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Effects of Contact Force on Vibrotactile Perceived Intensity Across the Upper Body



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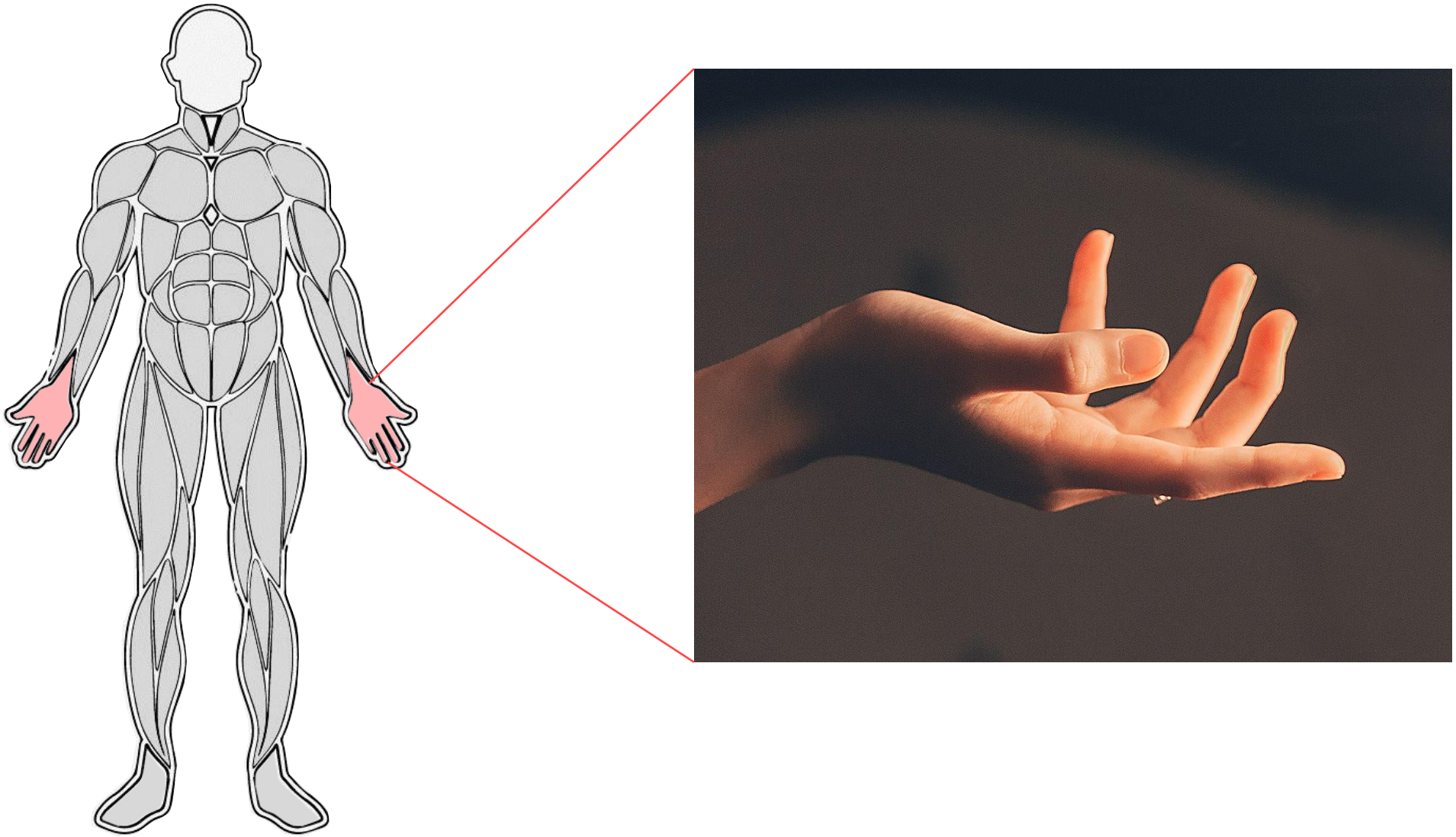
POSTECH INTERACTION LABORATORY

Background



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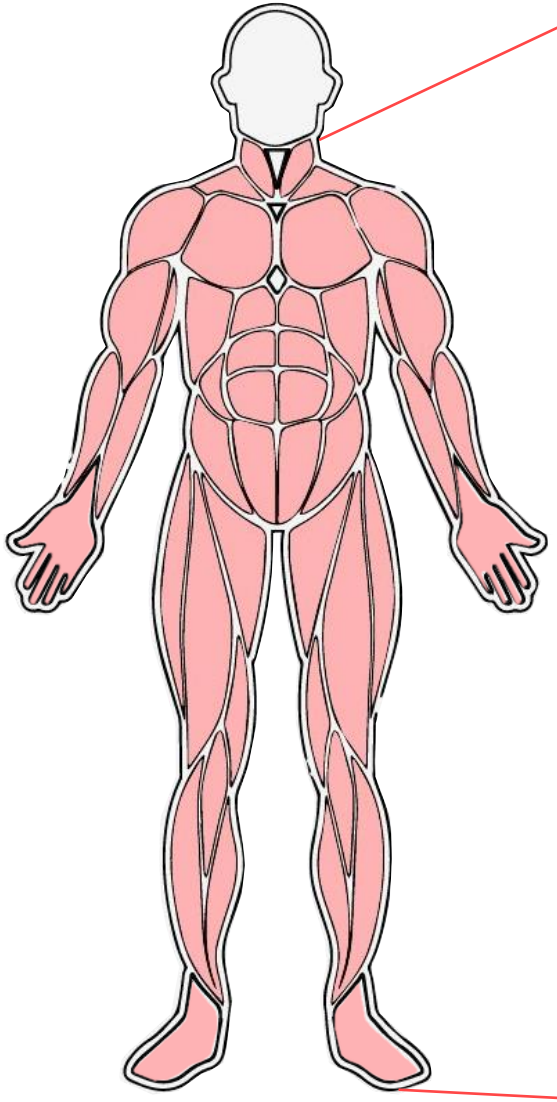

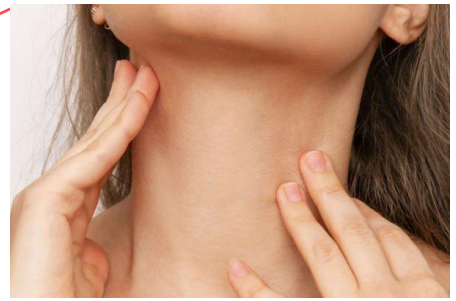

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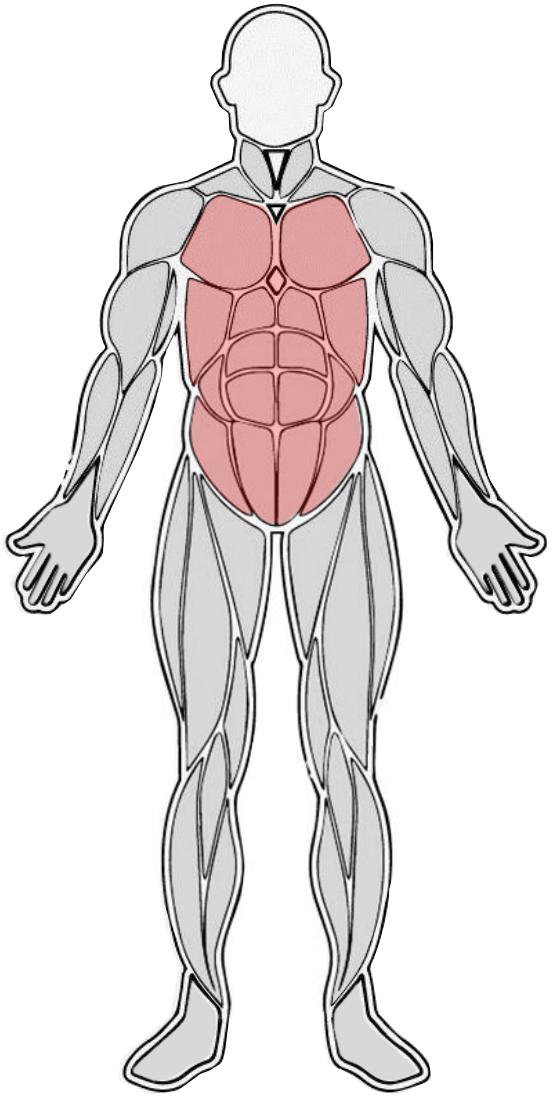

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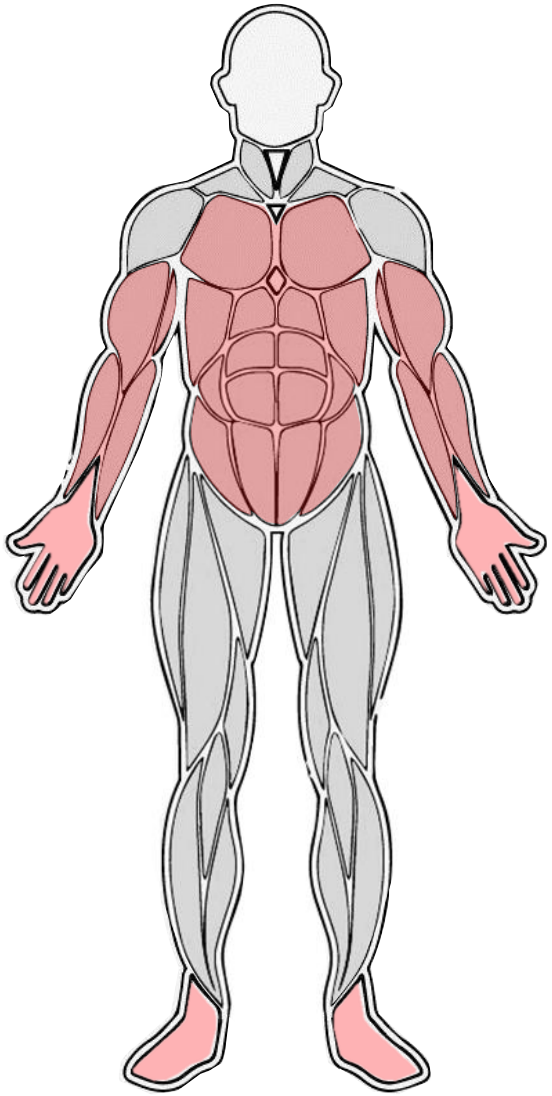
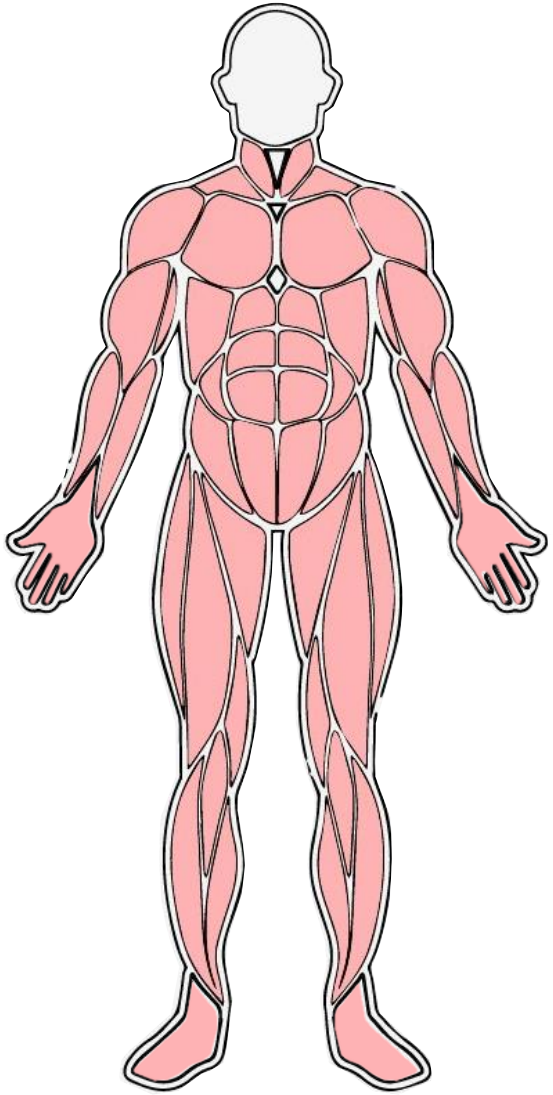
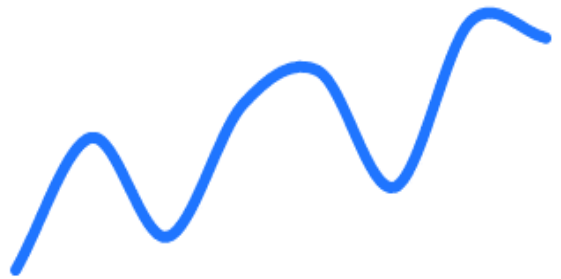


