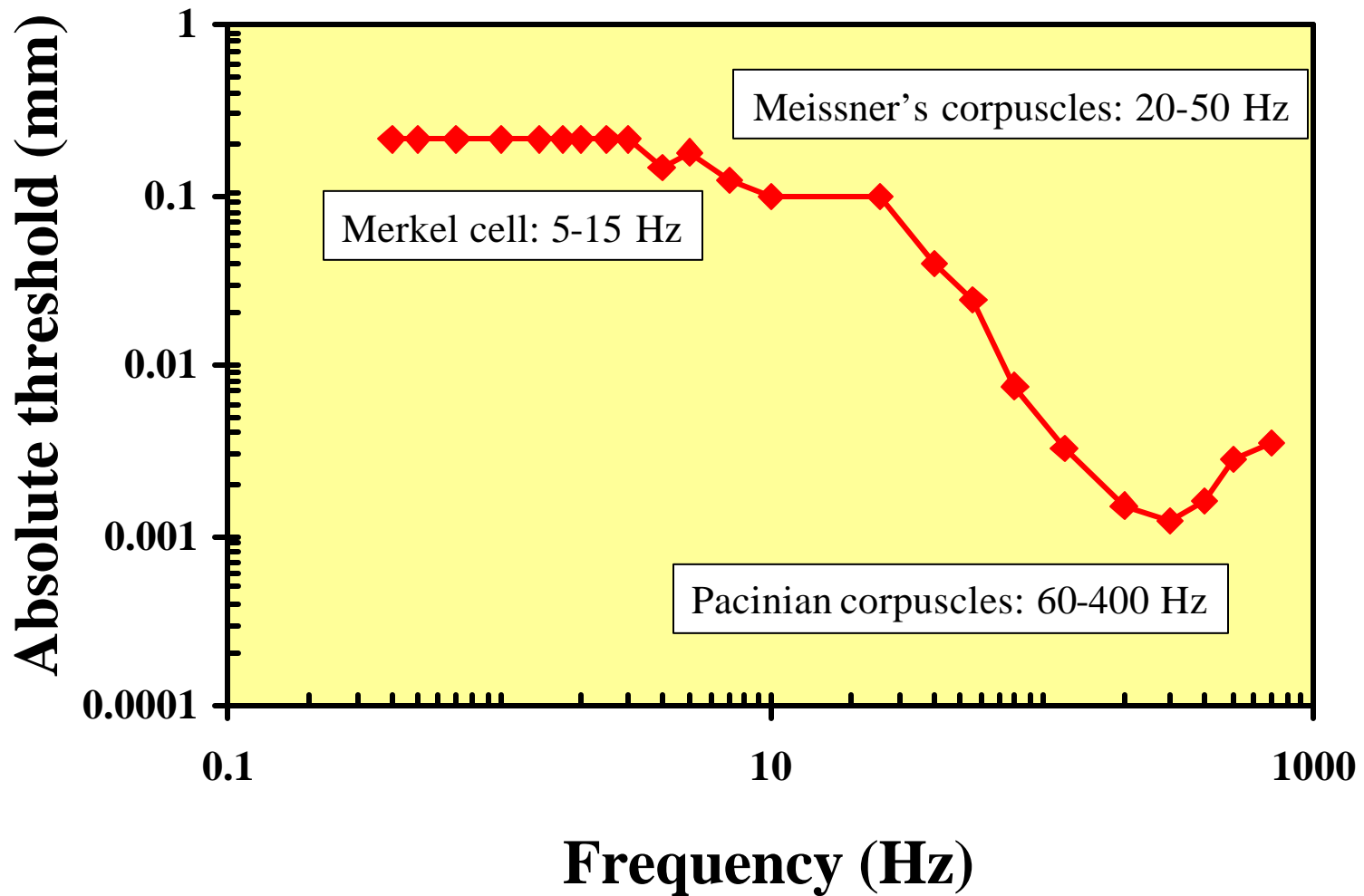
Tactile Receptor Types (7)

Cutaneous and subcutaneous Mechanoreceptors	Fiber group	Modality
Meissner corpuscle	A α , β	Stroking, fluttering
Merkel disk receptor	A α , β	Pressure, texture
Pacinian corpuscle	A α , β	Vibration
Ruffini ending	A α , β	Skin stretch
Hair tylotrich, hair-guard	A α , β	Stroking, fluttering
Hair-down	A δ	Light stroking
Field	A α , β	Skin stretch

Receptors Processing Vibration, Texture



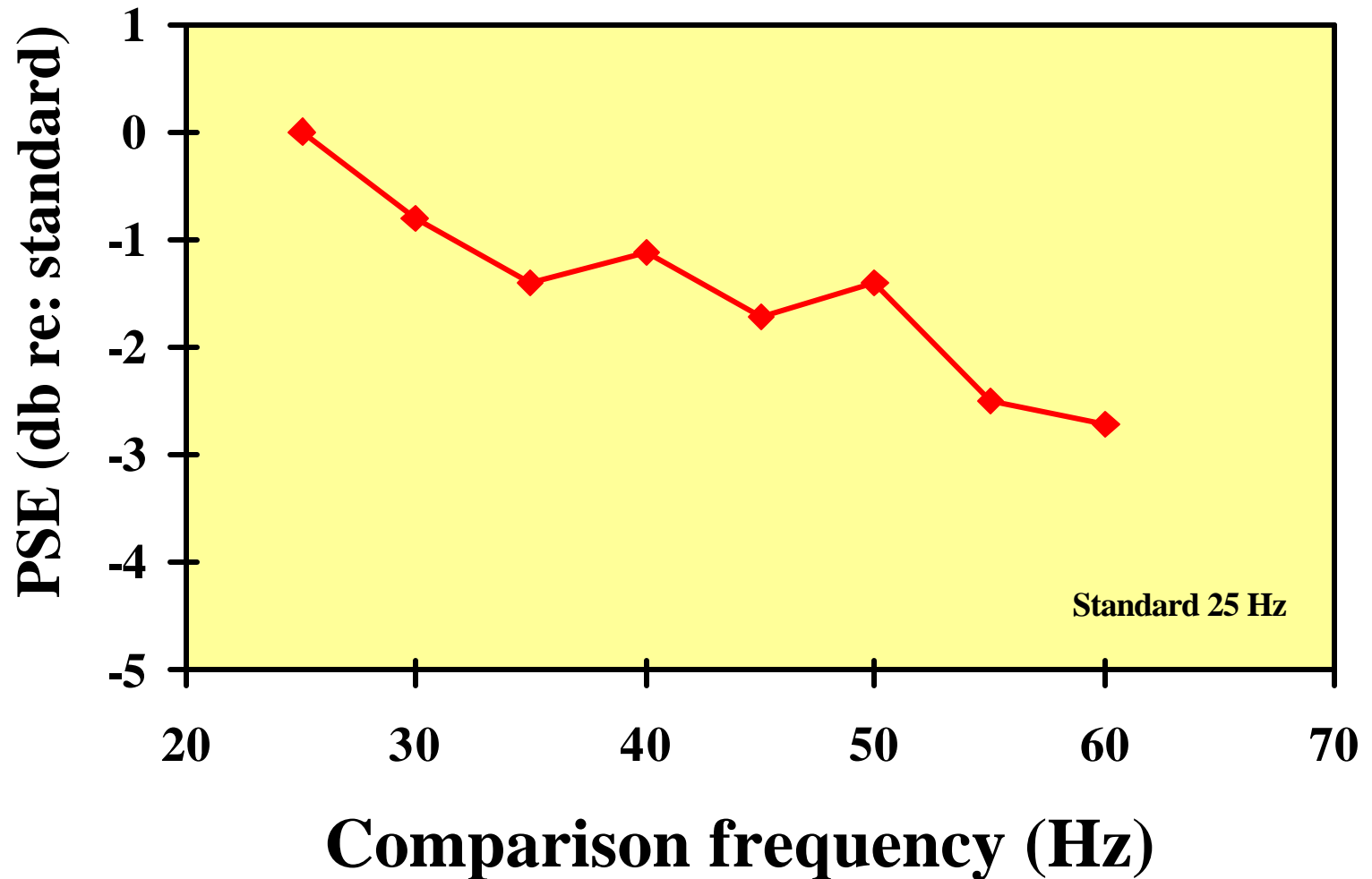
Tactile Tuning Curves



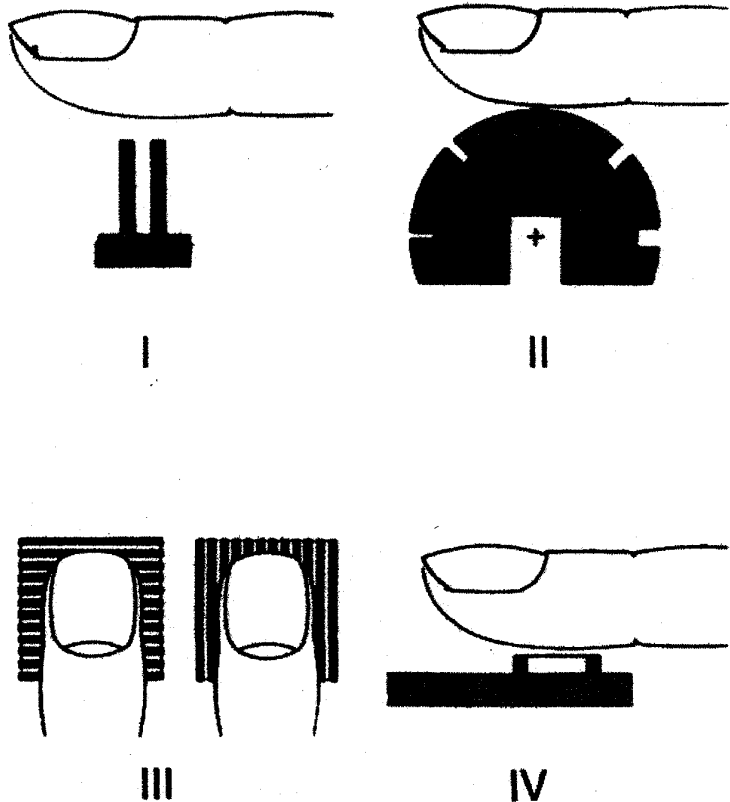
Perception of Vibrotactile Stimuli – Frequency and Intensity Interact

