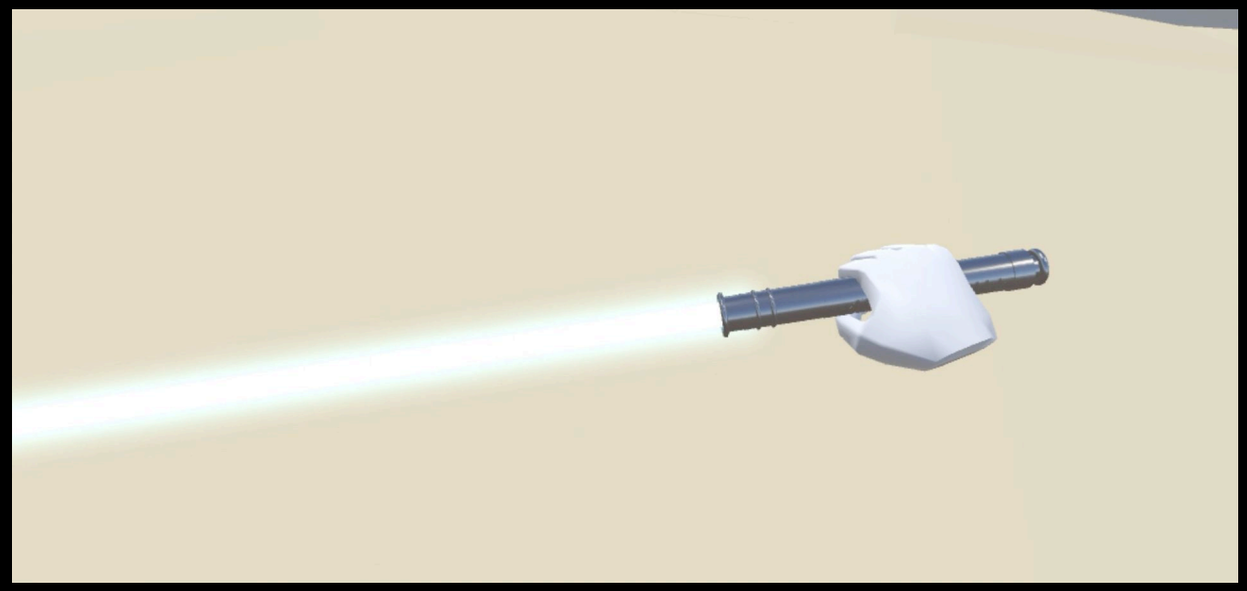
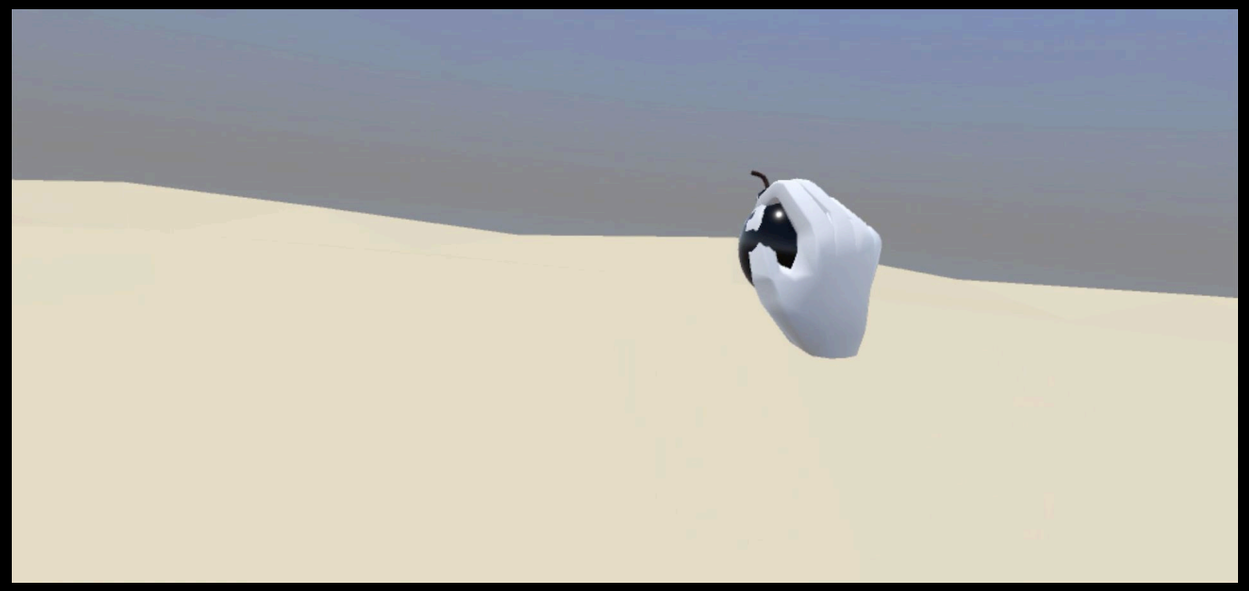
UIST 2018
BERLIN, GERMANY / OCTOBER 14-17, 2018

PuPoP:
Pop-up Prop on Palm for Virtual Reality

Shan-Yuan Teng Tzu-Sheng Kuo Chi Wang Chi-huan Chiang
Da-Yuan Huang Liwei Chan Bing-Yu Chen

National Taiwan University
National Chiao Tung University
TAIWAN TECH NATIONAL TAIWAN UNIVERSITY OF SCIENCE AND TECHNOLOGY