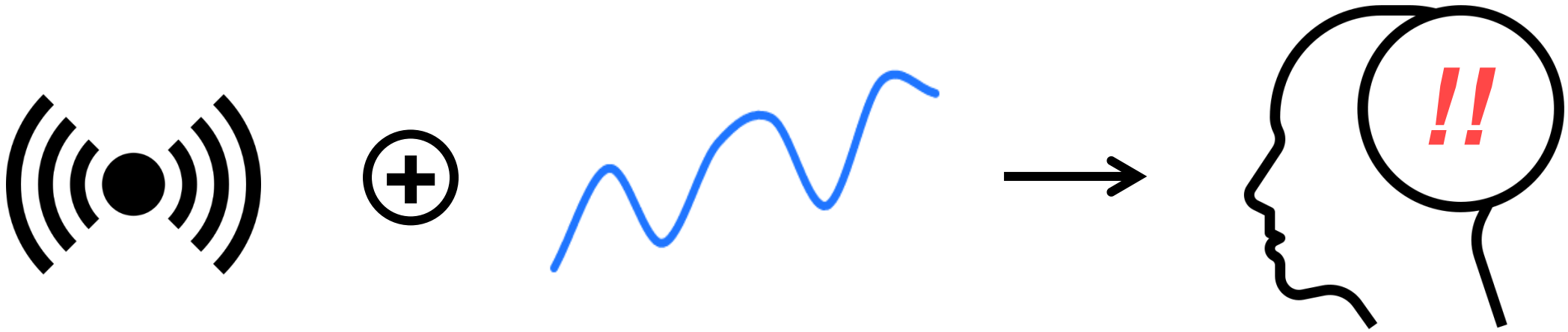
bHaptics

Background





Contact force changes!

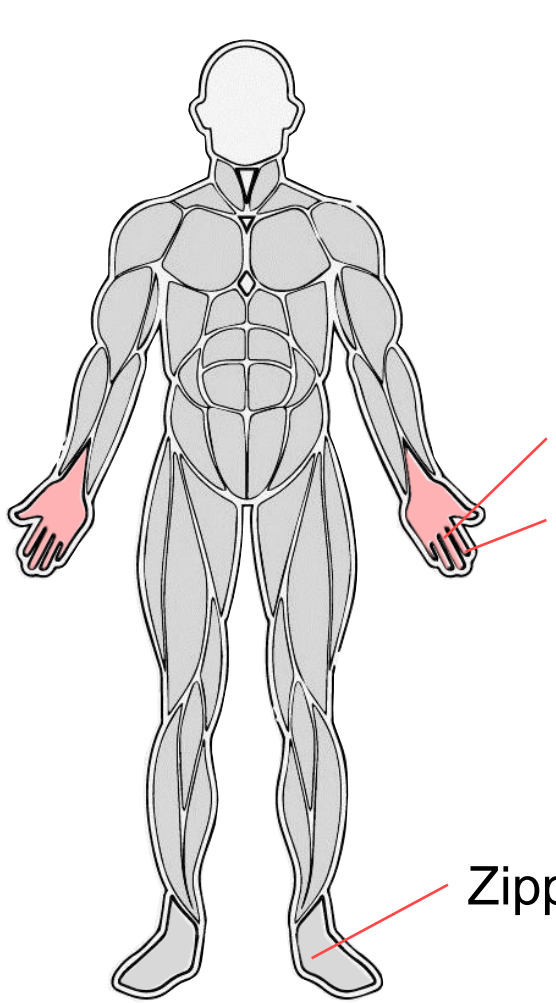


Same
stimuli

Different
contact force

Different
perception

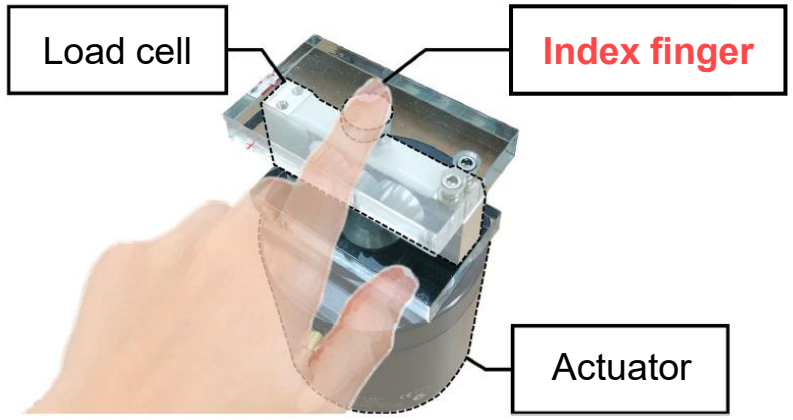
Contact force changes *detection threshold*



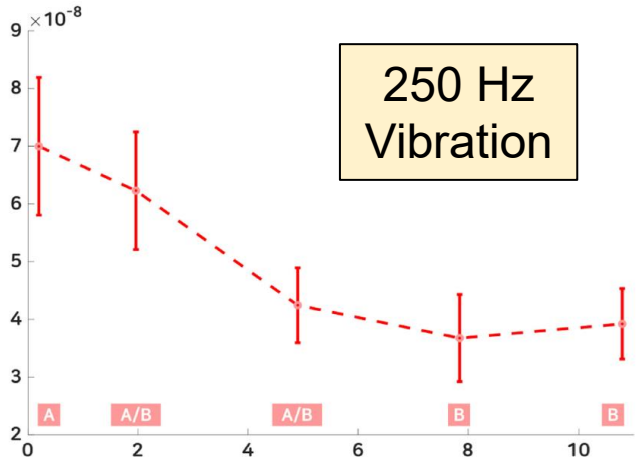
Greenspan, 1984

Oh and Choi, 2019

Zippenfennig et al., 2021

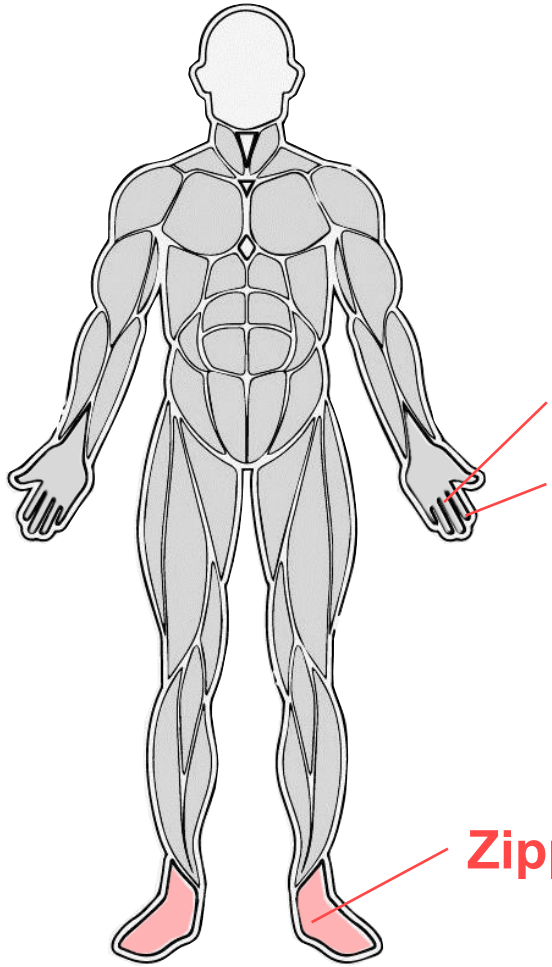


Detection threshold [m]



Pressing force [N]
(0.2~10.8 N)