- ❑ Perceived intensity of vibration varies as a function of frequency as well as amplitude
- ❑ If the amplitude of vibration is changed while frequency is maintained constant, at certain levels a noticeable change in rate occurs

Equal subjective intensity curves



Spatial acuity of the skin



(Johnson & Phillips, 1981)

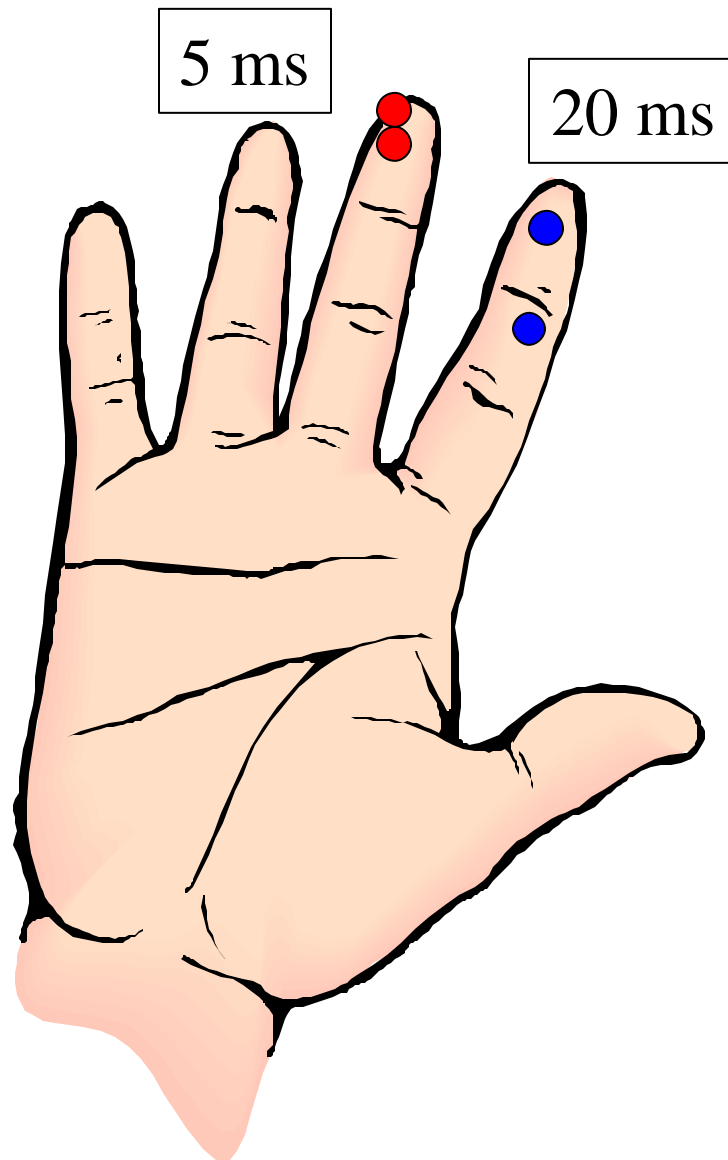
Skin movement: 0.1-0.2 mm (Gould et al., 1979)

Spatial frequency of grating: fingertip can distinguish 40-50 μm in spatial period of 0.7-1.0 mm (Morley et al., 1983)

On smooth glass surface, dot of height 1-3 μm and diameter of 550 μm can be detected by the fingertip (Johansson & LaMotte, 1983)

Temporal variation often improves acuity and spatially extensive stimuli improve performance

Temporal acuity and touch



Successiveness - 2 stimuli (1 ms duration) must be separated by 5.5 ms to be perceived as 2 at a single locus

Temporal order - 2 successive stimuli at separate sites must be separated by 20 ms in order to determine which site first

Haptic Displays

- Surface texture of object
- Contact in the environment
- Moving probe across surface - volume
- Compliance/stiffness of object
- Mass of object
- Thermal properties of object

Human Perception and Haptic Display Design

- ❑ Scaling (gain) of information between object and operator
- ❑ Bandwidth required to present information
- ❑ Mechanical properties of interface
- ❑ Magnitude of delays that are tolerable - symmetric, modality specific