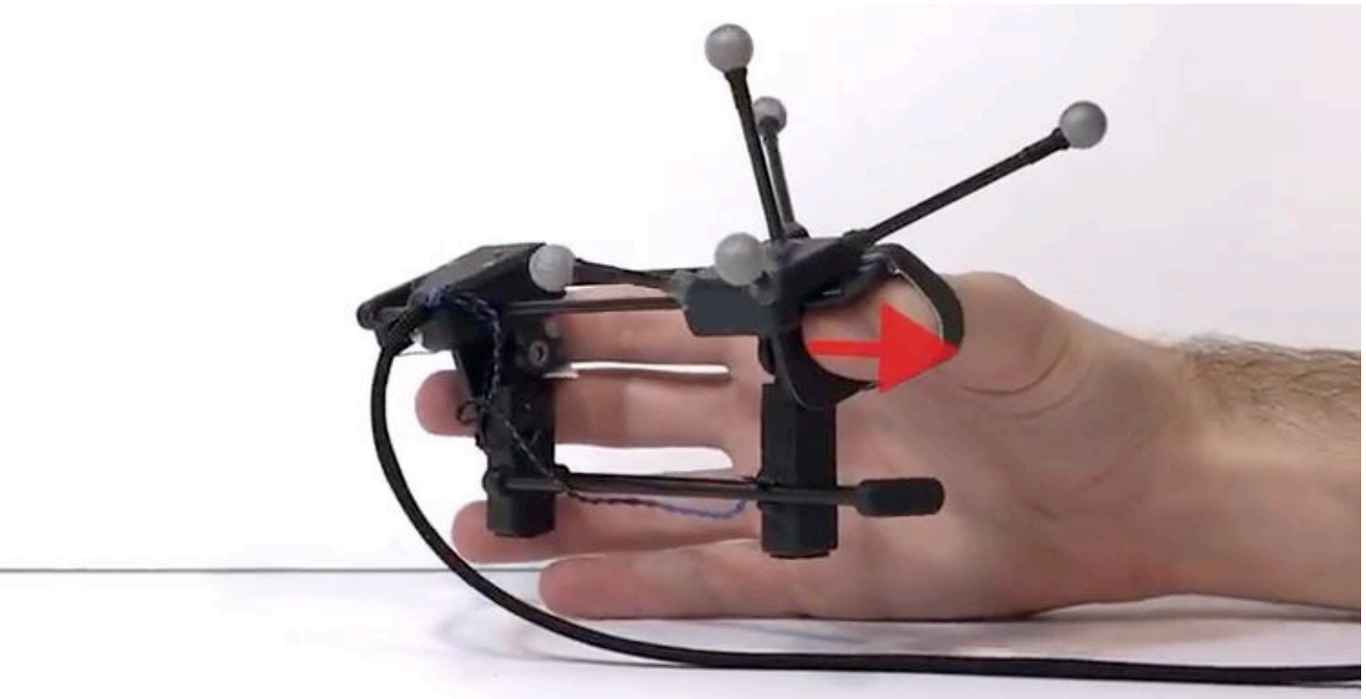


Pick up a Lightsaber

Throw a bomb

Related Work

Wearable Haptic Devices

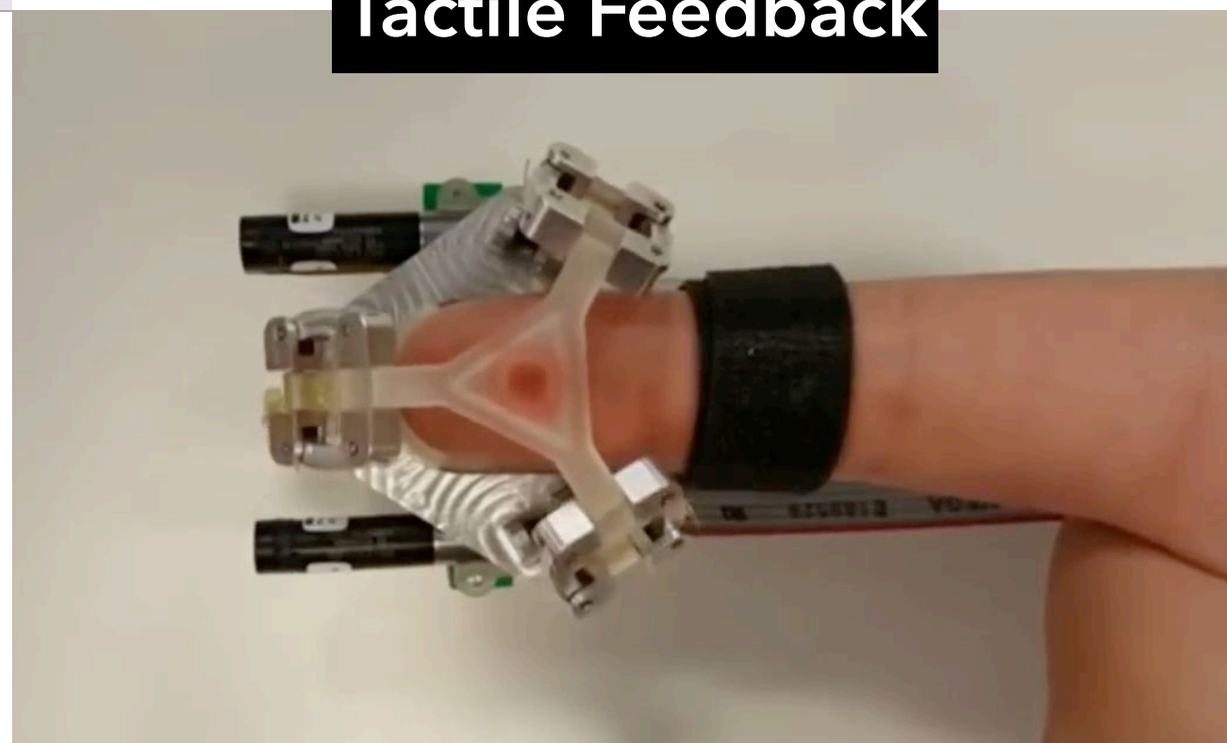


Force Feedback

Choi, et al. UIST '17

Schorr, et al. CHI '17

Tactile Feedback



Related Work

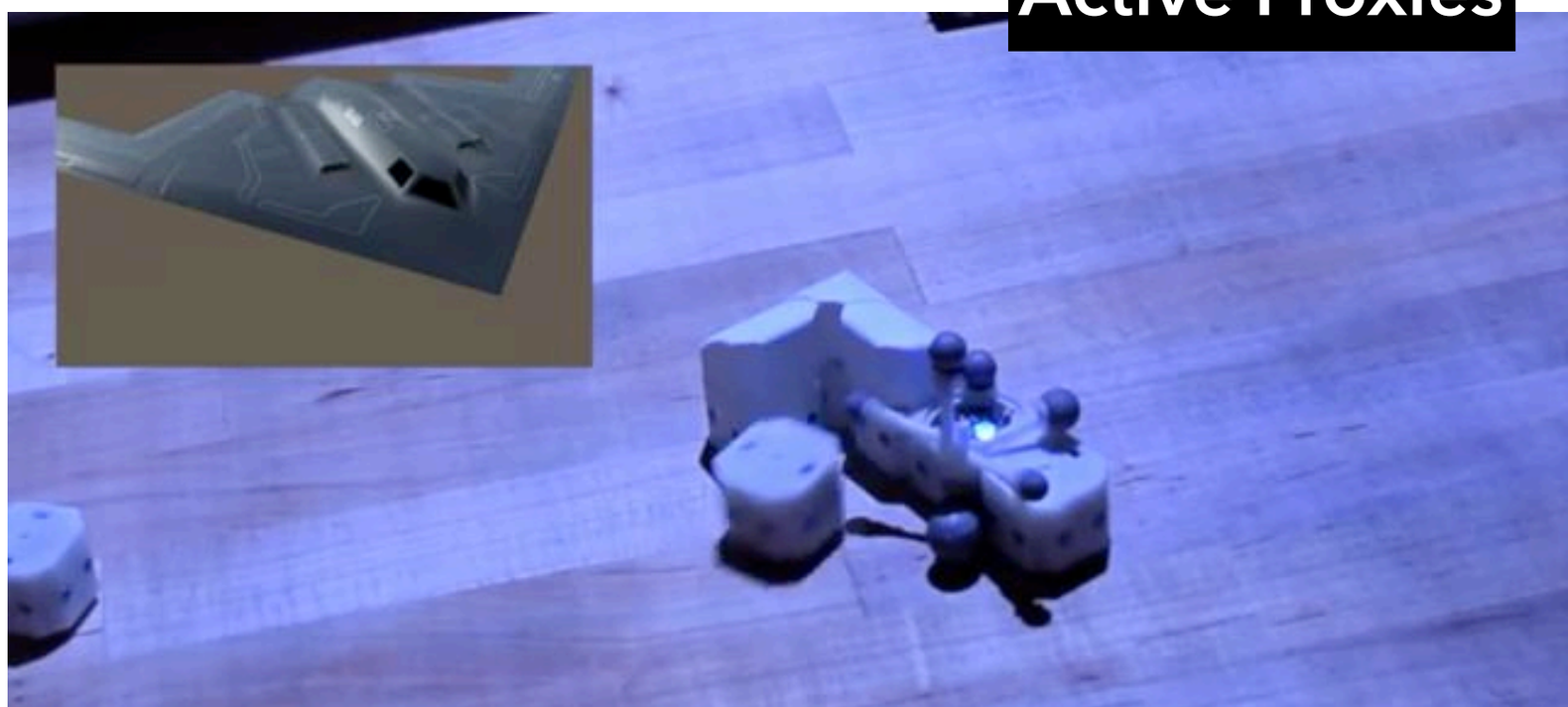
Physical Proxy Interfaces