Contact force changes *detection threshold*



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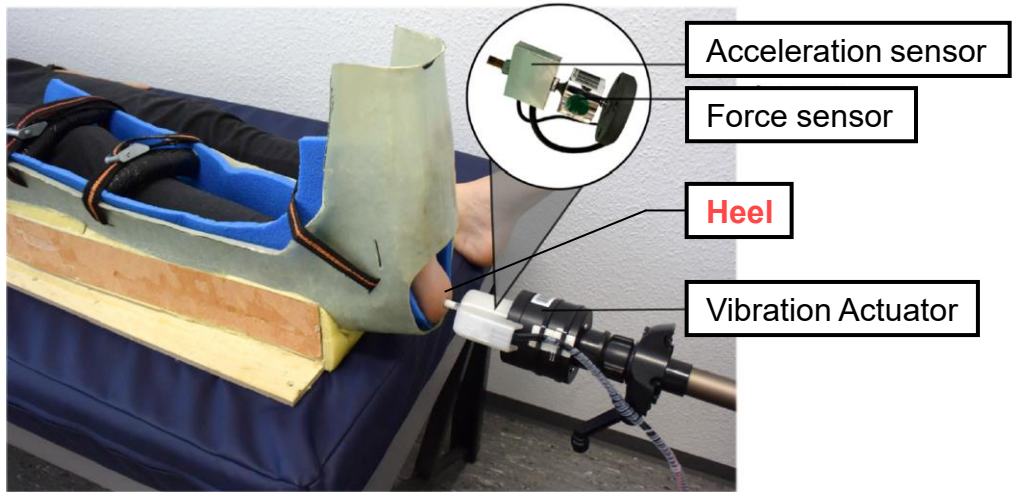
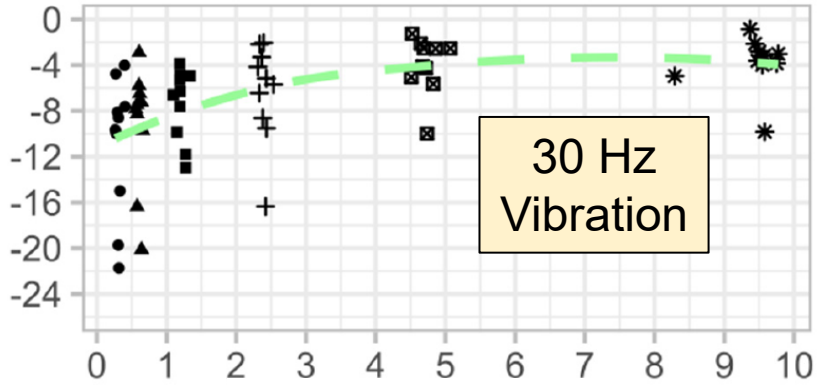


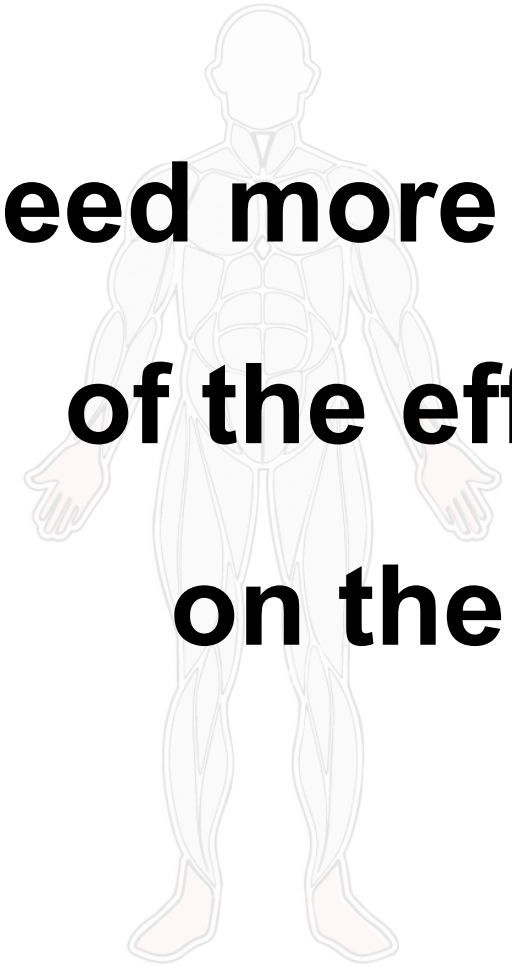
1/(Detection threshold)
[arbitrary unit]



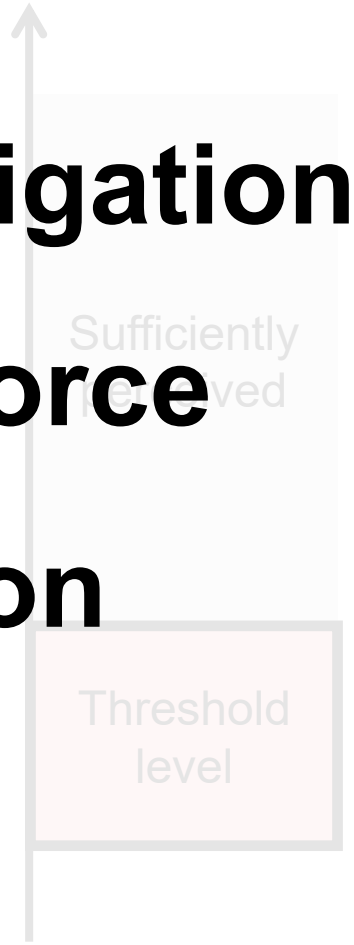
Contact force [N]
(0.3~9.6 N)

Limited body sites

Too weak stimuli



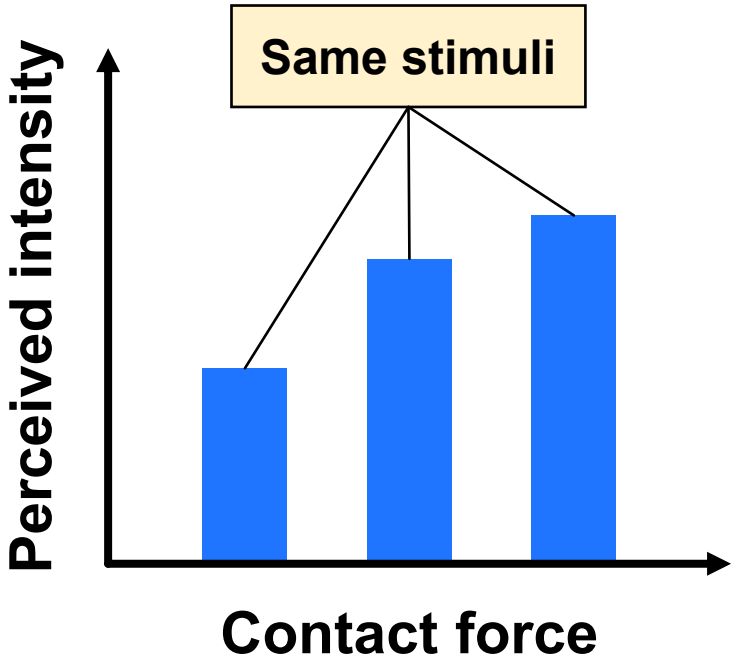
&



Need more *practical* investigation of the effect of contact force on the tactile perception