Force-reflecting Interfaces

□ Scaling (gain) of force between object and operator

Ring finger

Middle finger

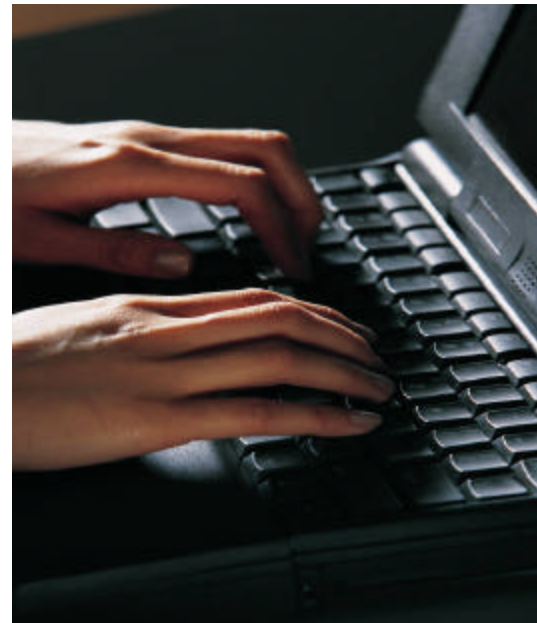
Women: 14 N

Men: 26 N

Index finger

Women: 19 N

Men: 35 N



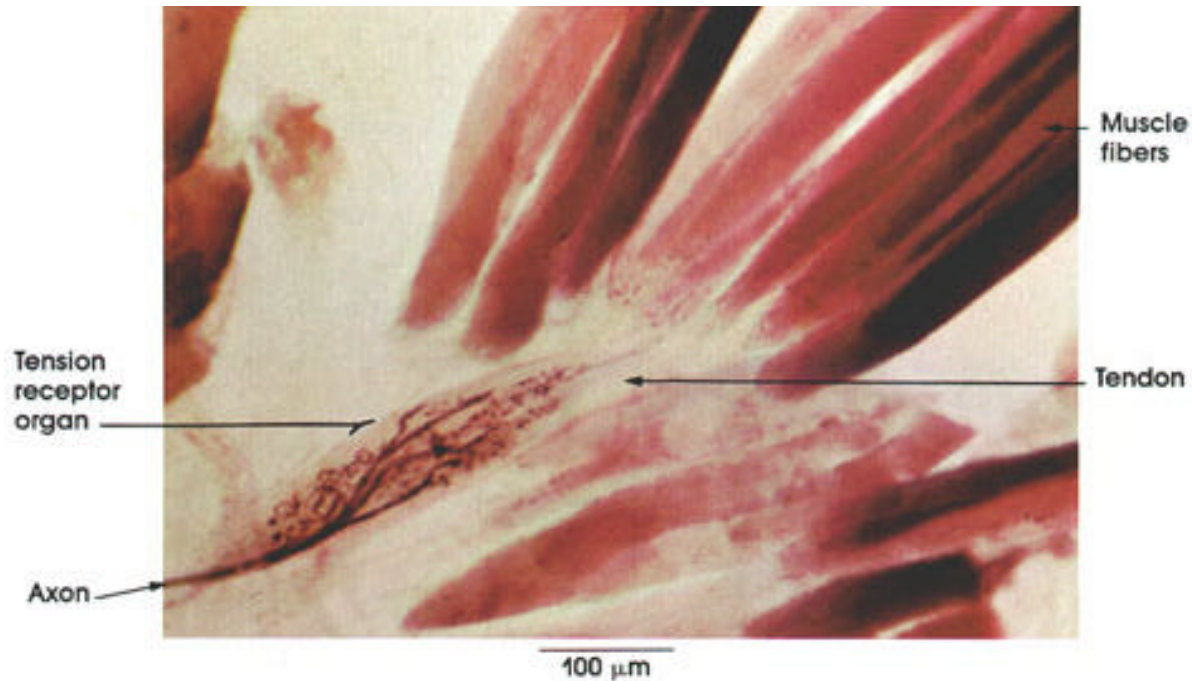
Activation force < 1 N

Mean force: 0.8-0.9 N

Peak force: 1.8-3.3 N

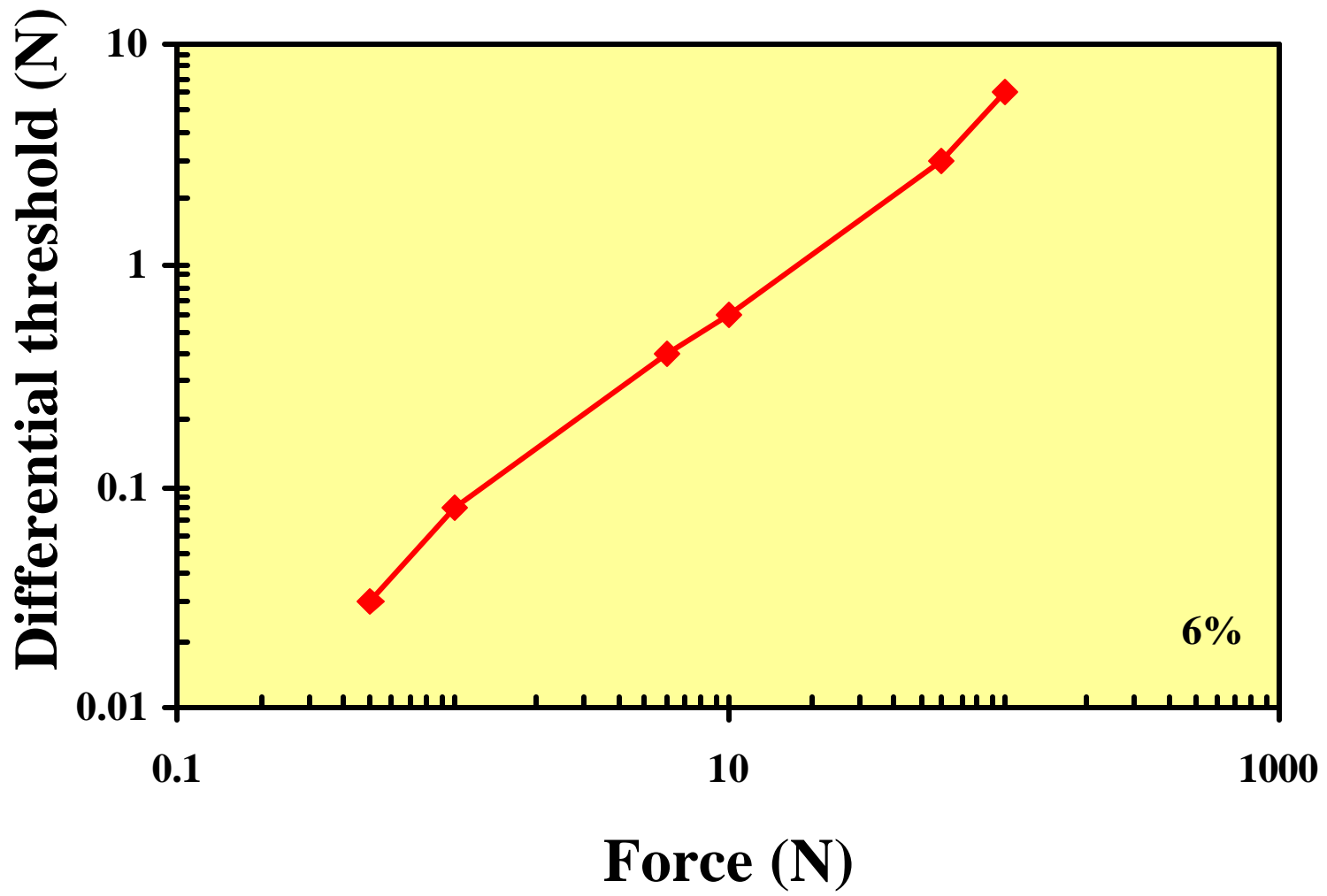
GOLGI TENDON ORGAN

Tendon of Achilles

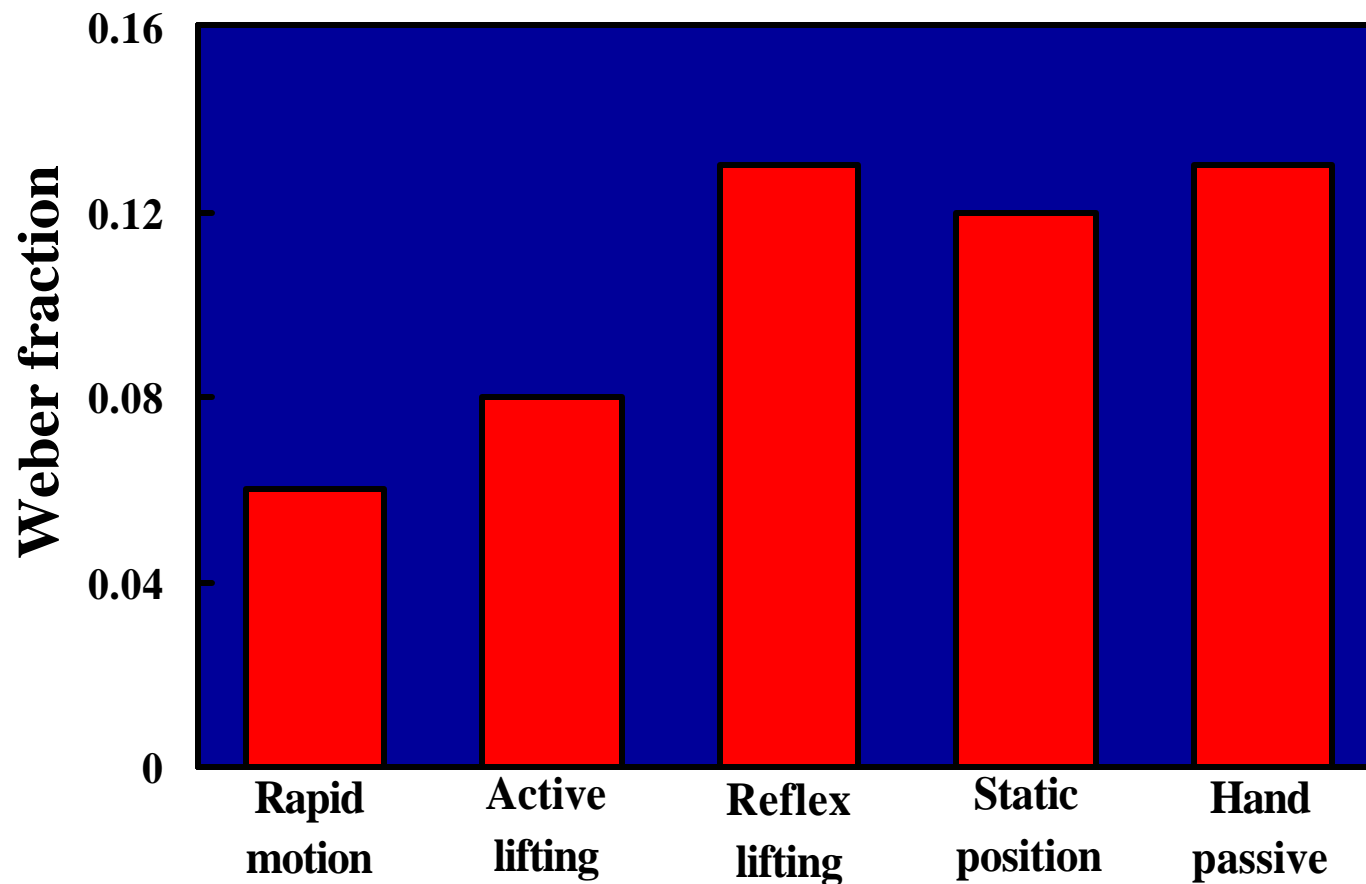


0-20 in mammalian muscles
Activation force: 0.5 – 1.7 mN

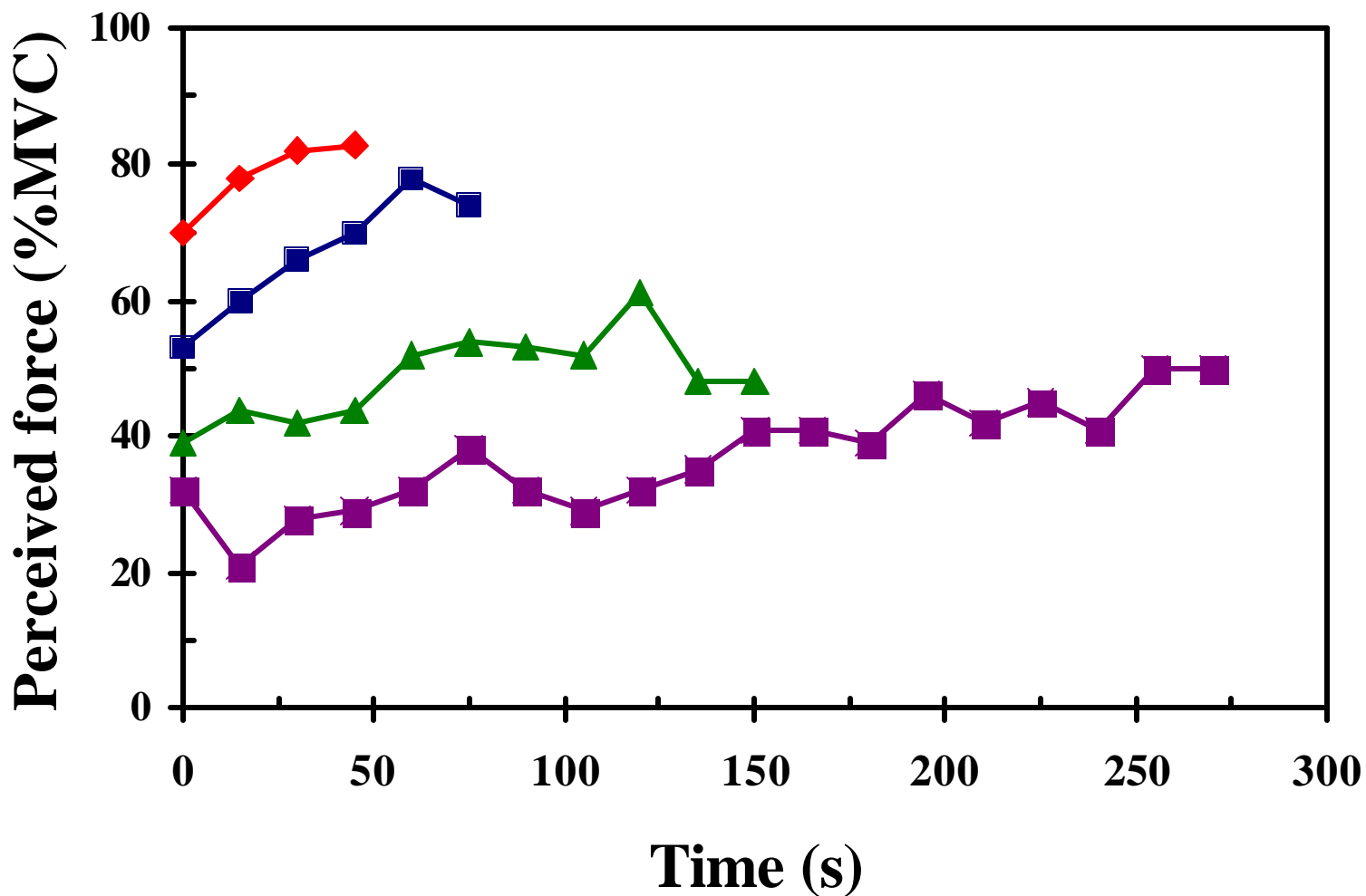
Force Discrimination