Passive Proxies

Hettiarachchi and Wigdor. CHI ‘16

Zhao, et al. ISS ‘17

Active Proxies



Related Work Visuo-Haptic Illusion

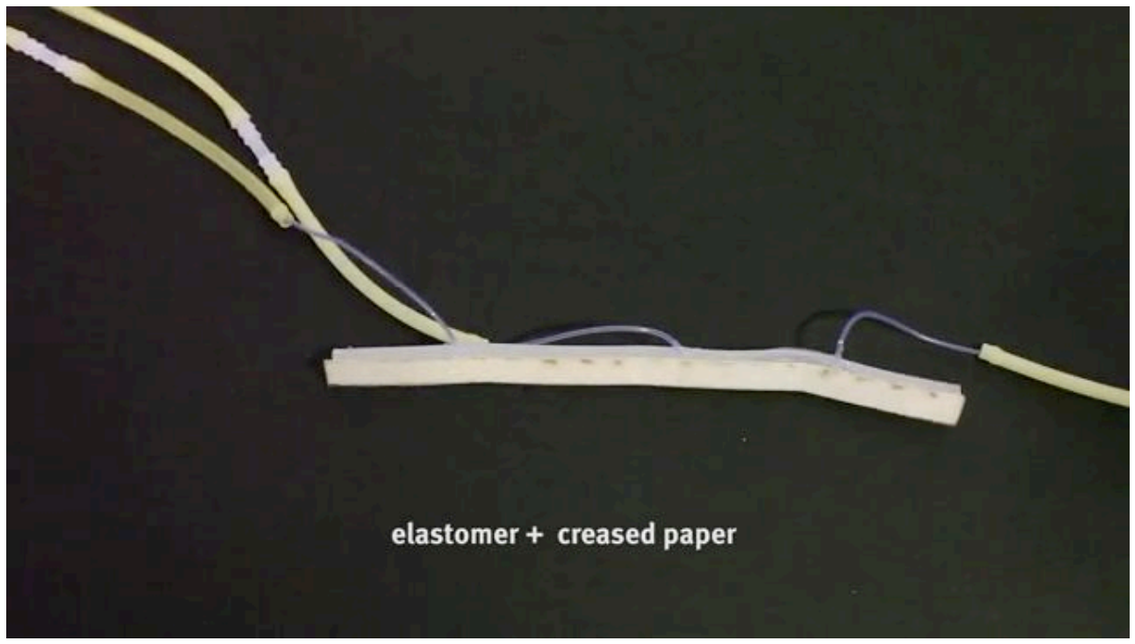
Simeone, et al. CHI ‘15

Fujinawa, et al. VRST ‘17

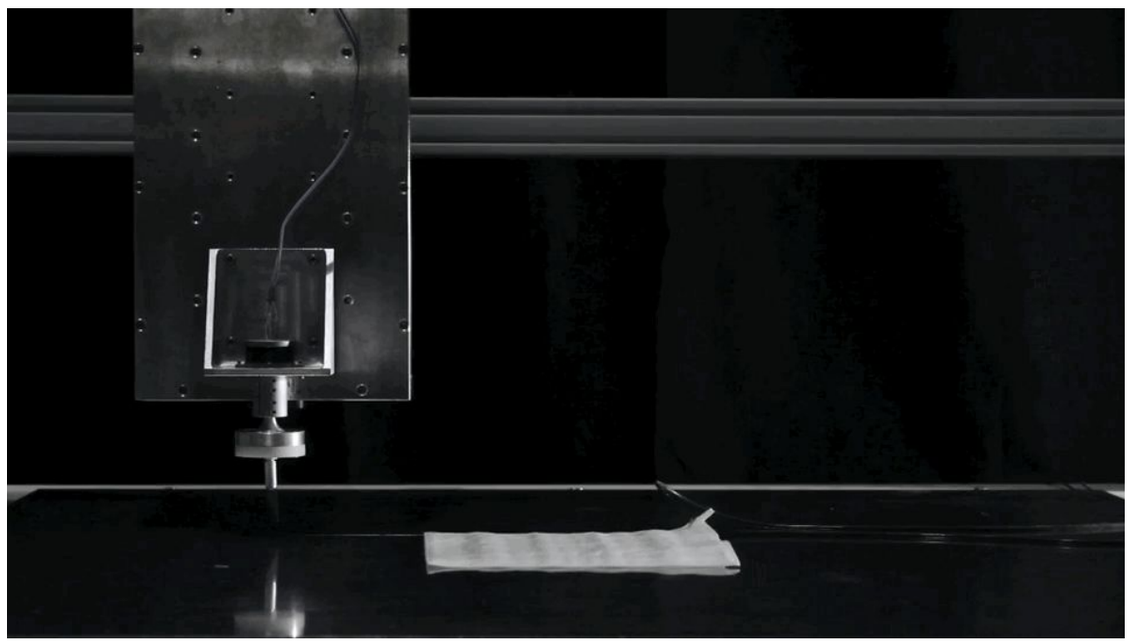
Related Work

Pneumatic Interfaces