Goal

Effect of contact force
on perceived intensity



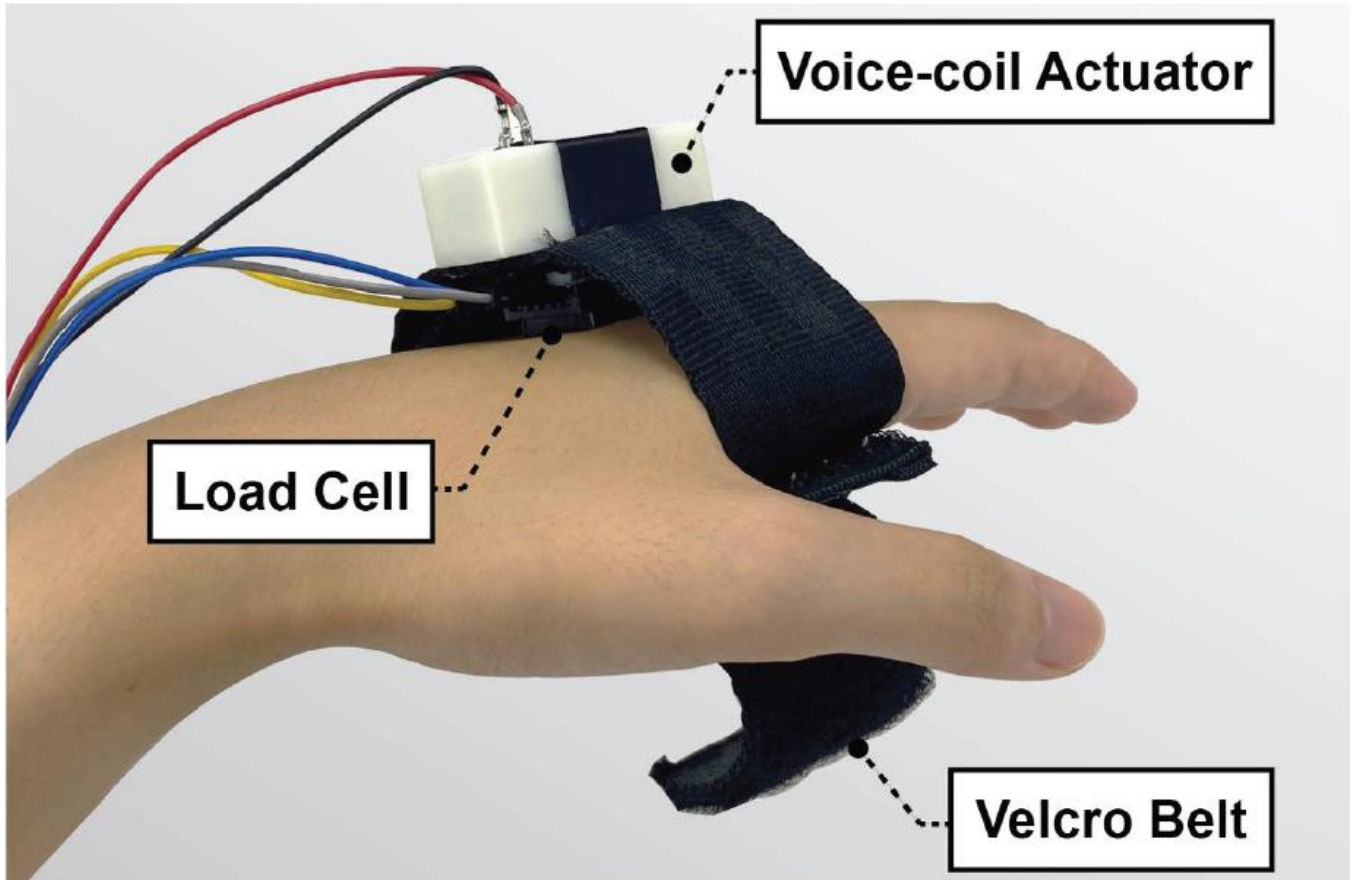
Guideline

How to adjust contact force
for intended tactile perception

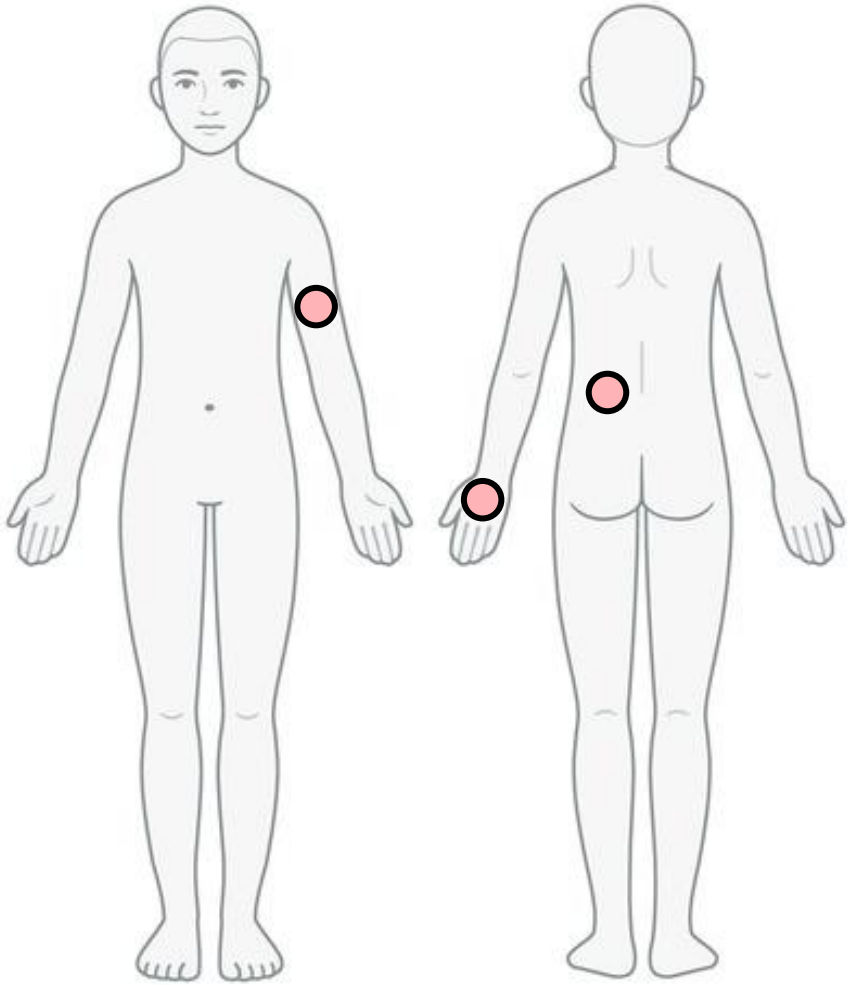
Contribution

Accurate & effective
haptic rendering

Haptic device



Experimental conditions



Body parts

- Dorsal hand
- Upper arm
- Lower back

Contact force [N]

	Weak	Medium	Strong
Dorsal hand	0.5	1.0	1.5
Upper arm	0.5	1.0	1.5
Lower back	0.4	0.7	1.0

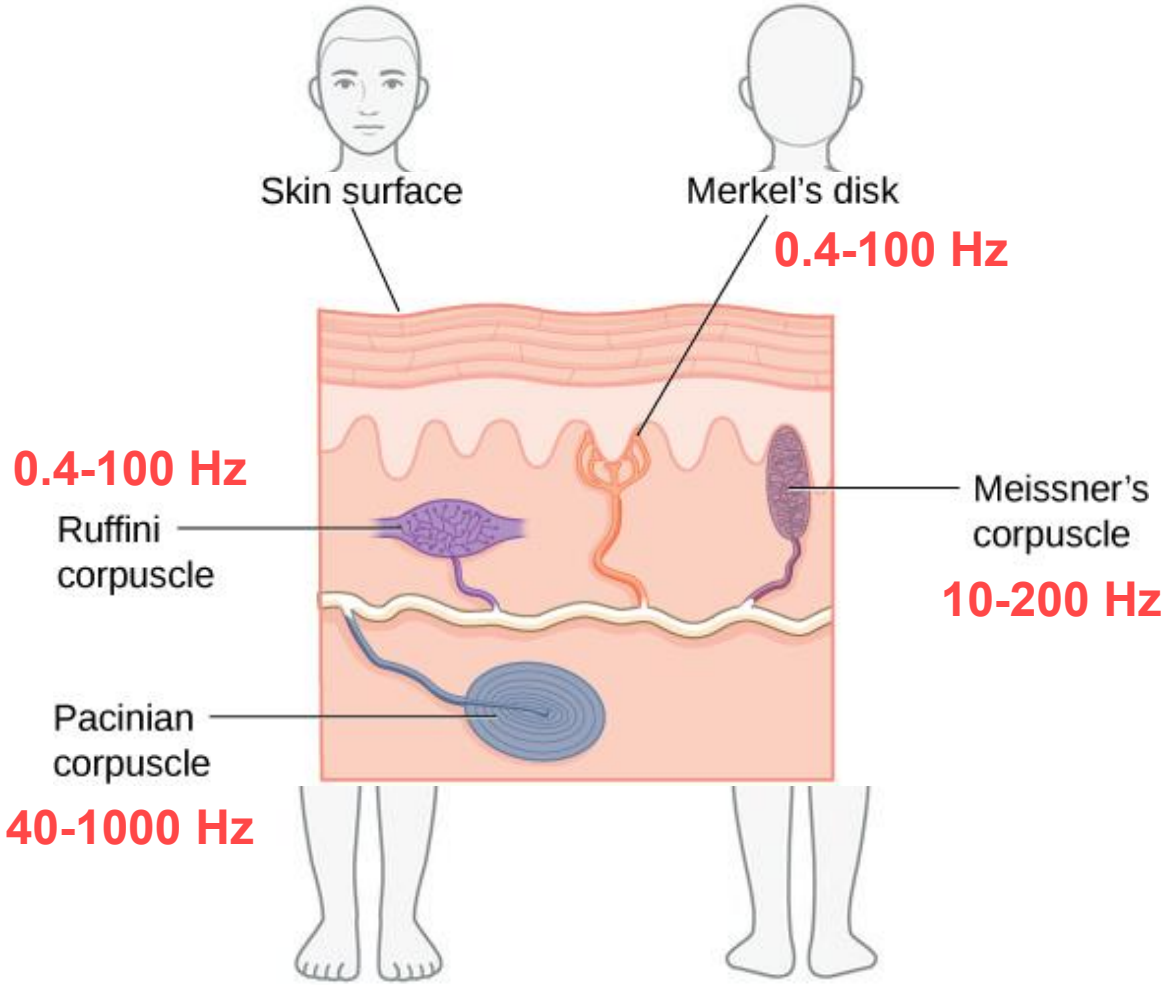
Vibration frequency [Hz]

- 75, 150

Vibration amplitude [G]

- 1.4, 2.9, 4.3

Experimental conditions



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Vibration frequency [Hz]

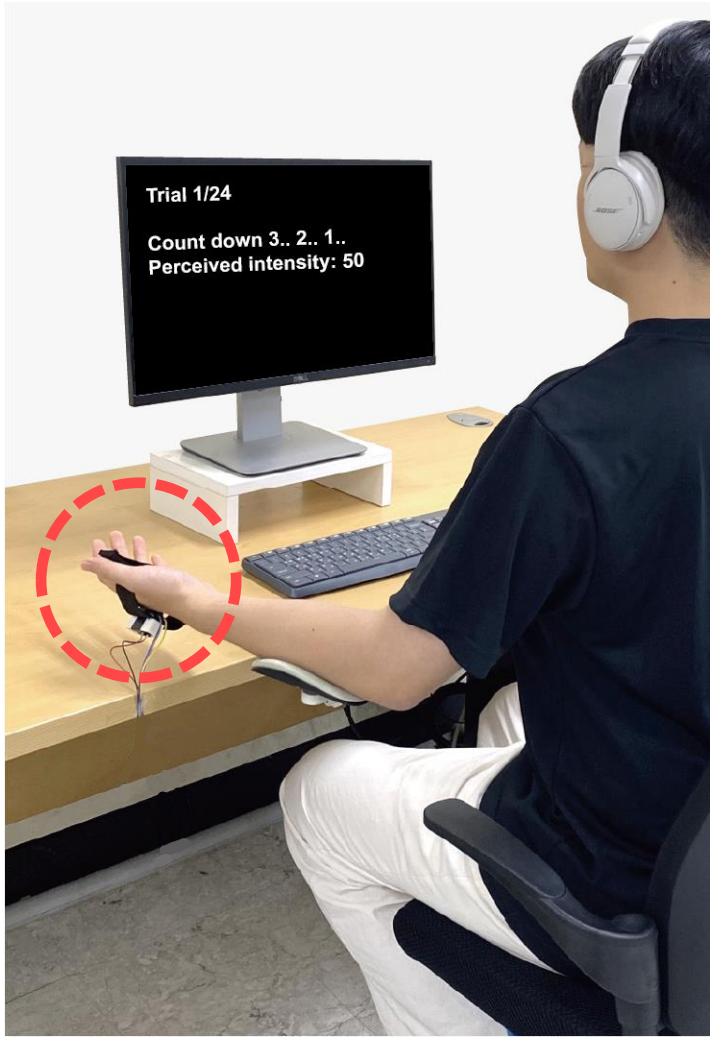
- 75, 150

Vibration amplitude [G]

- 1.4, 2.9, 4.3

Absolute magnitude estimation

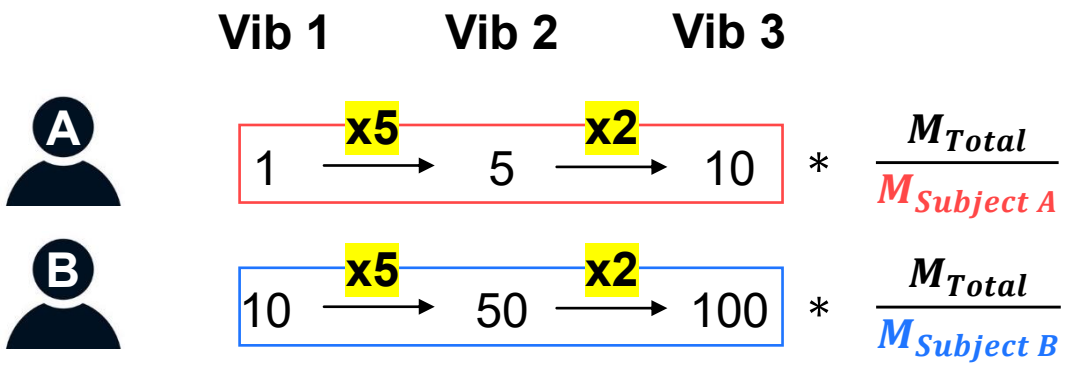
Dorsal hand



In my own criterion,
the perceived intensity
of this vibration is 50.