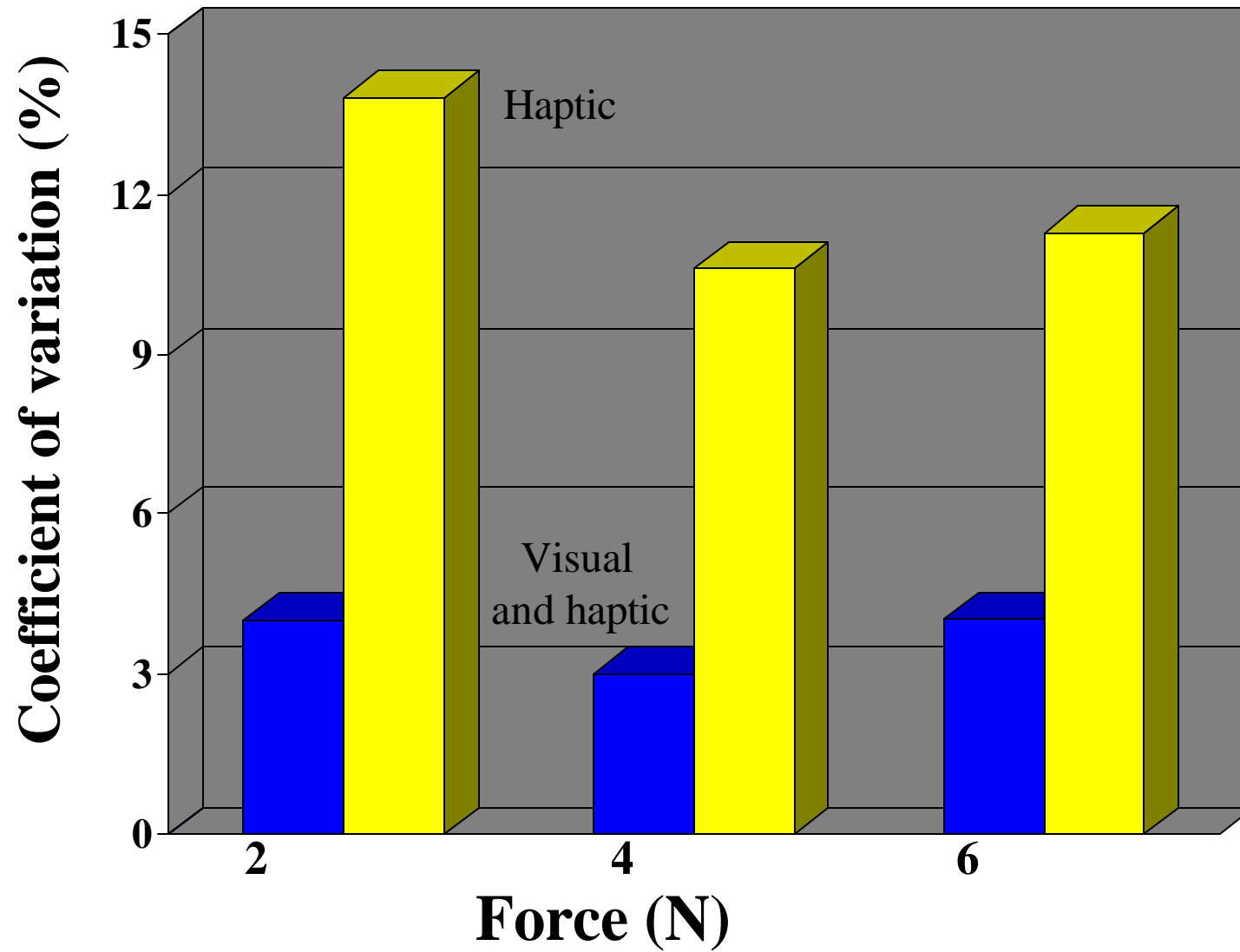
Weight Discrimination



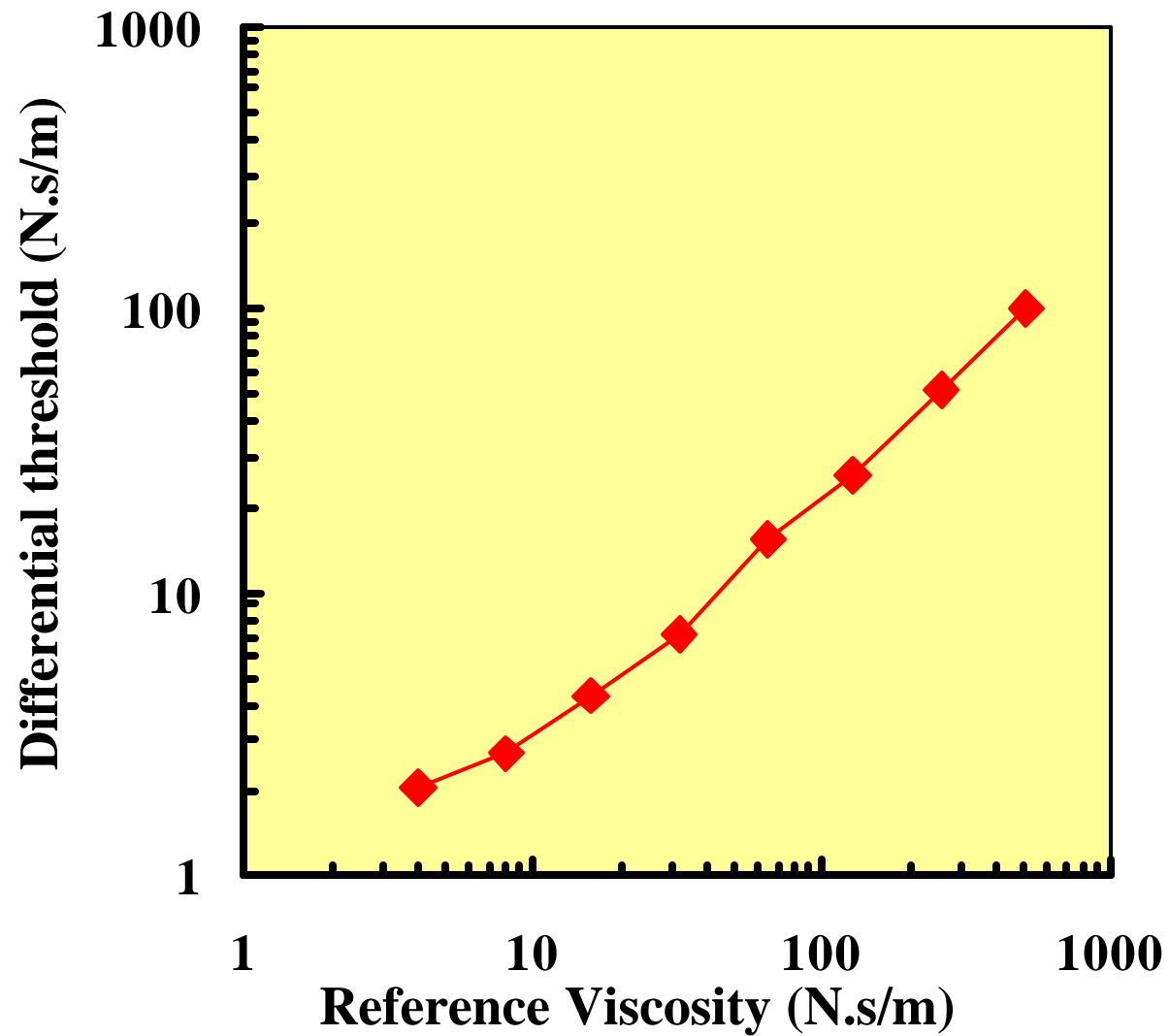
Fatigue and Perceived Force



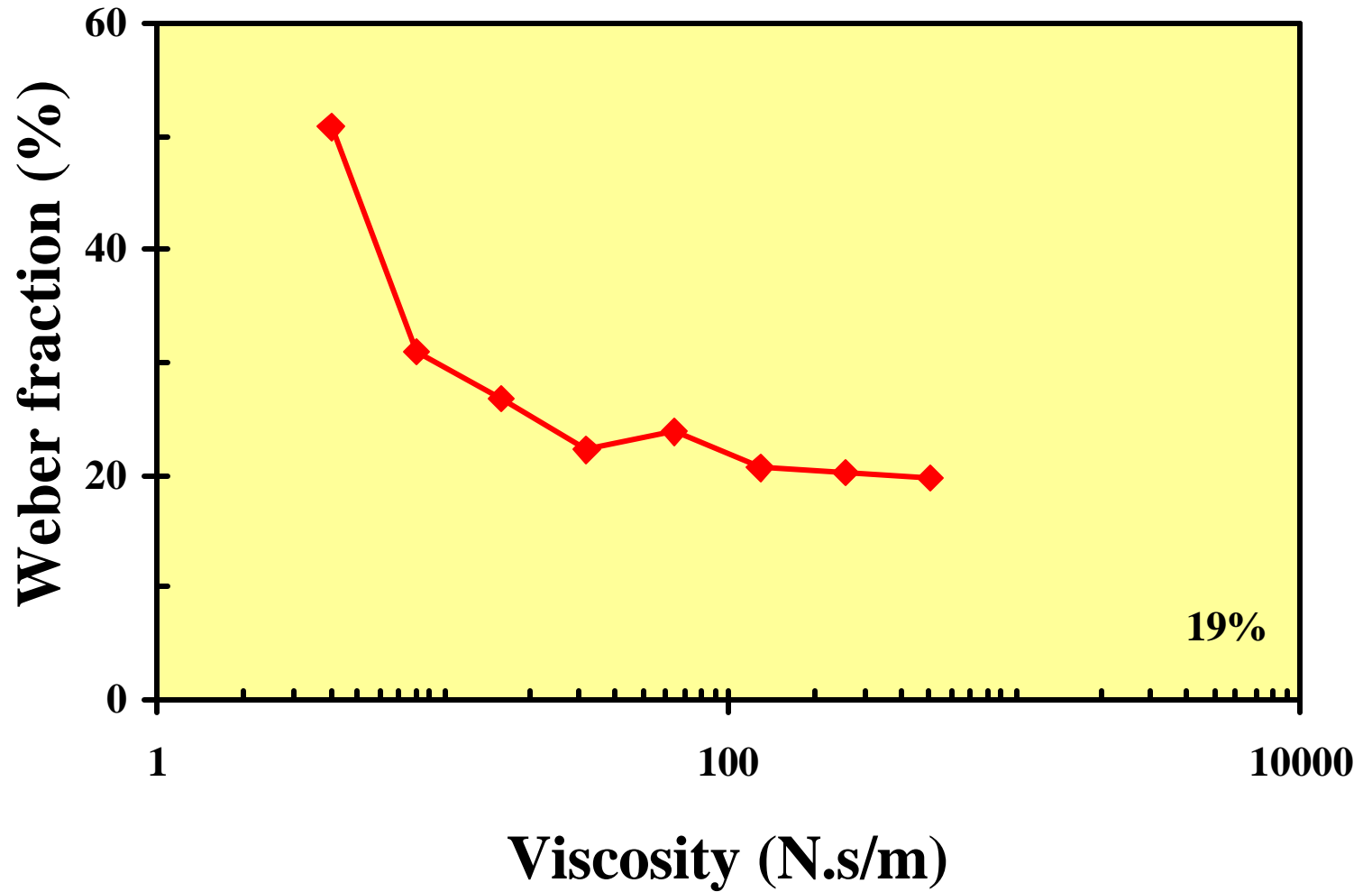
Force control - Index finger flexor



Viscosity Discrimination



Viscosity Discrimination



Discriminability Parameters

Variable	Weber fraction	Resolution
Amplitude of vibrotactile stimulation (20-300 Hz)	25%	0.1 μ m
Frequency of vibrotactile stimulation (5-200 Hz)	11%	0.4 Hz
Pressure on skin	12%	2 gm/mm ²
Force	7%	30 mN
Stiffness/compliance	17%	
Viscosity	19%	
Temperature (cold)	2%	0.02°C