Harrison and Hudson. CHI ‘09



Yao, et al. UIST ‘13



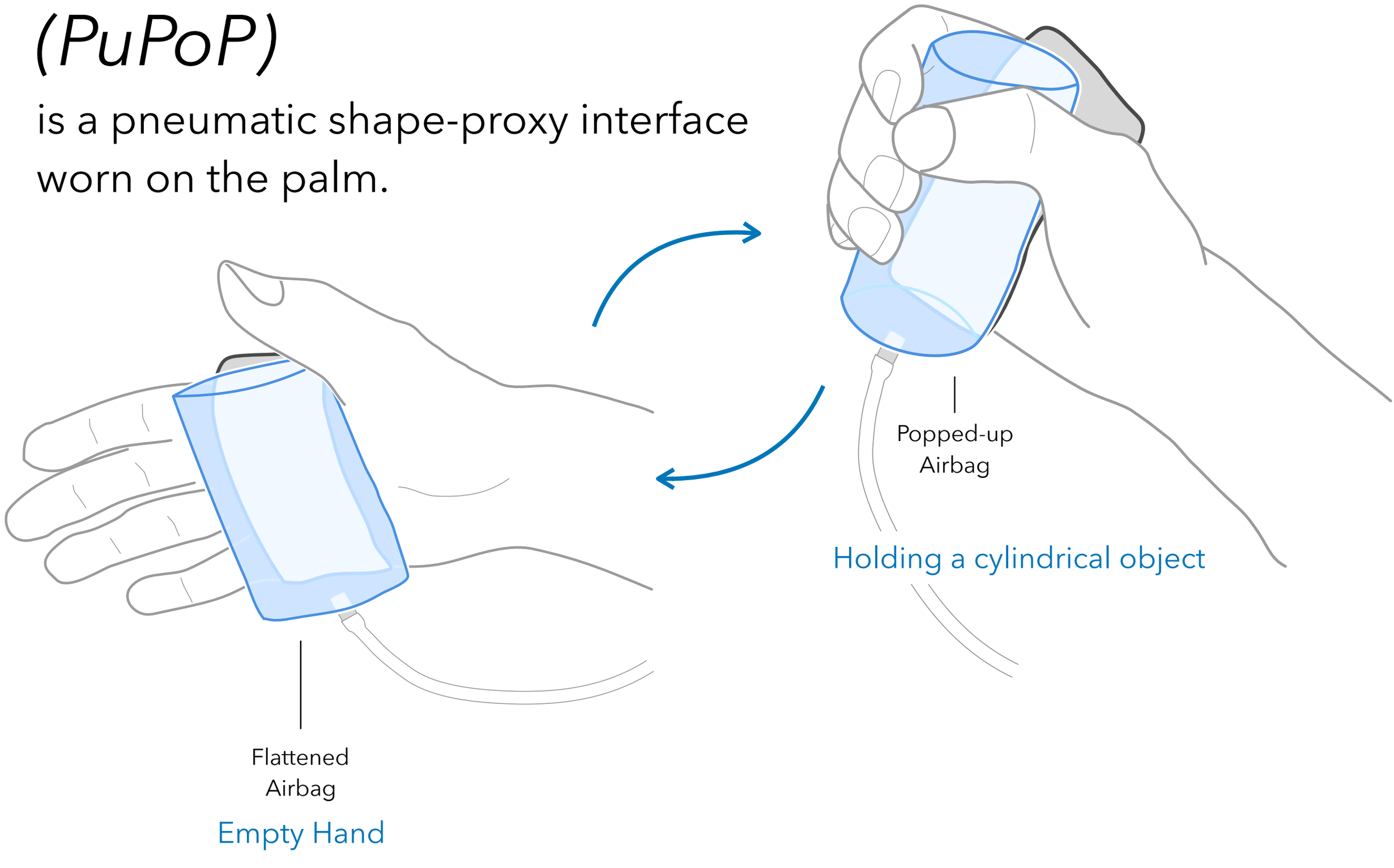
Ou, et al. UIST ‘16

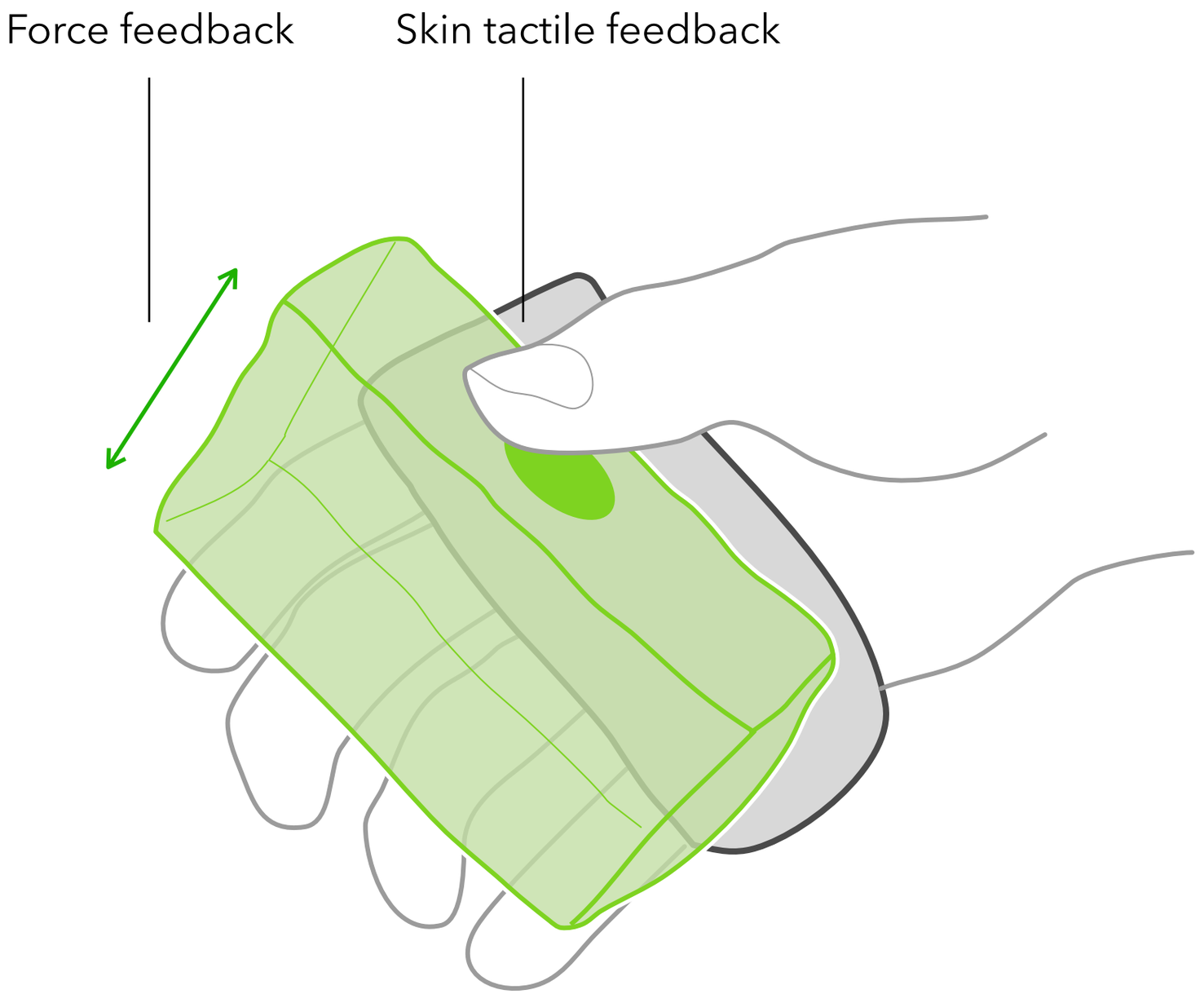
Physical Proxies

Always-available in VR

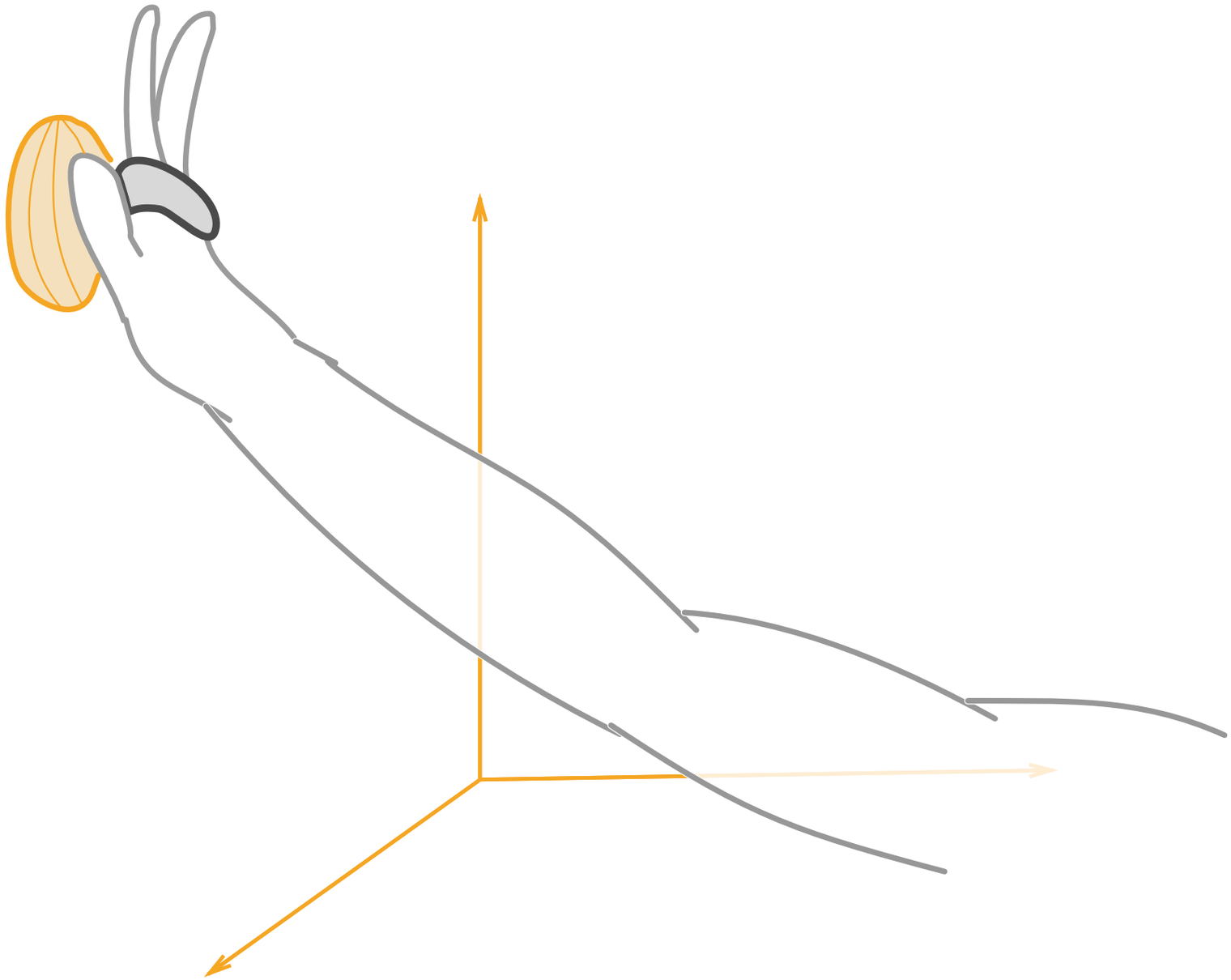
Pop-up Prop on Palm (PuPoP)

is a pneumatic shape-proxy interface worn on the palm.