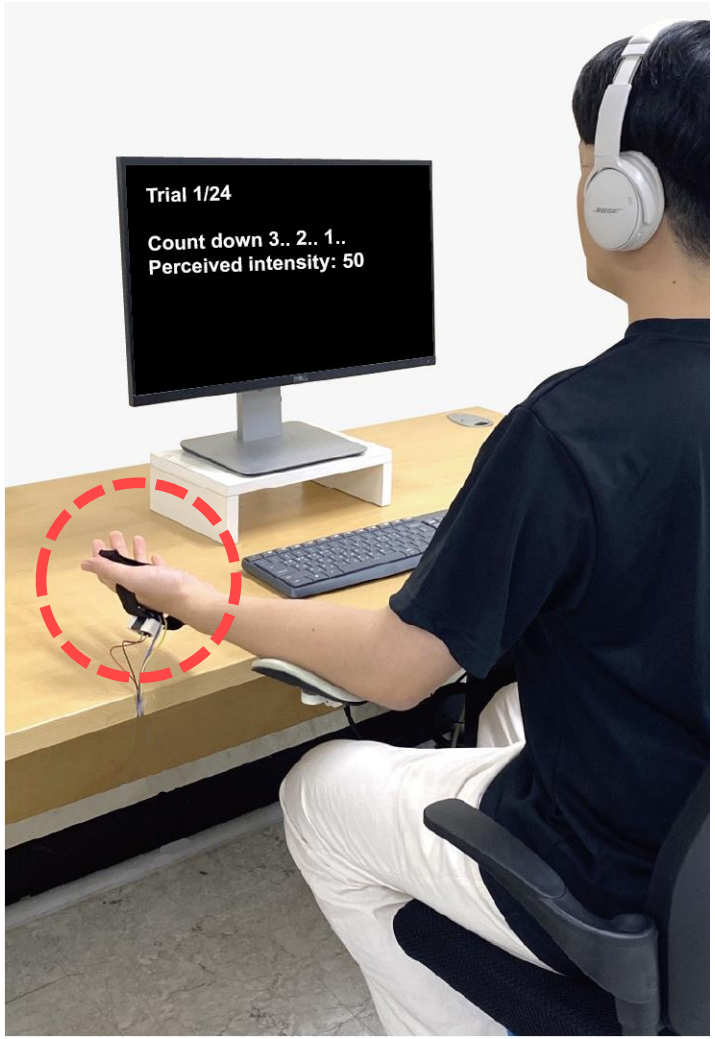
Any positive number
Proportional to perceived intensity

Data normalization (Murray et al., 2003)



Absolute magnitude estimation

Dorsal hand



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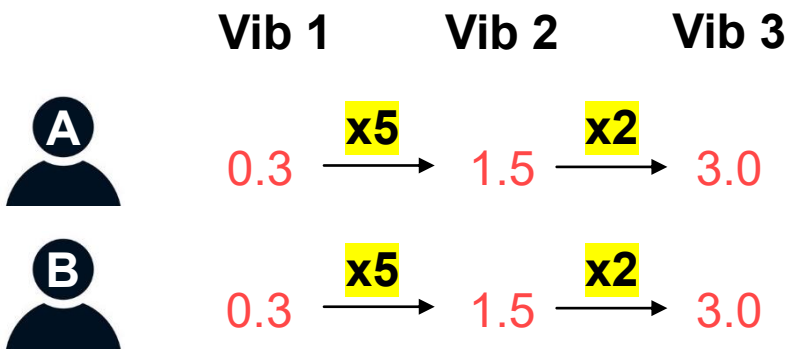


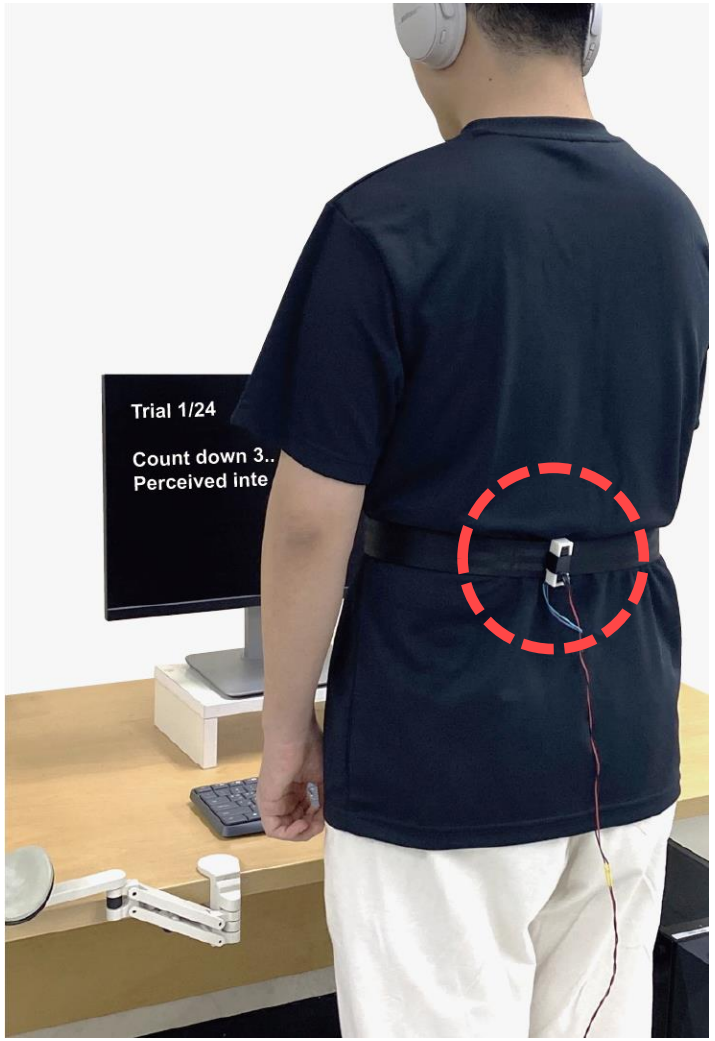
Normalized perceived intensity!