Discriminability Parameters

Variable	Weber fraction	Range
Limb position	7%	5-9%
Limb movement	8%	4-19%
Force	7%	5-12%
Stiffness/compliance	17%	7-26%
Viscosity	19%	10-29%

Hand movements and physical properties

Surface texture

Temperature

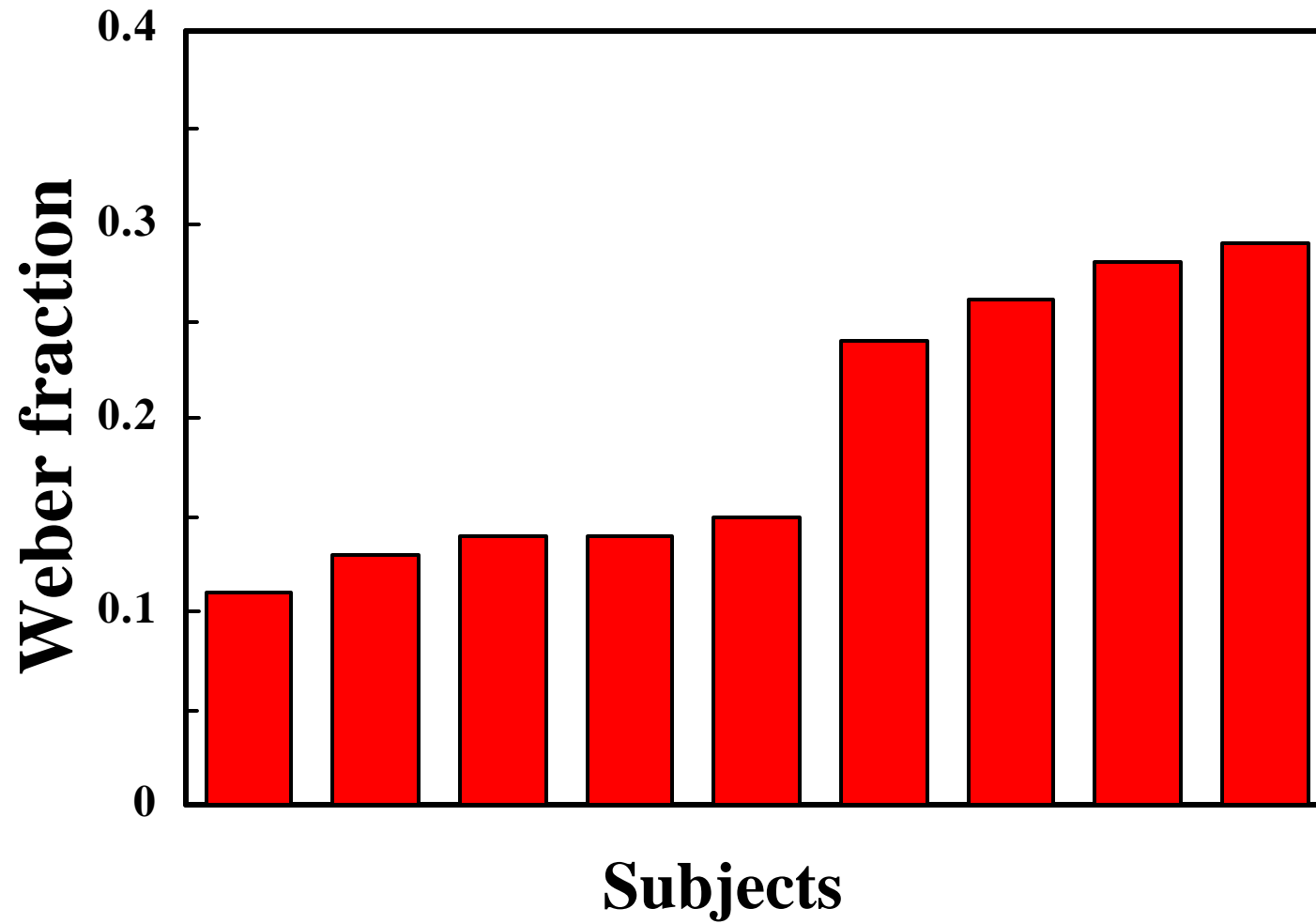
Size/volume

Hardness

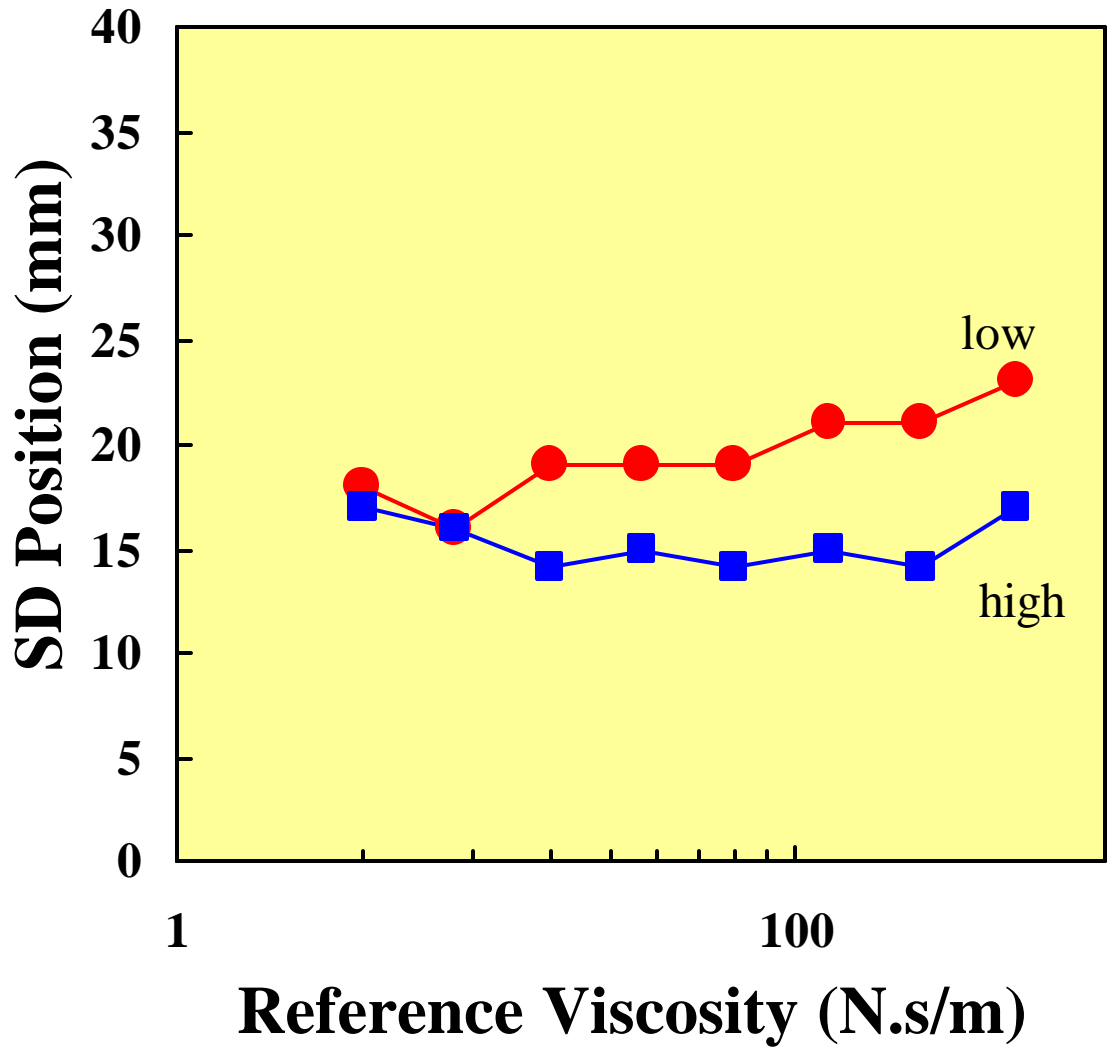


Weight

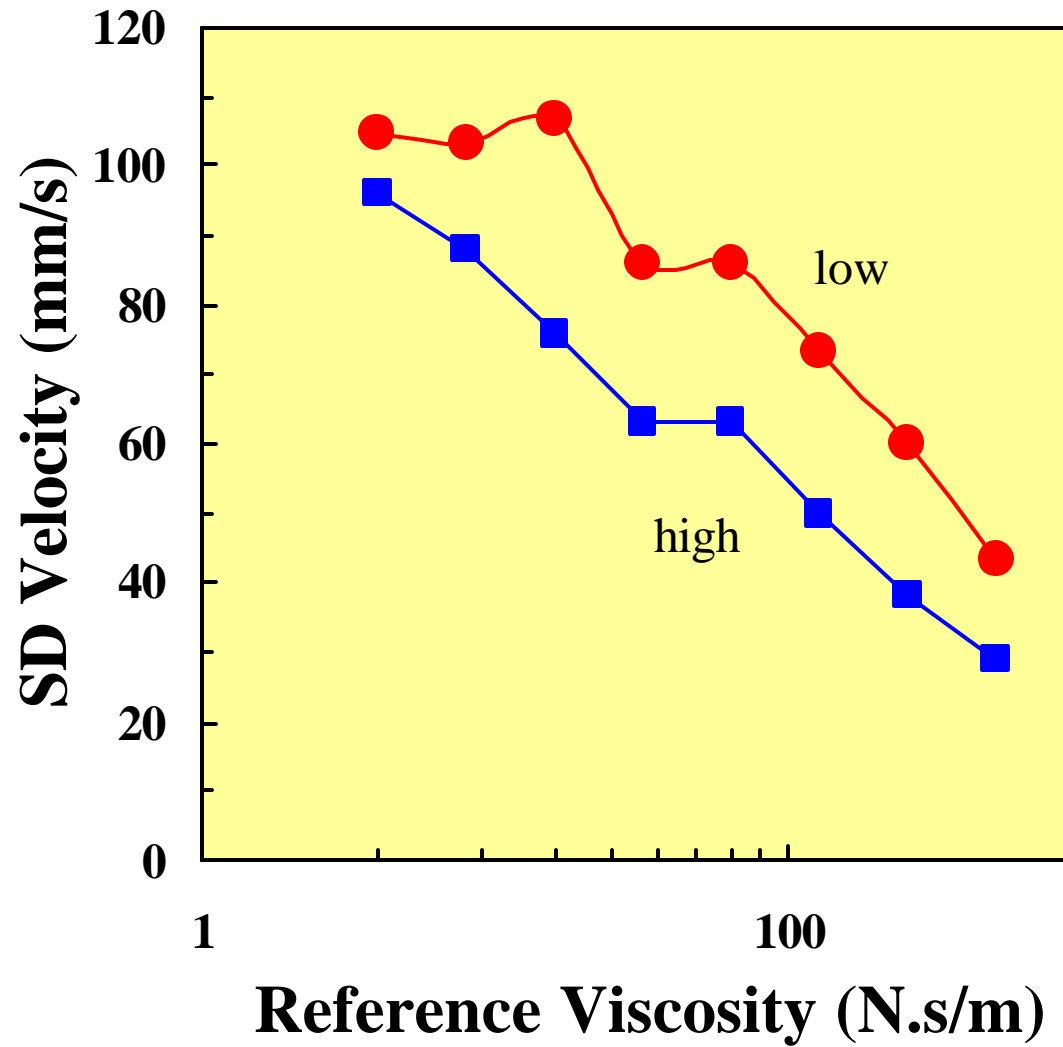
Individual Variability