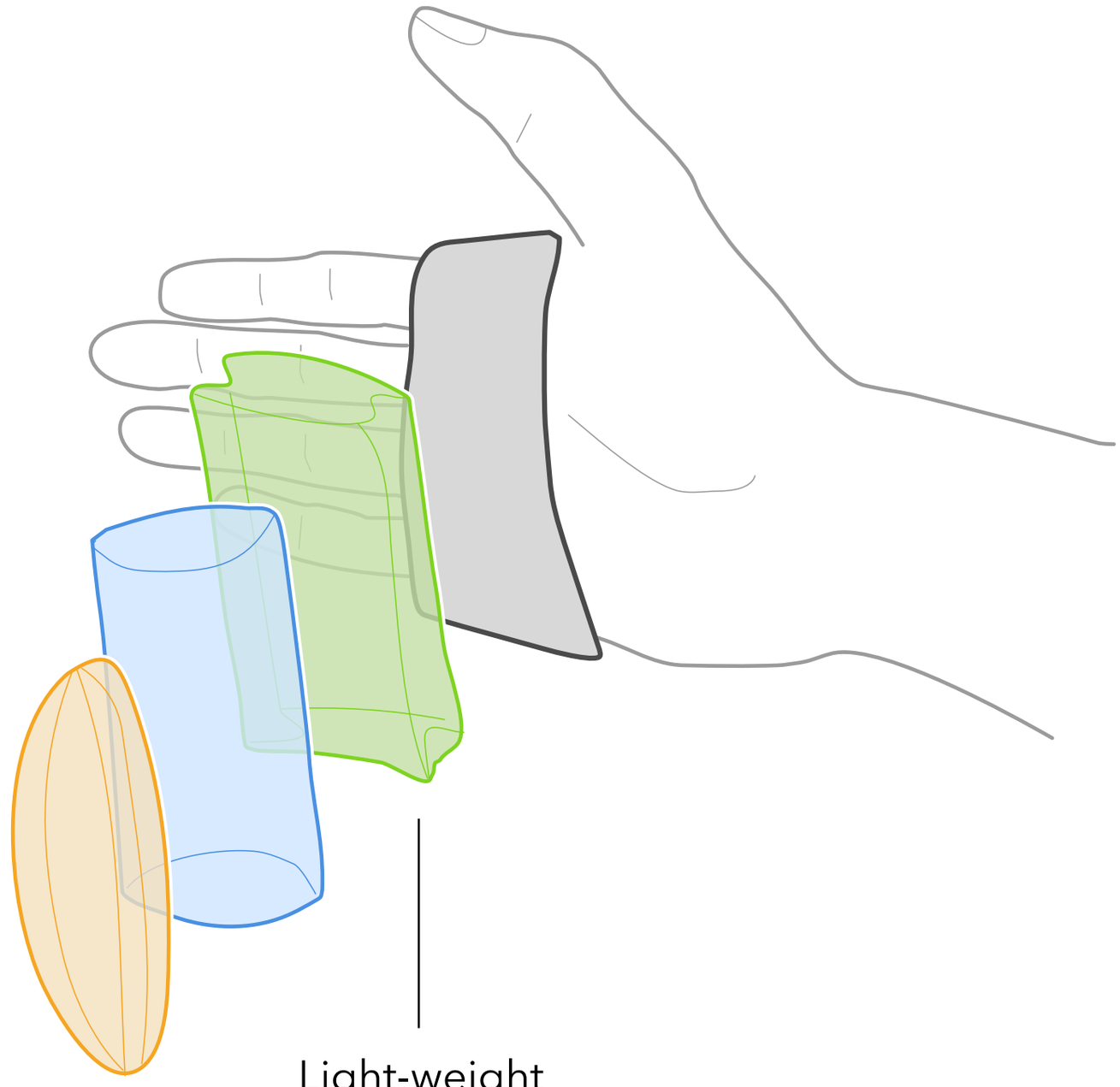




Natural grasping sensation.



Always available in the entire VR interaction space.

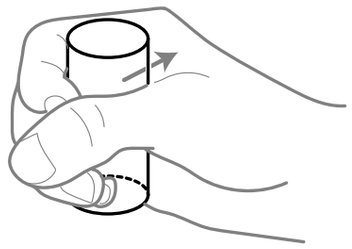


Easy to wear and take off.

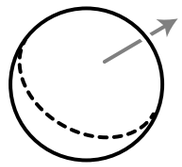
Design
& Implementation

Design Overview

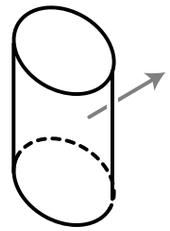
Primitive shapes



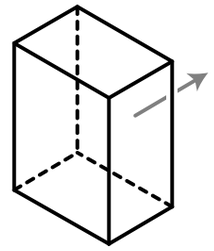
Power grasp



Sphere

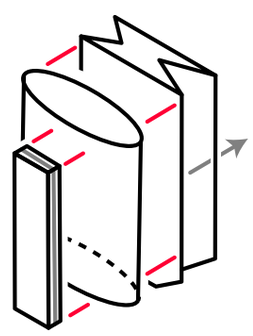


Cylinder

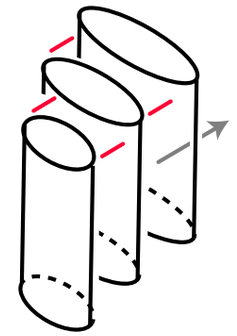


Box

Prop stacking

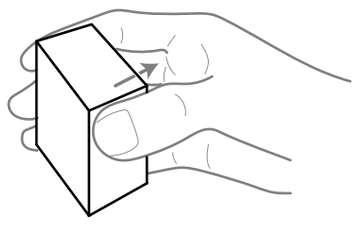


Shape stacking

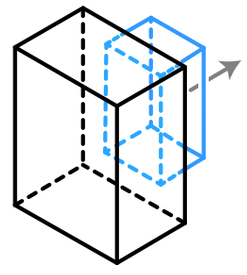


Size stacking

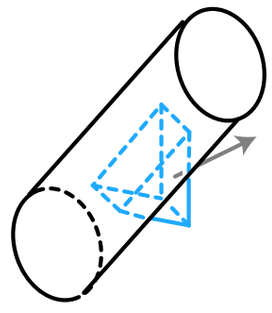
Prop extension



Precision grasp



Parallel extension



Tilt extension

Pneumatic Control System

Air Pressure Sensors

Maintenance Pumps

Solenoid Valves

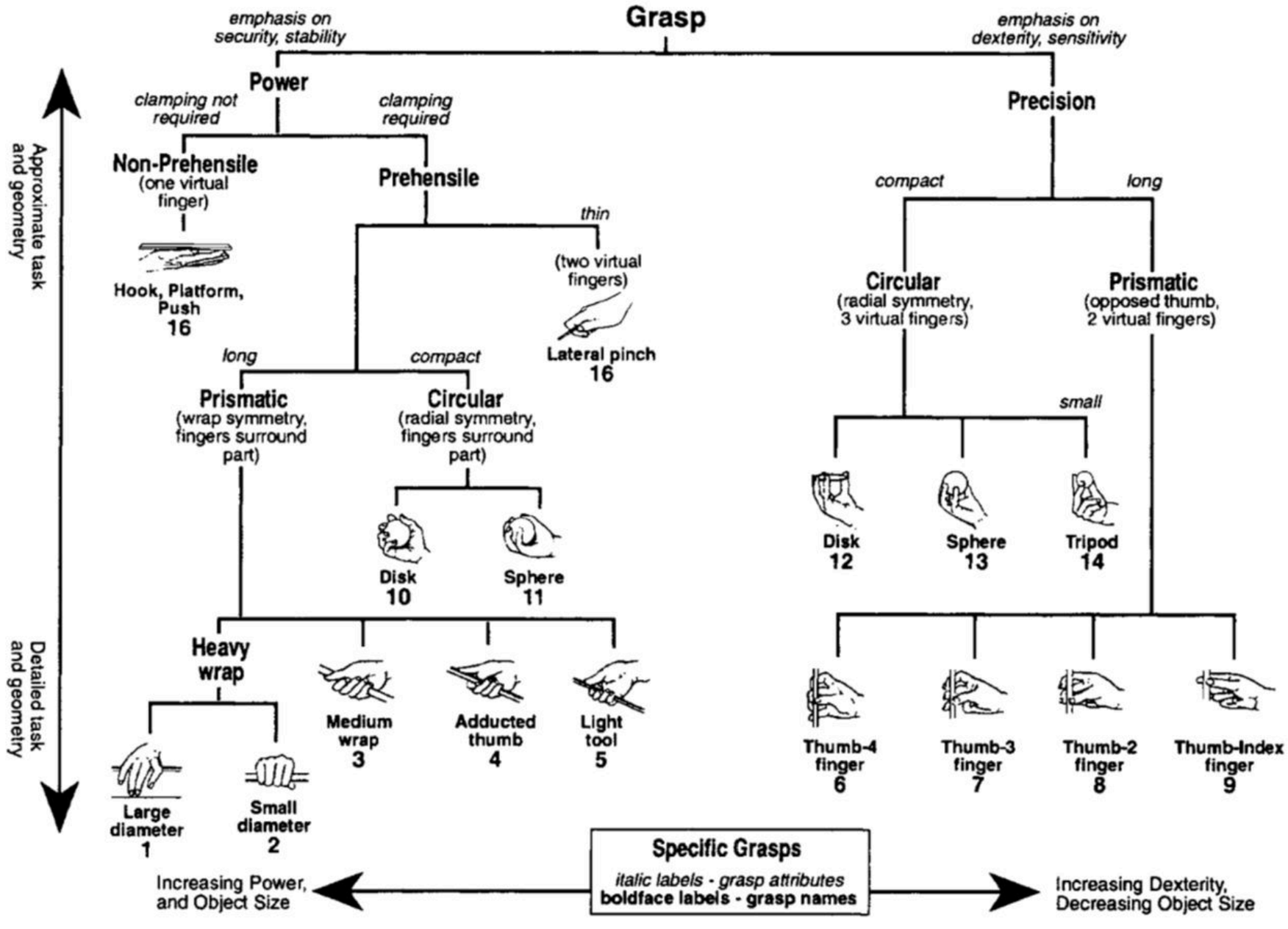
Fast Pump

Two-channel Airbags

Identify Primitive Shapes

Grasp Taxonomy

Cutkosky and Howe, 1990.