Experimental setup

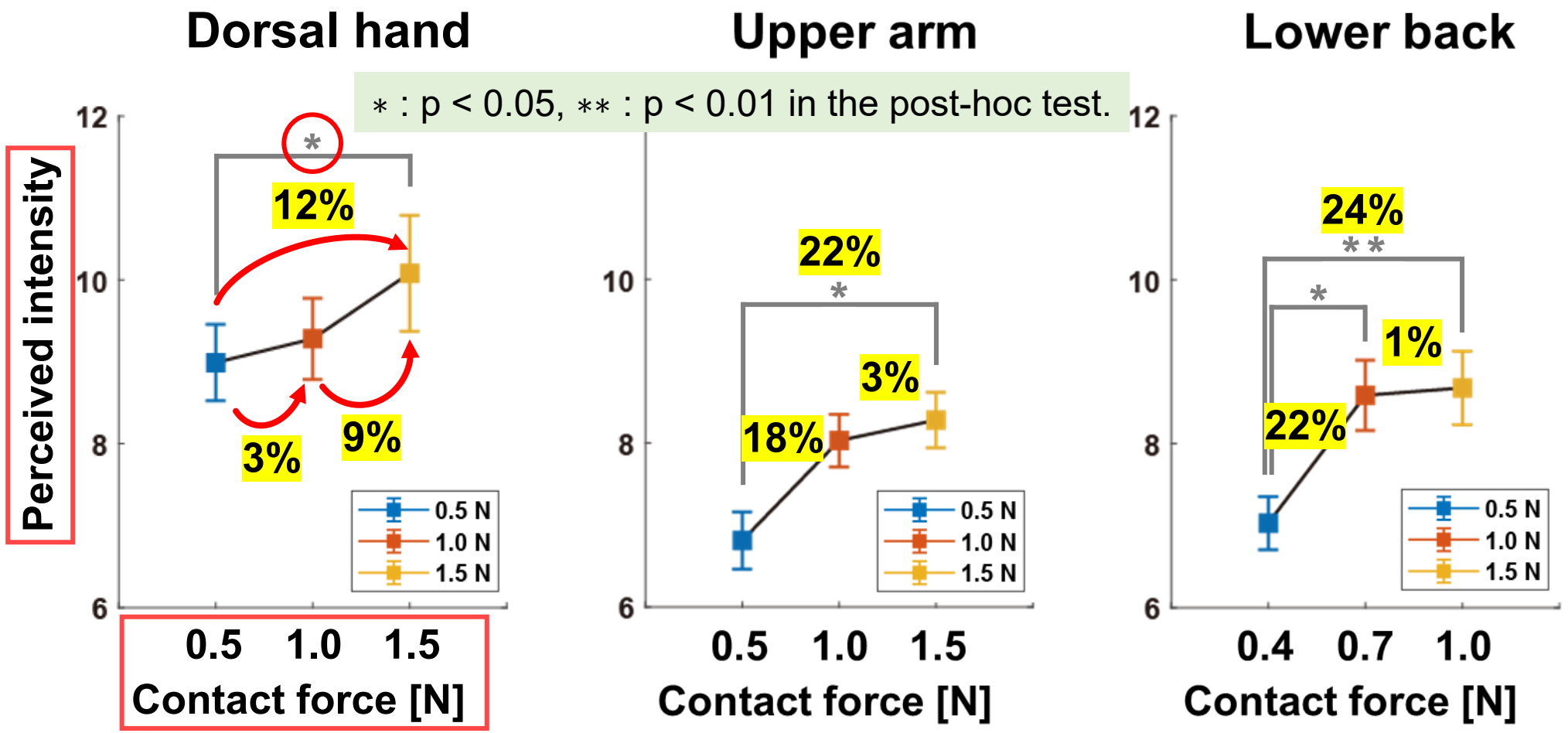
Dorsal hand

Upper arm

Lower back

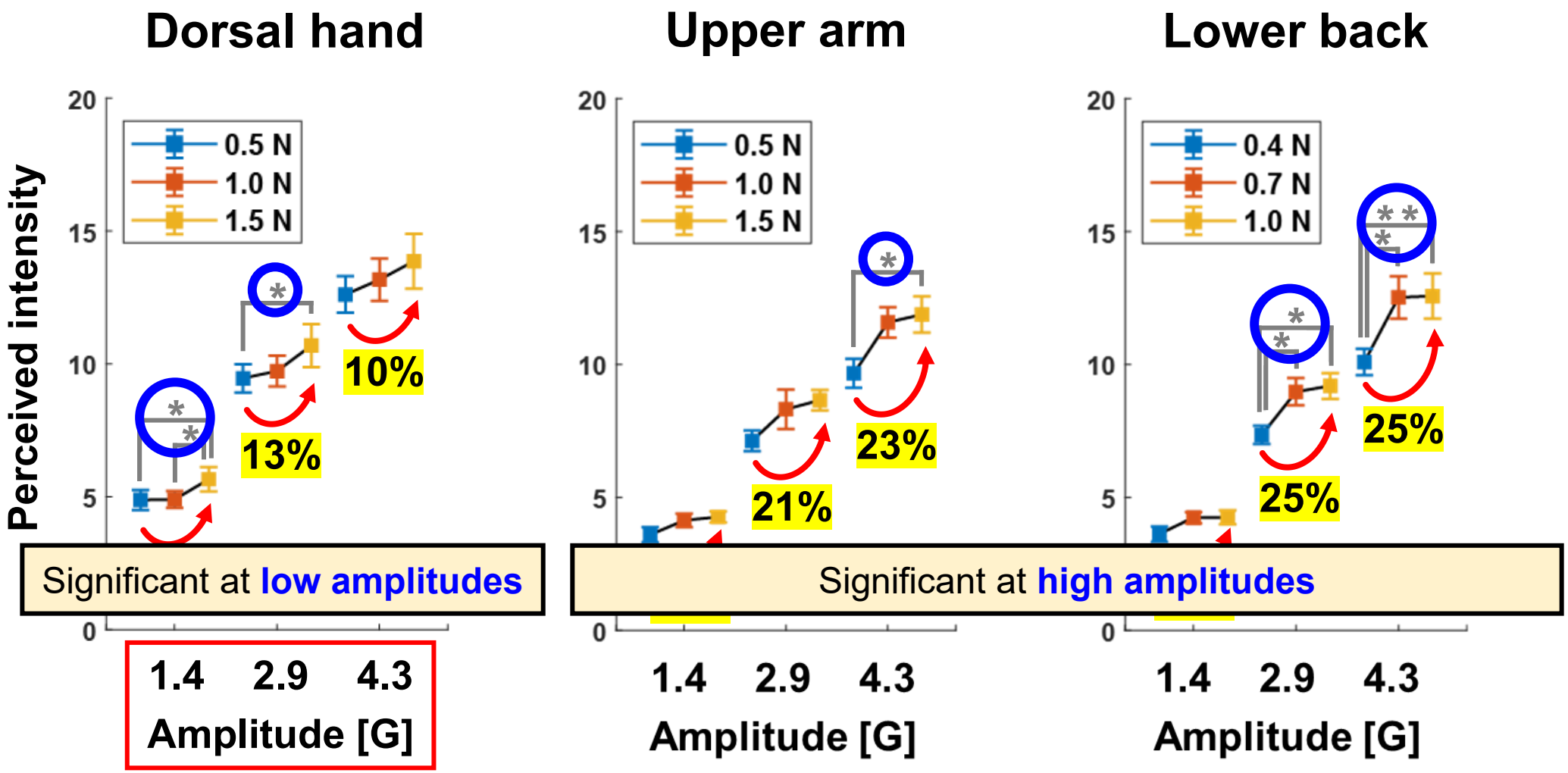


Contact force



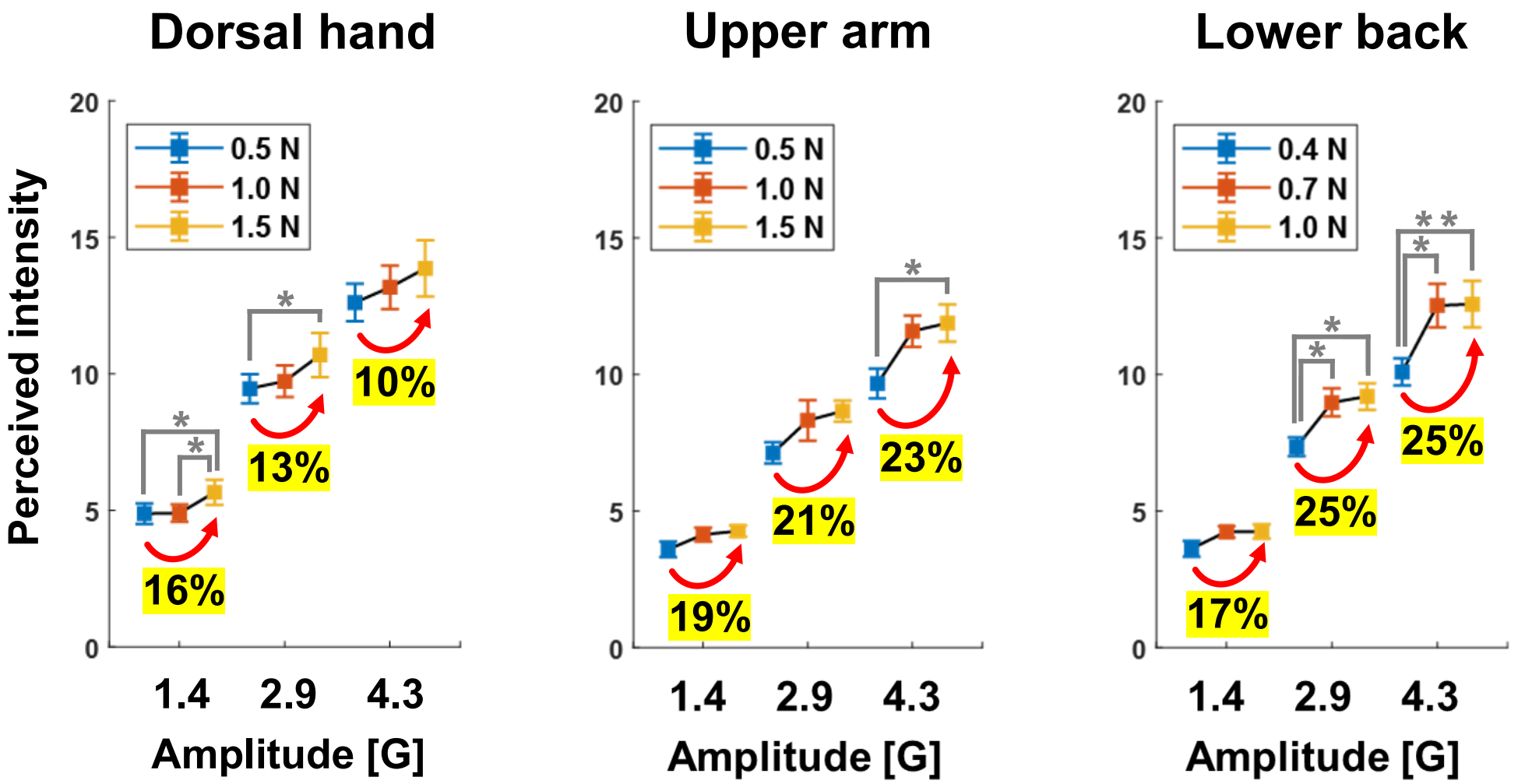
∗ : p < 0.05, ∗∗ : p < 0.01 in the post-hoc test.

Contact force X Vibration amplitude



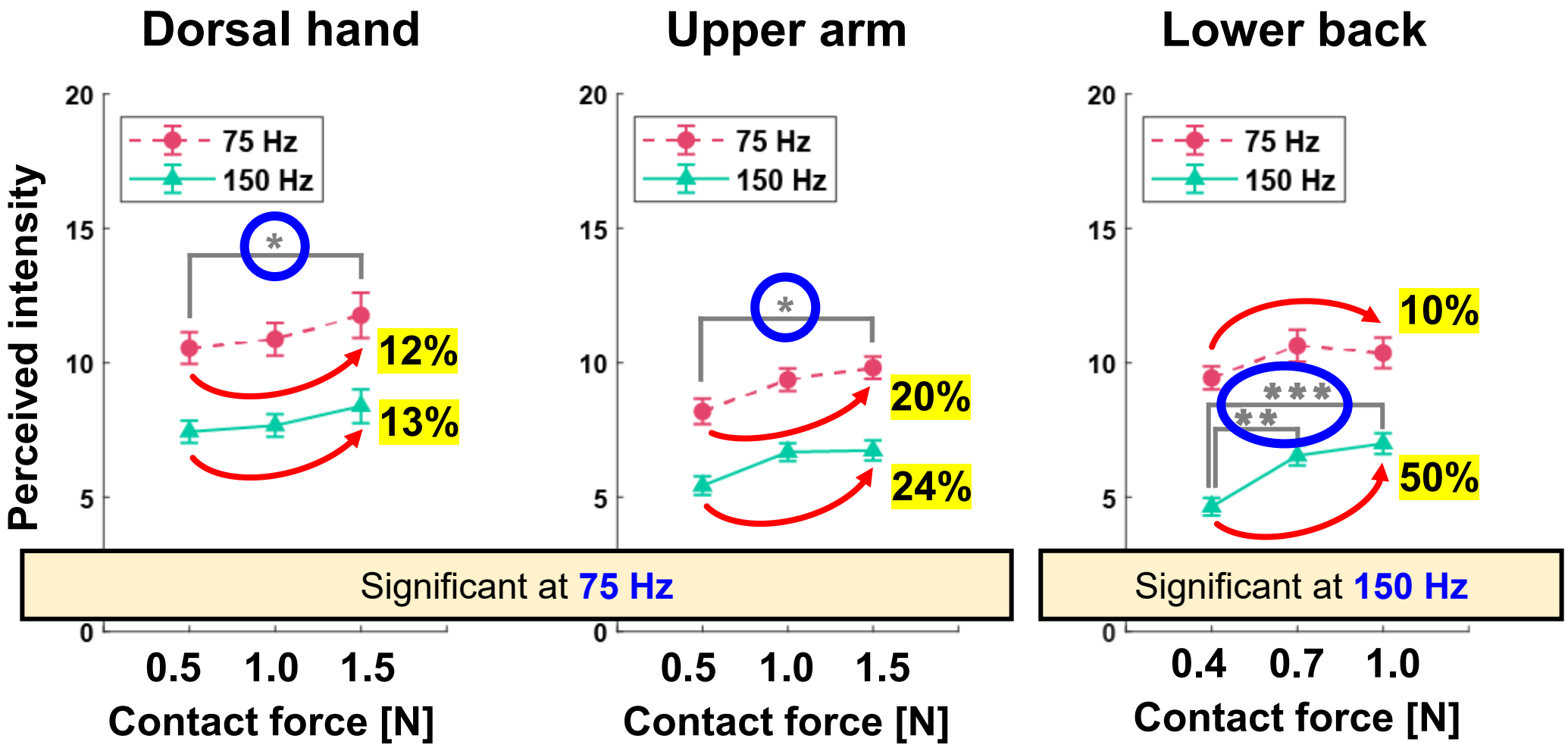
∗ : $p < 0.05$, ∗∗ : $p < 0.01$ in the post-hoc test.

Contact force X Vibration amplitude



∗ : $p < 0.05$, ∗∗ : $p < 0.01$ in the post-hoc test.