Movement Amplitudes



Movement Velocities

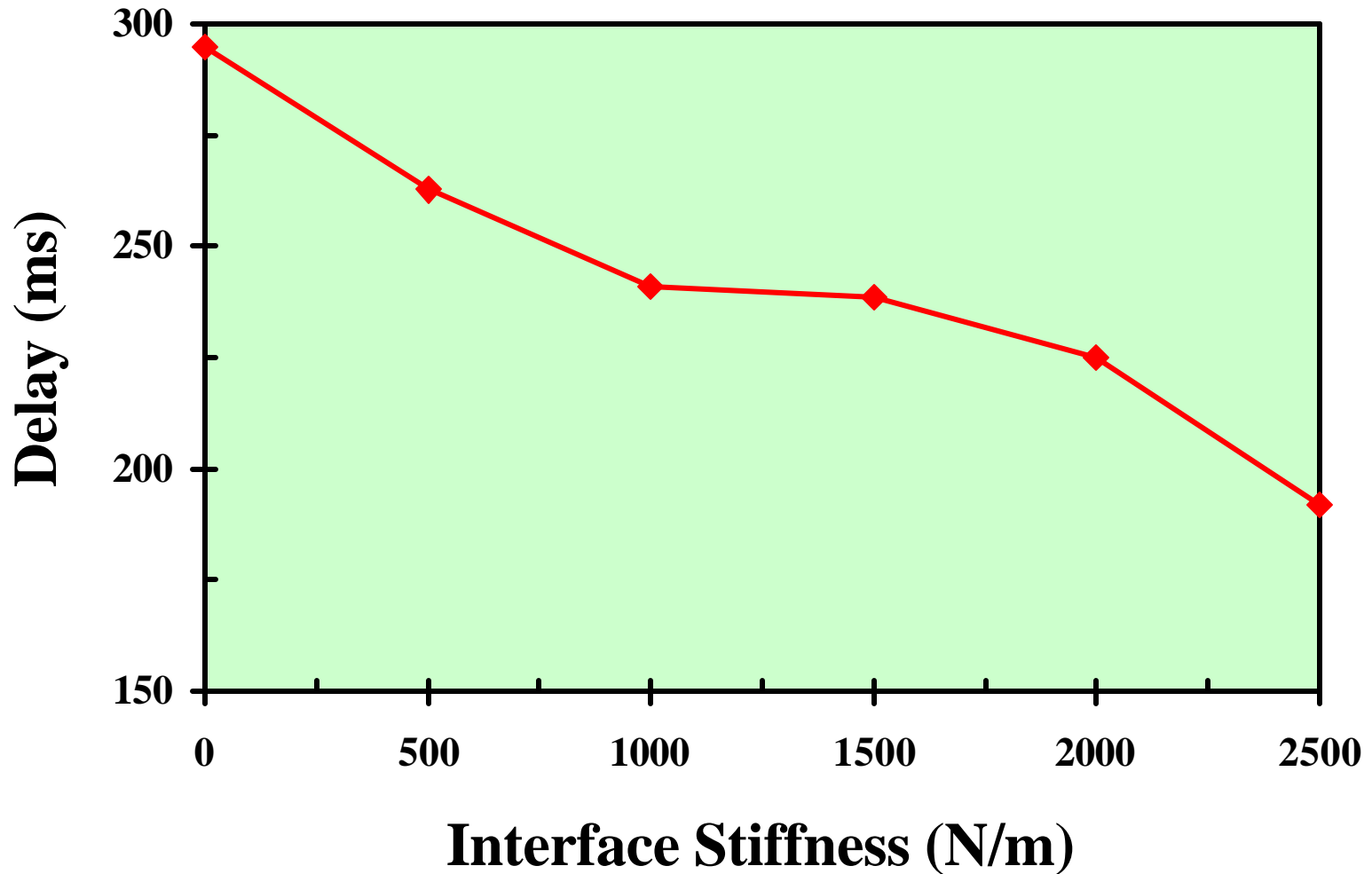


Training for the haptically inept

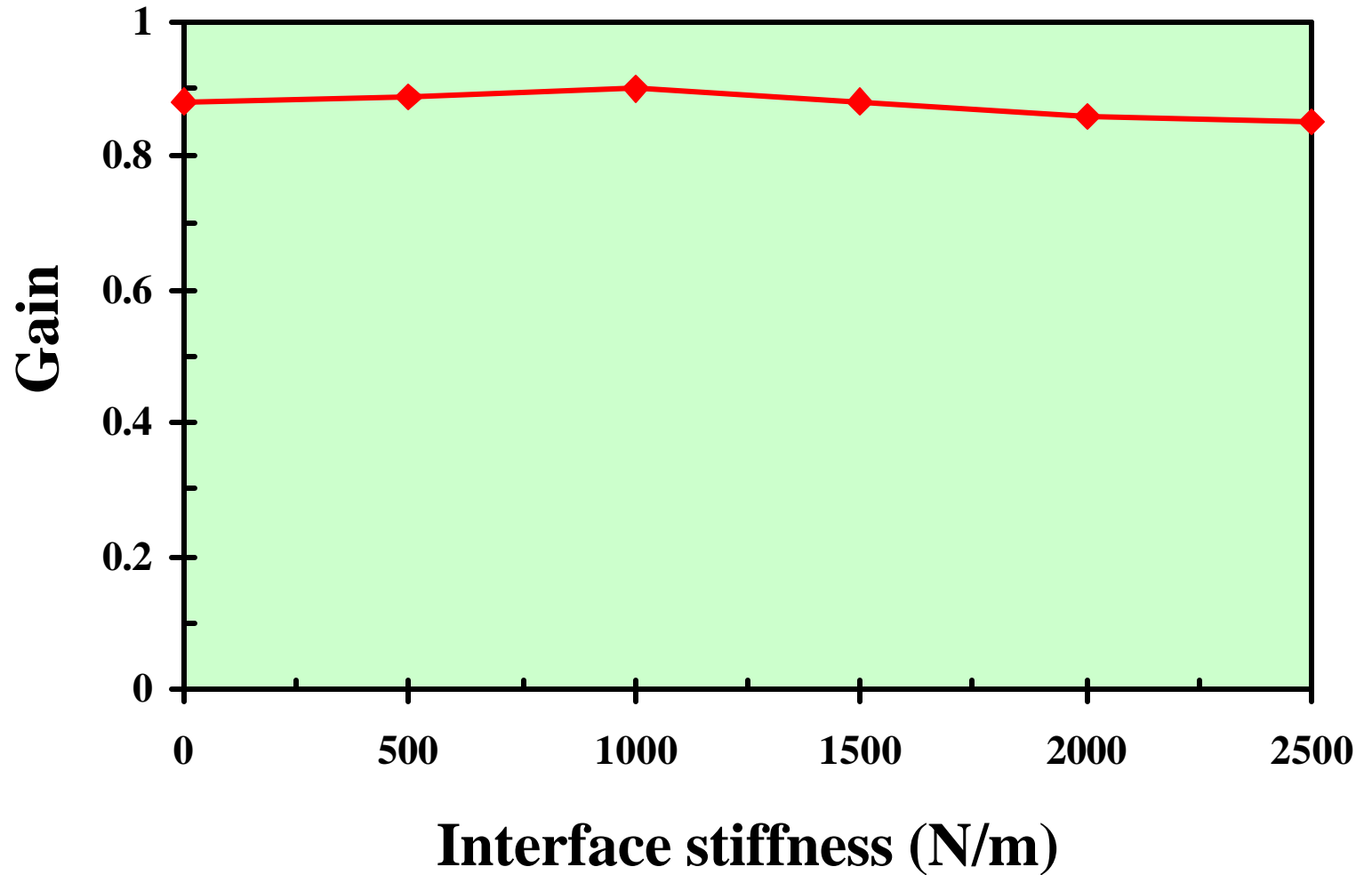


- Feedback
- Optimal motor strategy
- Improve discrimination but not detection

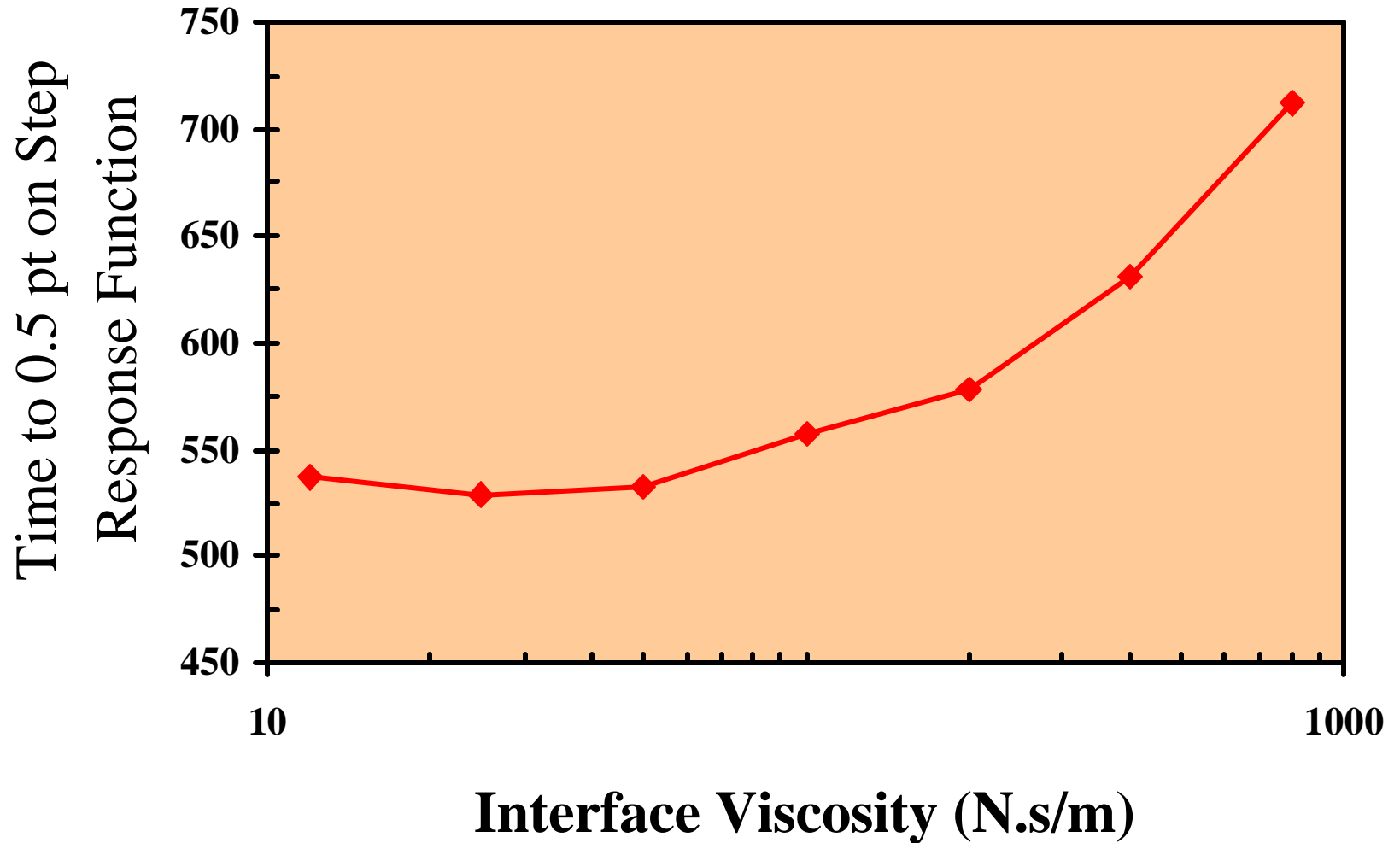
Interface Mechanical Properties and Human Operator Performance



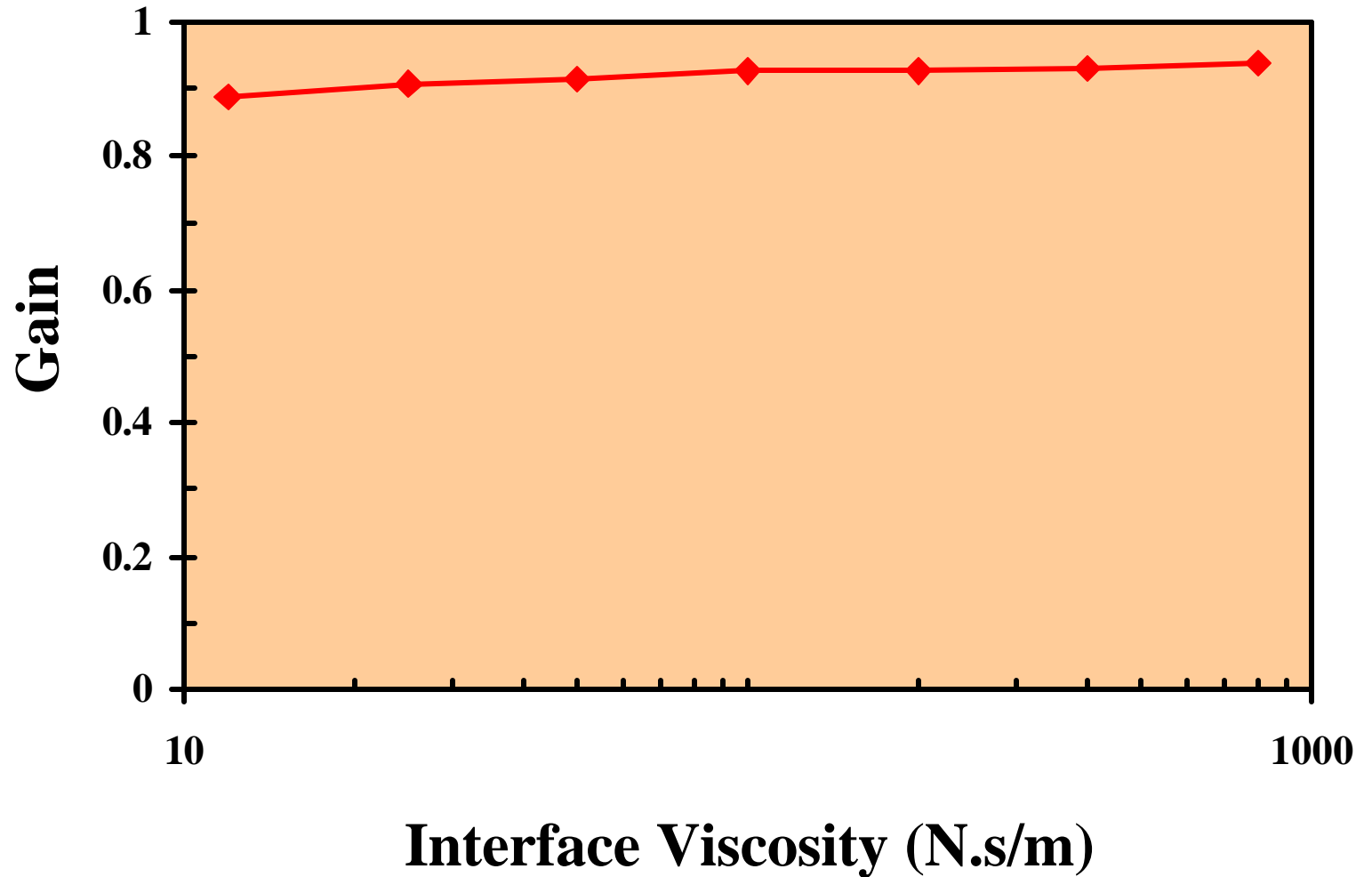