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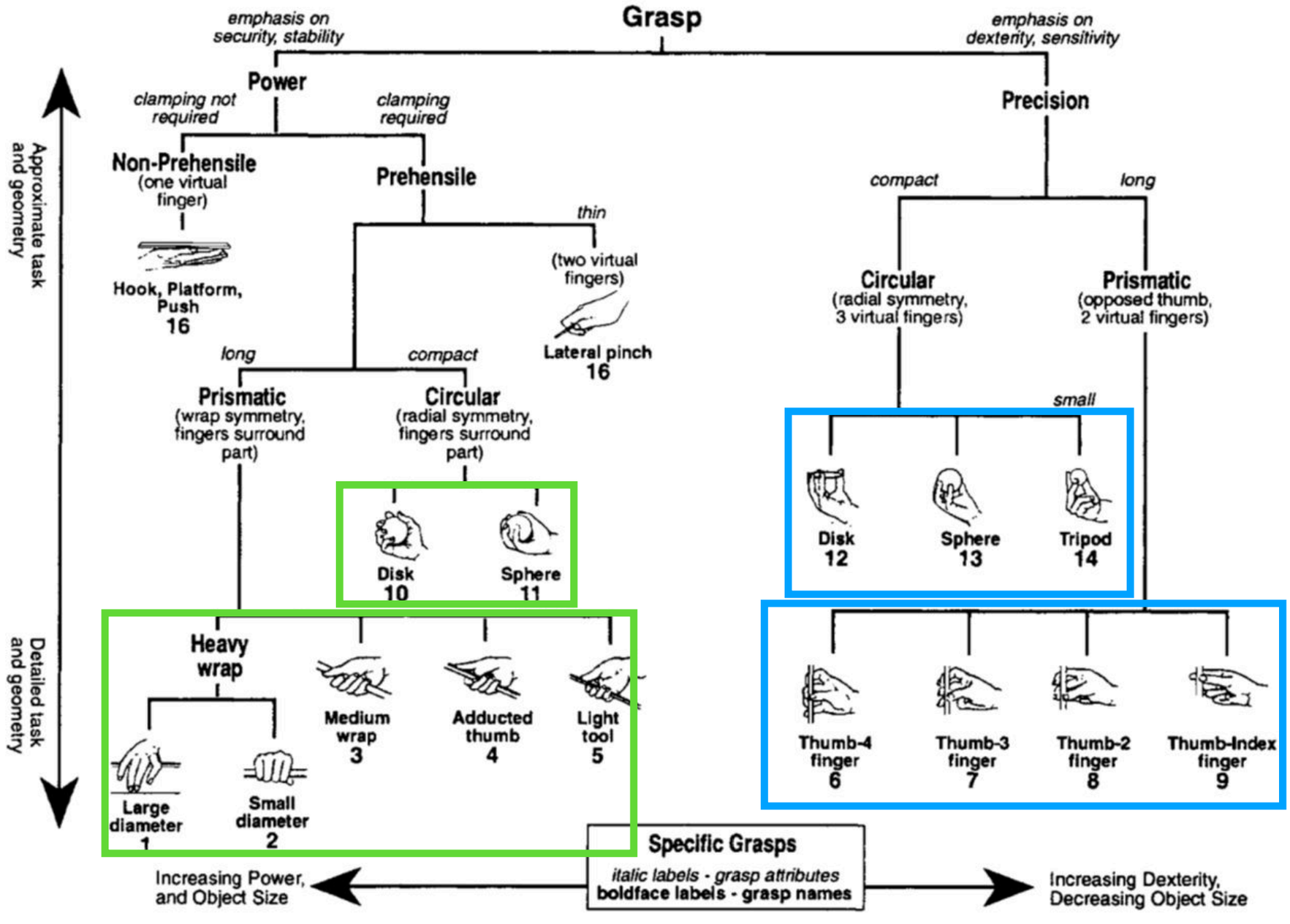
Power Grasp

Grasp Taxonomy

Cutkosky and Howe, 1990.

Precision Grasp



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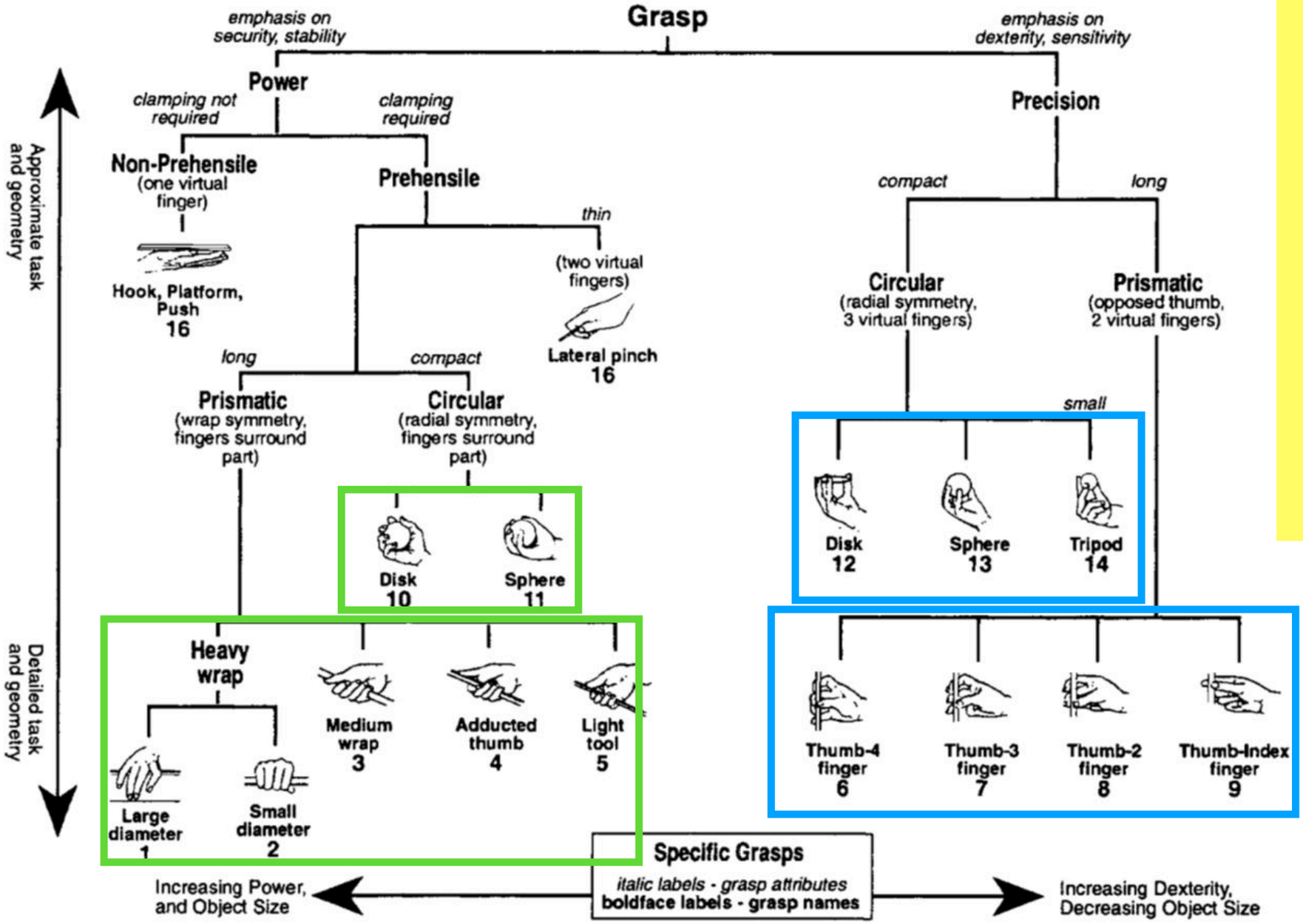
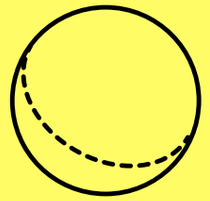
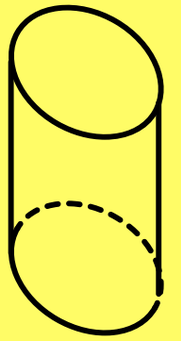




Sphere



Cylinder

Identify Primitive Shapes

VR Game Objects

111 hand-held objects found in 20 game trailers.