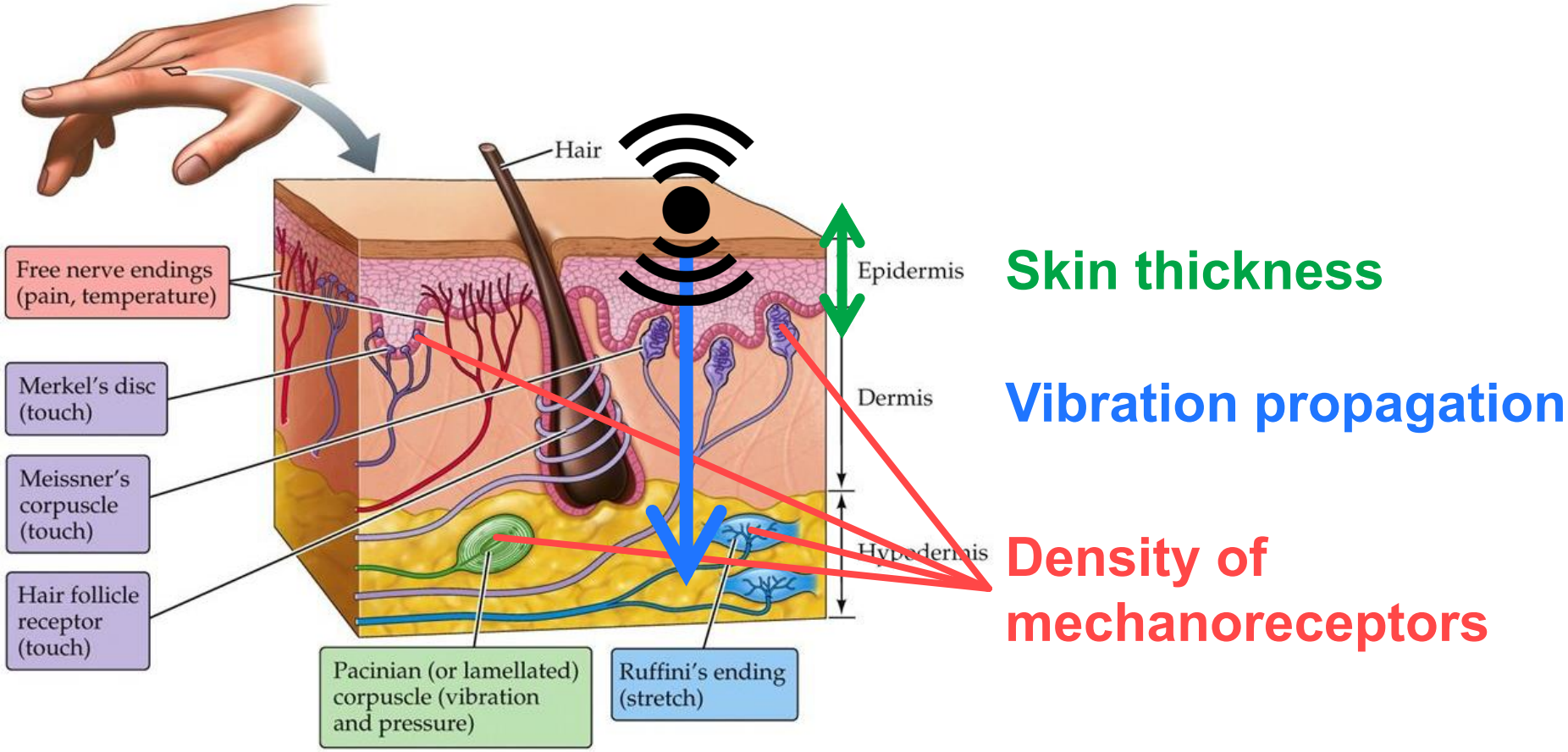
Contact force X Vibration frequency



∗ : $p < 0.05$, ∗∗ : $p < 0.01$ in the post-hoc test.

Contact force ↑ ⇒ Perceived intensity ↑

- Different effects depending on the body part, amplitude, and frequency
- Attributed to differences of …



How to utilize the contact force effect?

[Percent increase of perceived intensity by contact force]

Frequency	Amplitude	Dorsal Hand			Upper Arm			Lower Back		
		0.5 N→1.0 N	1.0 N→1.5 N	0.5 N→1.5 N	0.5 N→1.0 N	1.0 N→1.5 N	0.5 N→1.5 N	0.4 N→0.7 N	0.7 N→1.0 N	0.4 N→1.0 N
75 Hz	1.4 G	0.8%	17.5%	18.4%	12.7%	2.4%	15.4%	14.0%	-6.4%	6.7%
	2.9 G	1.4%	13.3%	14.8%	13.8%	6.5%	21.2%	11.8%	-2.2%	9.3%
	4.3 G	5.5%	1.5%	7.1%	17.1%	4.1%	21.9%	13.8%	-1.3%	12.3%
150 Hz	1.4 G	-0.2%	13.0%	12.8%	20.5%	3.6%	24.9%	25.2%	13.9%	42.6%
	2.9 G	5.1%	5.5%	10.9%	22.4%	0.7%	23.2%	46.3%	9.9%	60.9%
	4.3 G	2.9%	11.1%	14.3%	26.3%	0.0%	26.2%	43.8%	2.6%	47.5%

How to utilize the contact force effect?

[Percent increase of perceived intensity by contact force]

Frequency	Amplitude	Dorsal Hand			Upper Arm			Lower Back		
		0.5 N→1.0 N	1.0 N→1.5 N	0.5 N→1.5 N	0.5 N→1.0 N	1.0 N→1.5 N	0.5 N→1.5 N	0.4 N→0.7 N	0.7 N→1.0 N	0.4 N→1.0 N
75 Hz	1.4 G	0.8%	17.5%	18.4%	12.7%	2.4%	15.4%	14.0%	-6.4%	6.7%
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	4.3 G	5.5%	1.5%	7.1%	17.1%	4.1%	21.9%	13.8%	-1.3%	12.3%
150 Hz	1.4 G	-0.2%	13.0%	12.8%	20.5%	3.6%	24.9%	25.2%	13.9%	42.6%
	2.9 G	5.1%	5.5%	10.9%	22.4%	0.7%	23.2%	46.3%	9.9%	60.9%
	4.3 G	2.9%	11.1%	14.3%	26.3%	0.0%	26.2%	43.8%	2.6%	47.5%

- **Minimize the impact of contact force?**

  → Find an appropriate **range of contact forces** for the target body part.

How to utilize the contact force effect?

[Percent increase of perceived intensity by contact force]

Frequency	Amplitude	Dorsal Hand			Upper Arm			Lower Back		
		0.5 N→1.0 N	1.0 N→1.5 N	0.5 N→1.5 N	0.5 N→1.0 N	1.0 N→1.5 N	0.5 N→1.5 N	0.4 N→0.7 N	0.7 N→1.0 N	0.4 N→1.0 N
75 Hz	1.4 G	0.8%	17.5%	18.4%	12.7%	2.4%	15.4%	14.0%	-6.4%	6.7%
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	4.3 G	5.5%	1.5%	7.1%	17.1%	4.1%	21.9%	13.8%	-1.3%	12.3%
150 Hz	1.4 G	-0.2%	13.0%	12.8%	20.5%	3.6%	24.9%	25.2%	13.9%	42.6%
	2.9 G	5.1%	5.5%	10.9%	22.4%	0.7%	23.2%	46.3%	9.9%	60.9%
	4.3 G	2.9%	11.1%	14.3%	26.3%	0.0%	26.2%	43.8%	2.6%	47.5%

- **Minimize the impact of contact force?**
  → Find an appropriate **range of contact forces** for the target body part.

- **Maximize the impact of contact force?**
  → Use a **high frequency** vibration at the **lower back**.

How to utilize the contact force effect?

[Percent increase of perceived intensity by contact force]

Frequency	Amplitude	Dorsal Hand			Upper Arm			Lower Back		
		0.5 N→1.0 N	1.0 N→1.5 N	0.5 N→1.5 N	0.5 N→1.0 N	1.0 N→1.5 N	0.5 N→1.5 N	0.4 N→0.7 N	0.7 N→1.0 N	0.4 N→1.0 N
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150 Hz	1.4 G	-0.2%	13.0%	12.8%	20.5%	3.6%	24.9%	25.2%	13.9%	42.6%
	2.9 G	5.1%	5.5%	10.9%	22.4%	0.7%	23.2%	46.3%	9.9%	60.9%
	4.3 G	2.9%	11.1%	14.3%	26.3%	0.0%	26.2%	43.8%	2.6%	47.5%

- **Minimize the impact of contact force?**
  → Find an appropriate **range of contact forces** for the target body part.
- **Maximize the impact of contact force?**
  → Use a **high frequency** vibration at the **lower back**.

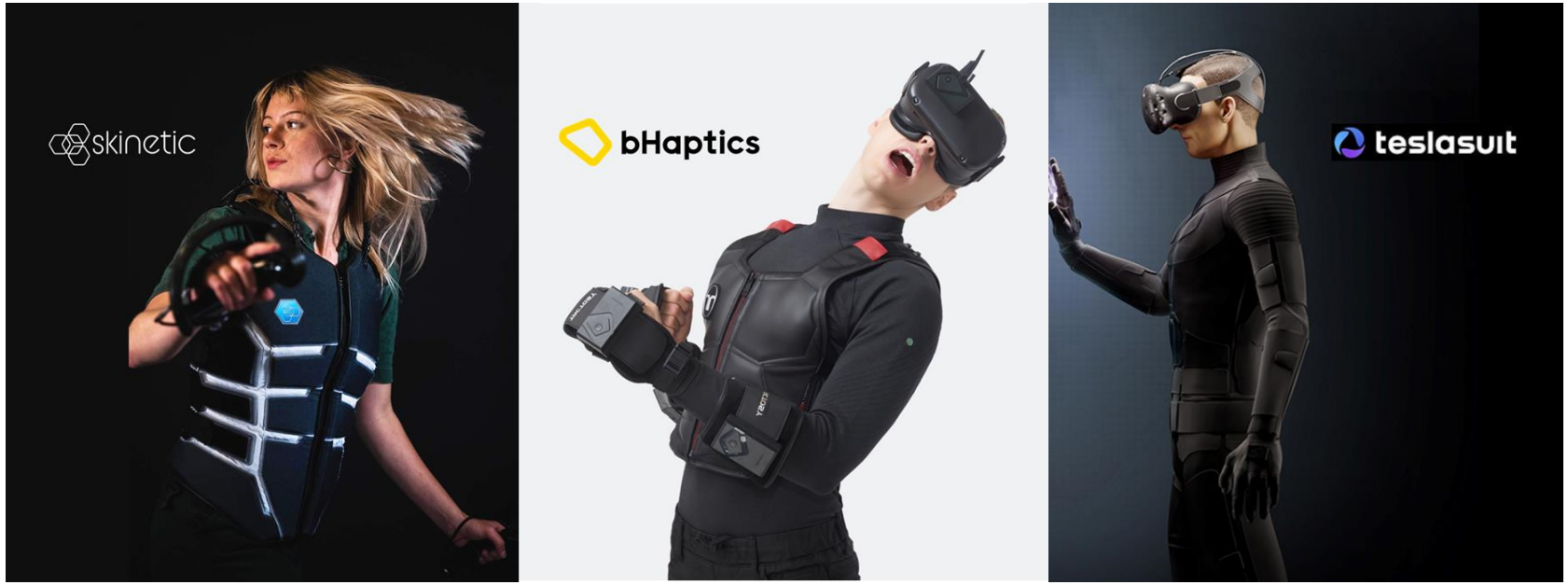
Take-home messages

- As the contact force increases, the perceived intensity increases across the upper body.
- The effect of contact force depends on the body parts and the characteristics of vibration.