Human Operator Performance



Human Operator Performance



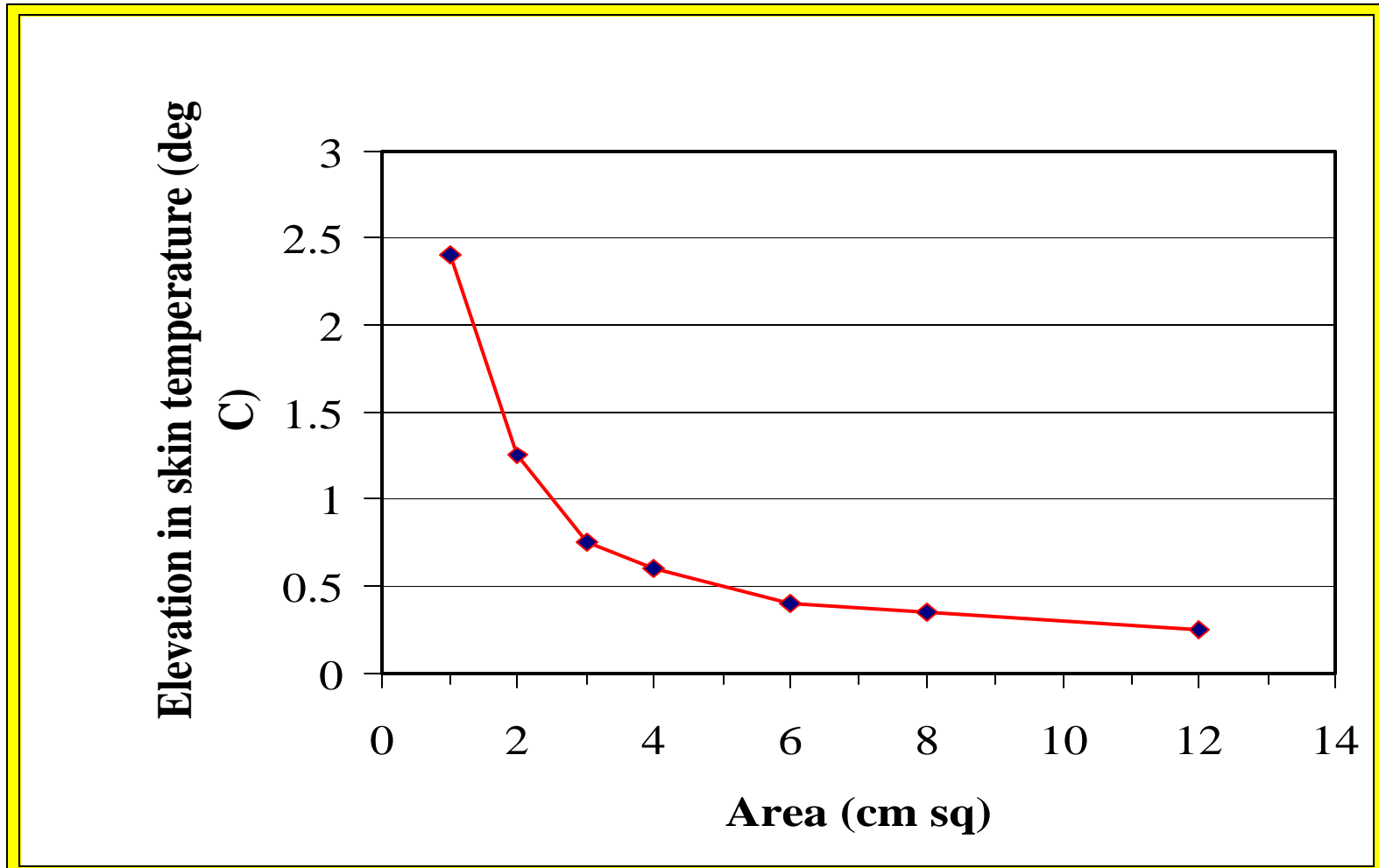
Human Operator Performance



Thermal Interfaces and Perception

- ❑ Thermoreceptor range: 13-45° C
- ❑ Resolution: 0.02-0.05° C (transient)
- ❑ Thermal discriminability: 2%
- ❑ Neutral thermal sensation: 31-36° C
- ❑ Skin temperature correlates well with perception of cold not warmth
- ❑ Thermoreceptors are NOT thermometers