Sphere	balls in sports, snowballs, bombs, and grenades, etc.
Cylinder	rackets, bottles, hammers, and swords, etc.
Box	sandwiches, books, milk package, and camera, etc.
Disk	Frisbee
Cone	carrot
Hemisphere	bowl
Others	scissors, clothes, chain, fish, cat, etc.

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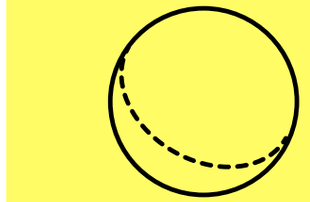

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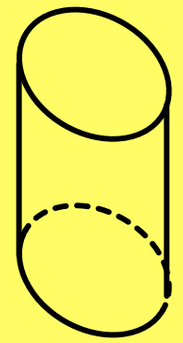
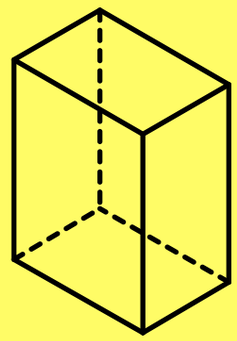
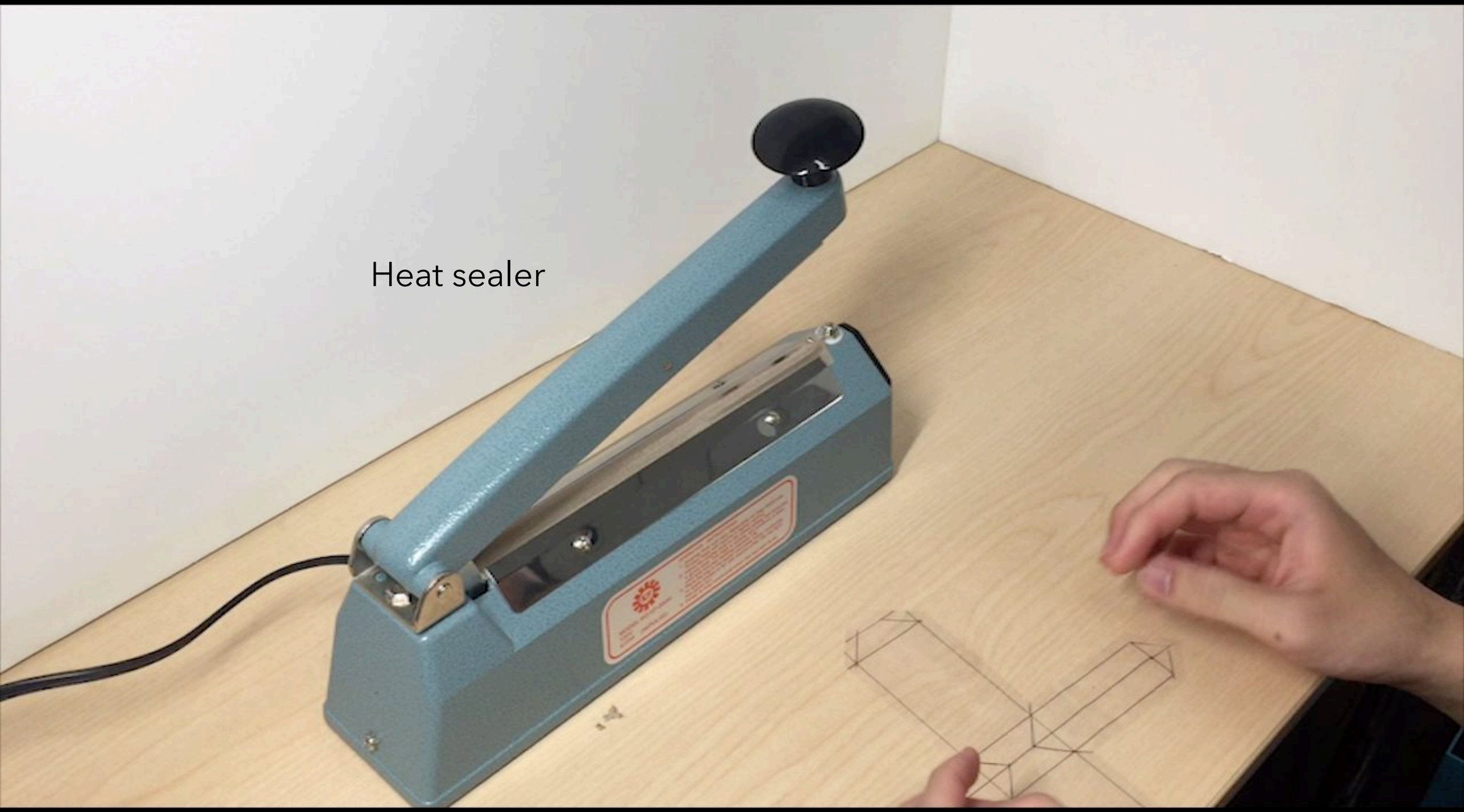