Contributions

- Expanding the range of contact force effects to suprathreshold levels
- Guidelines for perceptually accurate and effective full-body haptic rendering

Paper here!



Acknowledgment

This work was supported by the Mid-Career Researcher Program of the National Research Foundation of Korea (NRF) under Grant 2022R1A2C2091161.

Effects of Contact Force on Vibrotactile Perceived Intensity Across the Upper Body

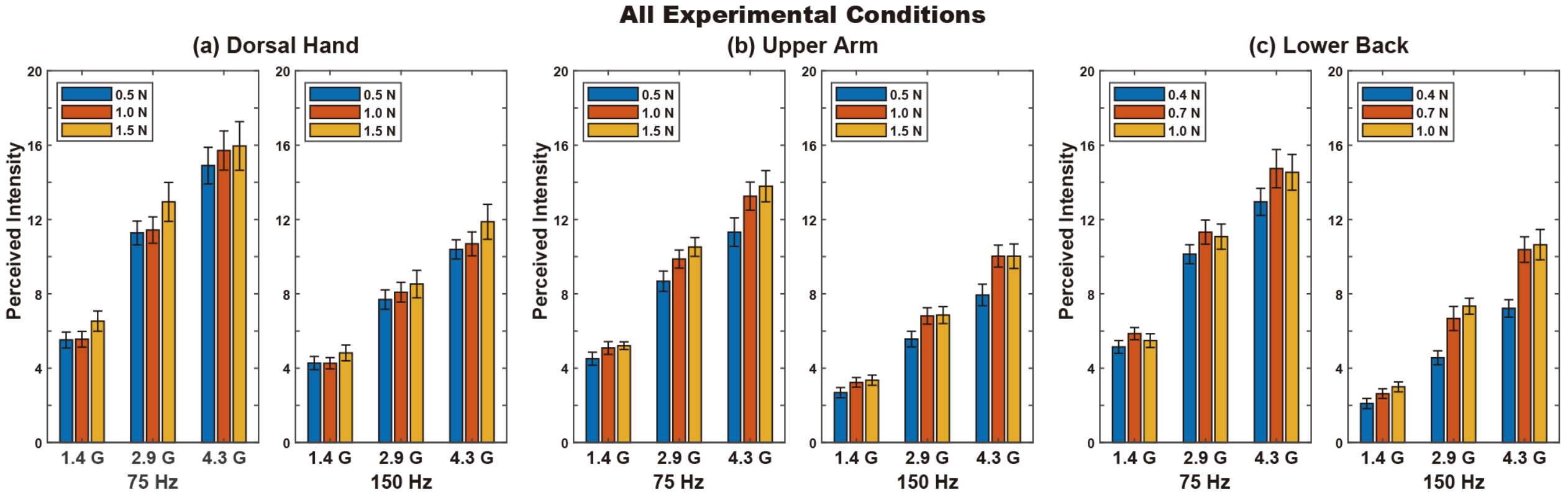
Paper here!

2024 Haptics Symposium

POSTECH

INTERACTION LABORATORY

Appendix A. Effects of Contact Force on Perceived Intensity

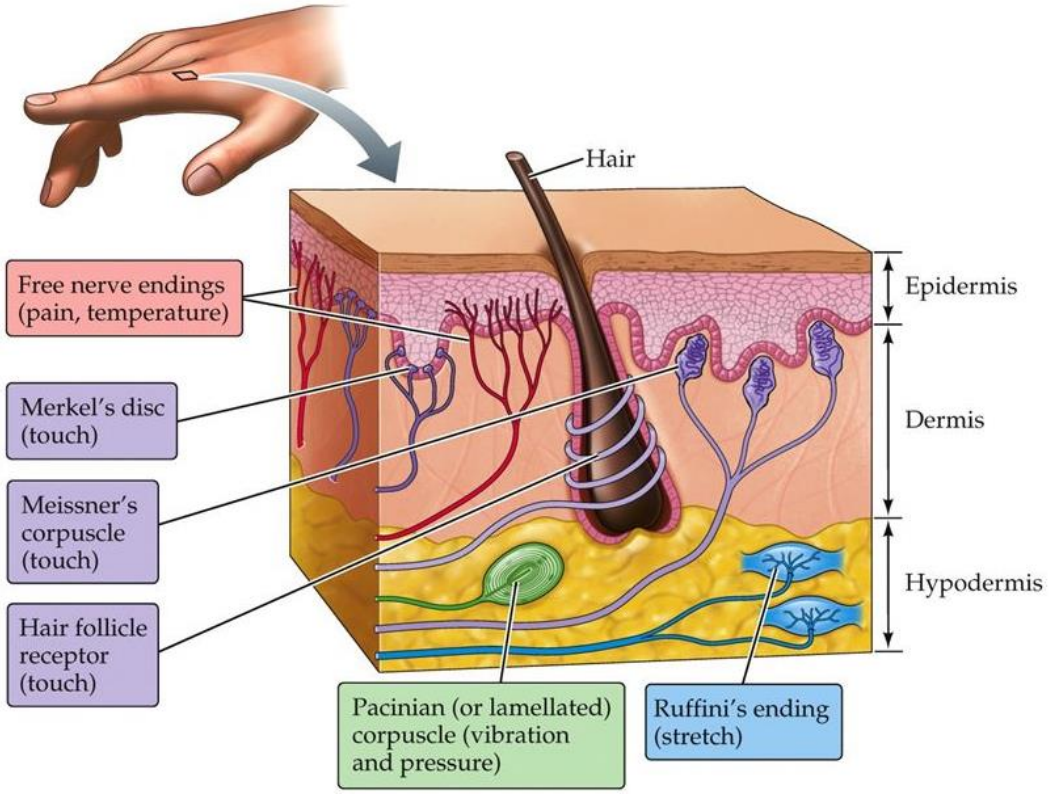


Percent Increase of Perceived Intensity by Contact Force at (a)							
Frequency		75 Hz			150 Hz		
Ampliude		1.4 G	2.9 G	4.3 G	1.4 G	2.9 G	4.3 G
Contact Force	0.5 N→1.0 N	0.8%	1.4%	5.5%	-0.2%	5.1%	2.9%
	1.0 N→1.5 N	17.5%	13.3%	1.5%	13.0%	5.5%	11.1%
	0.5 N→1.5 N	18.4%	14.8%	7.1%	12.8%	10.9%	14.3%

Percent Increase of Perceived Intensity by Contact Force at (b)							
Frequency		75 Hz			150 Hz		
Ampliude		1.4 G	2.9 G	4.3 G	1.4 G	2.9 G	4.3 G
Contact Force	0.5 N→1.0 N	12.7%	13.8%	17.1%	20.5%	22.4%	26.3%
	1.0 N→1.5 N	2.4%	6.5%	4.1%	3.6%	0.7%	0.0%
	0.5 N→1.5 N	15.4%	21.2%	21.9%	24.9%	23.2%	26.2%

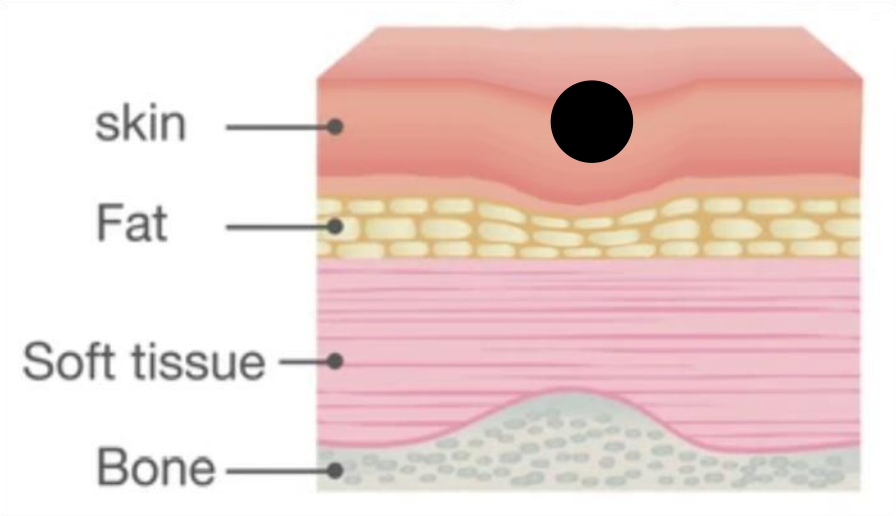
Percent Increase of Perceived Intensity by Contact Force at (c)							
Frequency		75 Hz			150 Hz		
Ampliude		1.4 G	2.9 G	4.3 G	1.4 G	2.9 G	4.3 G
Contact Force	0.4 N→0.7 N	14.0%	11.8%	13.8%	25.2%	46.3%	43.8%
	0.7 N→1.0 N	-6.4%	-2.2%	-1.3%	13.9%	9.9%	2.6%
	0.4 N→1.0 N	6.7%	9.3%	12.3%	42.6%	60.9%	47.5%

Appendix B. Characteristics of the Four Mechanoreceptors



Feature	Meissner Corpuscles	Pacinian Corpuscles	Merkel's Disks	Ruffini Endings
Rate of adaptation	Rapid	Rapid	Slow	Slow
Location	Superficial dermis	Dermis and subcutaneous	Basal epidermis	Dermis and subcutaneous
Mean receptive area	13 mm^2	101 mm^2	11 mm^2	59 mm^2
Spatial resolution	Poor	Very poor	Good	Fair
Sensory units	43%	13%	25%	19%
Response frequency range	10 – 200 Hz	70 – 1000 Hz	0.4 – 100 Hz	0.4 – 100 Hz
Min. threshold frequency	40 Hz	200 – 250 Hz	50 Hz	50 Hz
Sensitive to temperature	No	Yes	Yes	> 100 Hz
Spatial summation	Yes	No	No	Unknown
Temporal summation	Yes	No	No	Yes
Physical parameter sensed	Skin curvature, velocity, local shape, flutter, slip	Vibration, slip, acceleration	Skin curvature, local shape, pressure	Skin stretch, local force

Low contact force



High contact force