Thermal thresholds



Thermal Interfaces

Disadvantages

- ❑ Slow response
- ❑ Poor localization (improves with increases in temperature – 40° C)
- ❑ Prodigious capacity for adaptation and summation (intensity and areal extent traded)

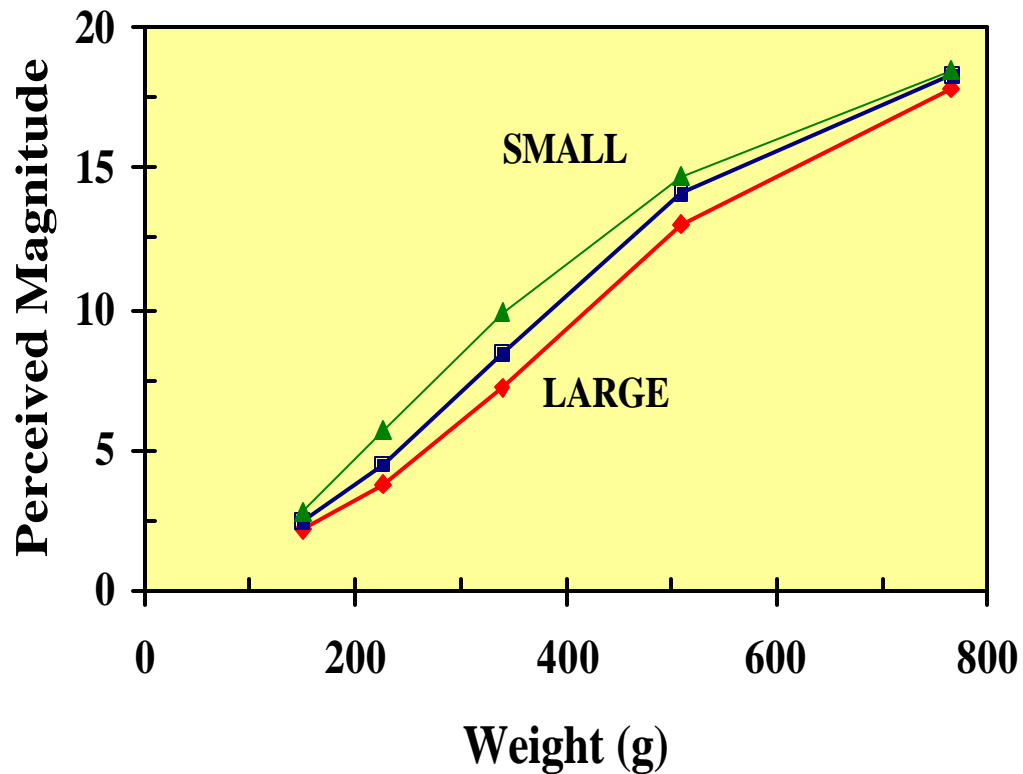
But could be analogous to color in visual displays.

Illusions – can they be used to trick the haptic system?

- ❑ Size-weight illusions – visual and haptic phenomenon
- ❑ Saltation effect
- ❑ Use auditory cues to enhance haptic perception

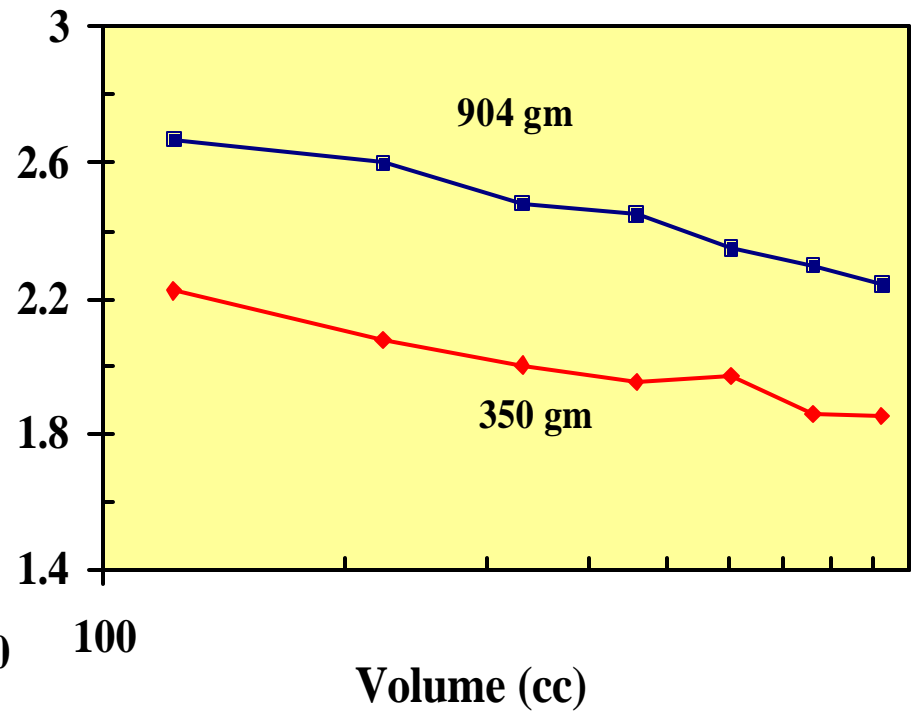
Size-weight Illusion

Visual



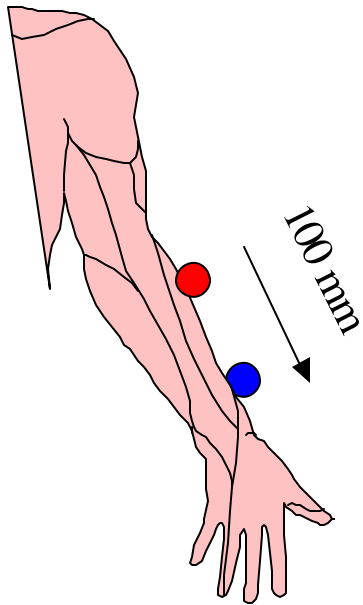
(Masin & Crestoni, 1988)

Haptic



(Ellis & Lederman, 1993)

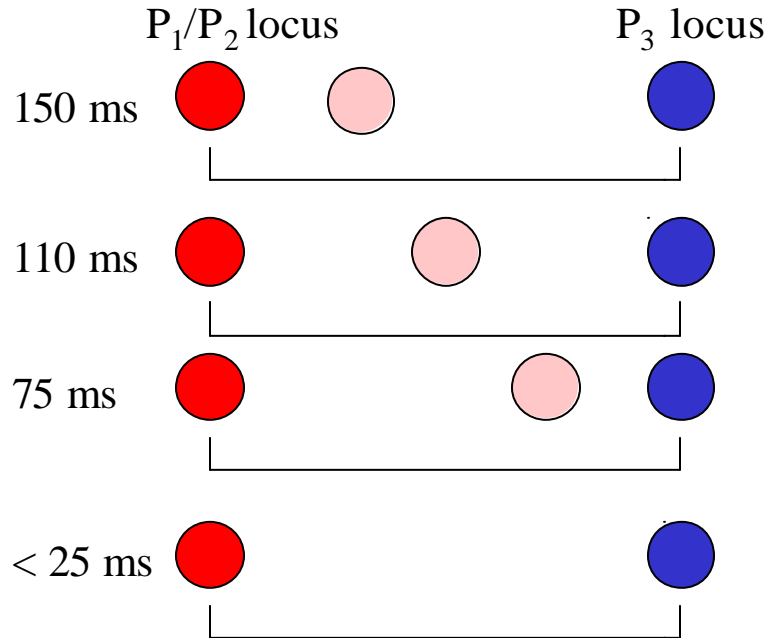
Saltation effect

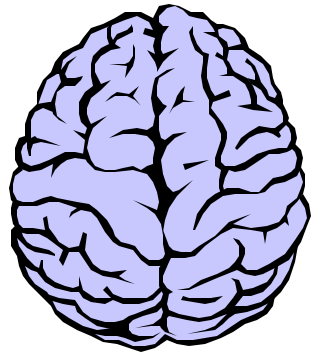


Warning stimulus (P_1) 1 s prior to two taps on skin. Present a stimulus at one location (P_2 red) and a second at another (P_3 blue).

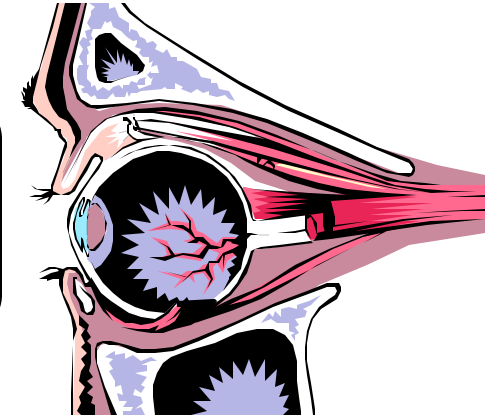
At short and long time intervals (20-30 and > 200 ms) P_1 will appear near to or coincident with P_2

As time disparity increases above 50 ms the first stimulus travels back to its veridical locus





Conclusions



- Spatial and temporal processing characteristics of different modalities (pressure, vibration, temperature, force) vary, but can be used to enhance stimulus presentation in a haptic display
- Cross-modal interactions provide an additional tool for representing object properties