Cylinder



Box

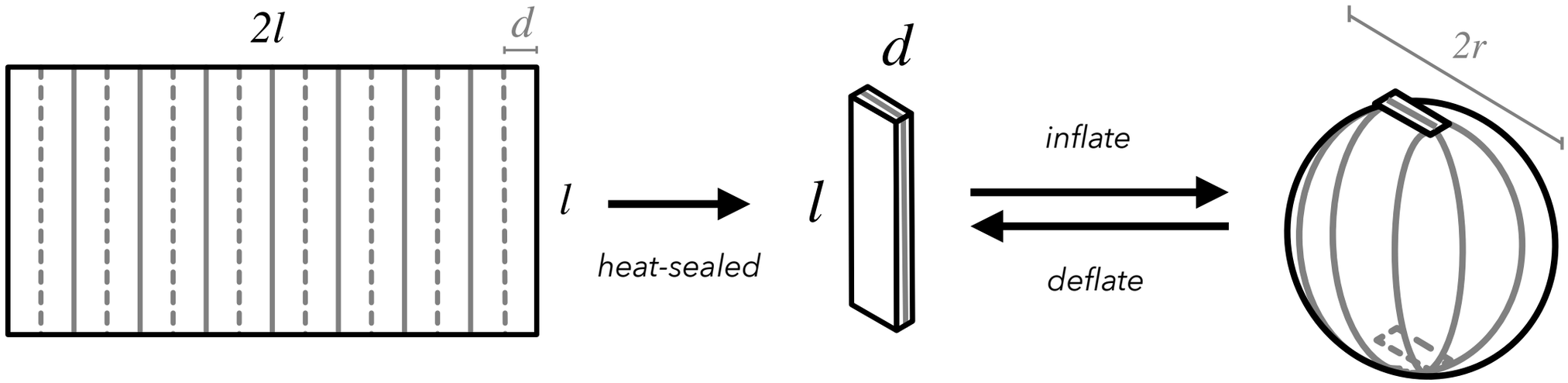
Material

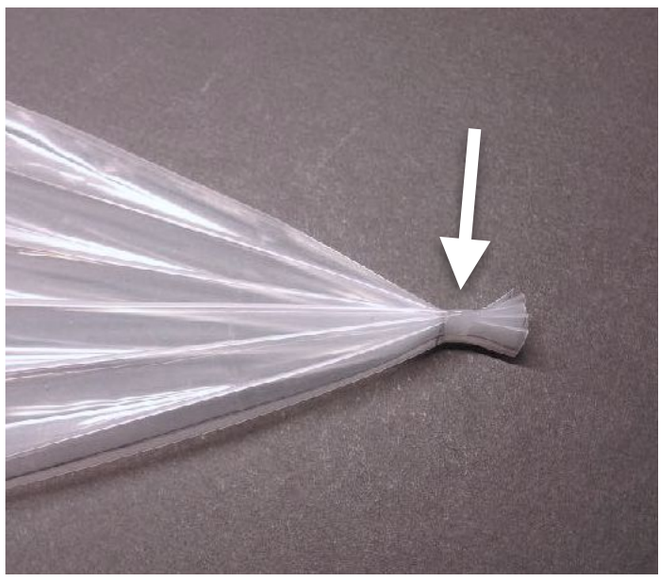


PE sheet

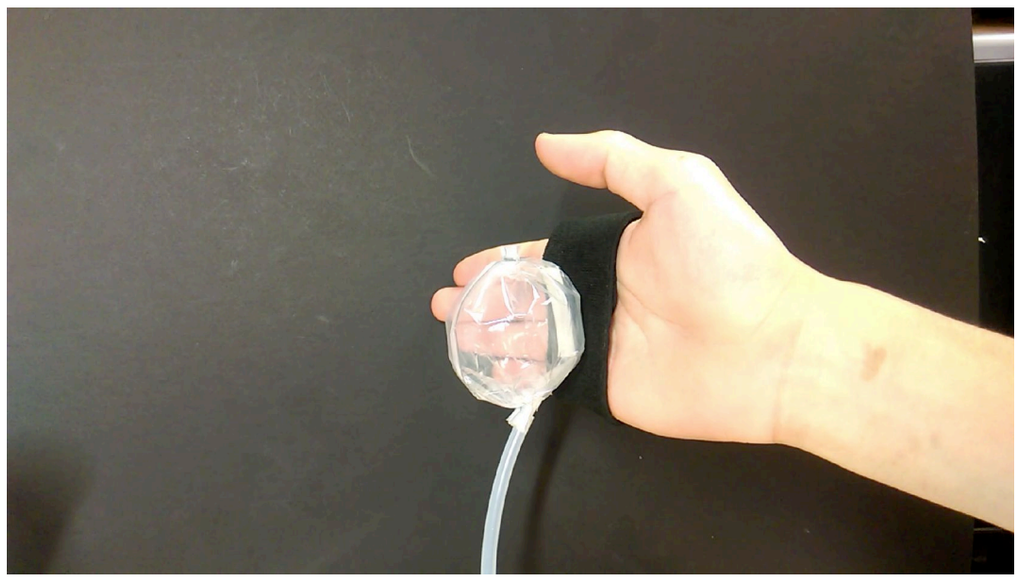
Shape Folding Structures

Sphere



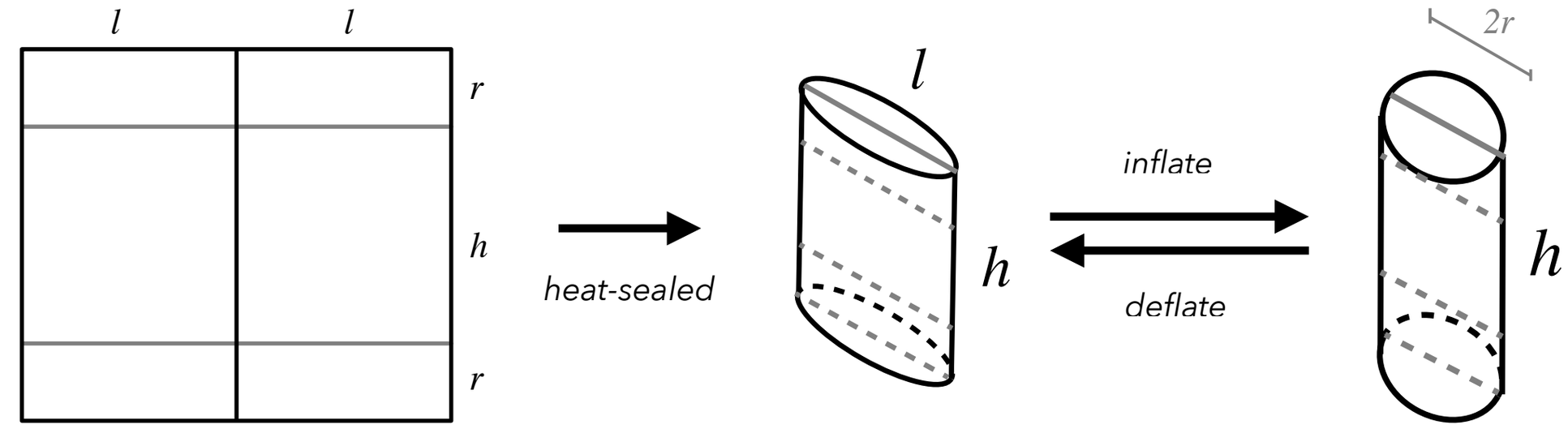


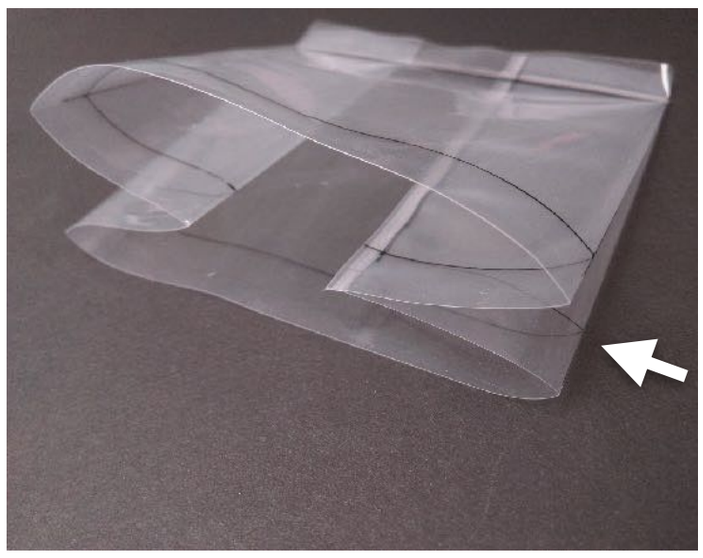
Fabrication detail



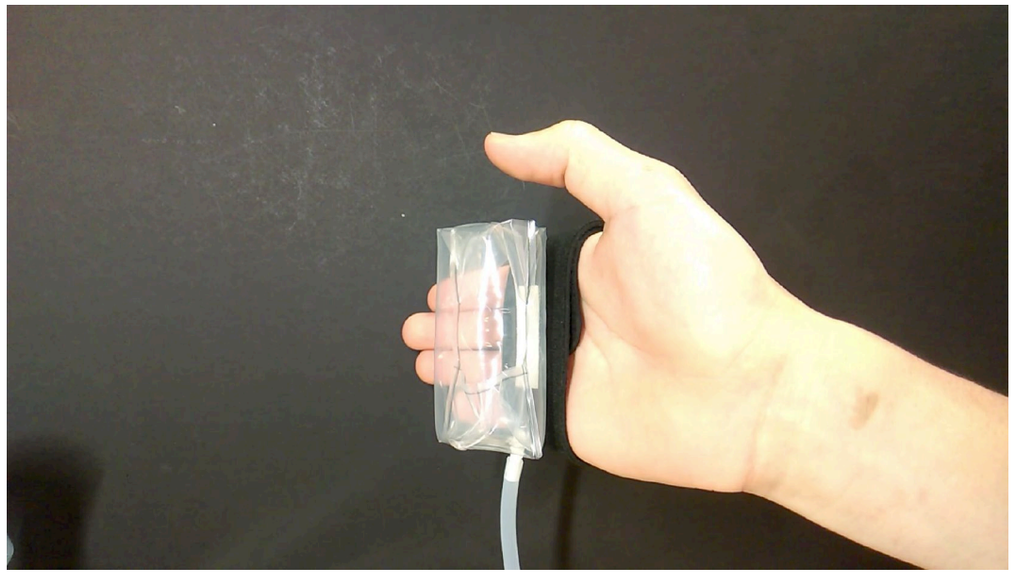
Inflation video

Cylinder



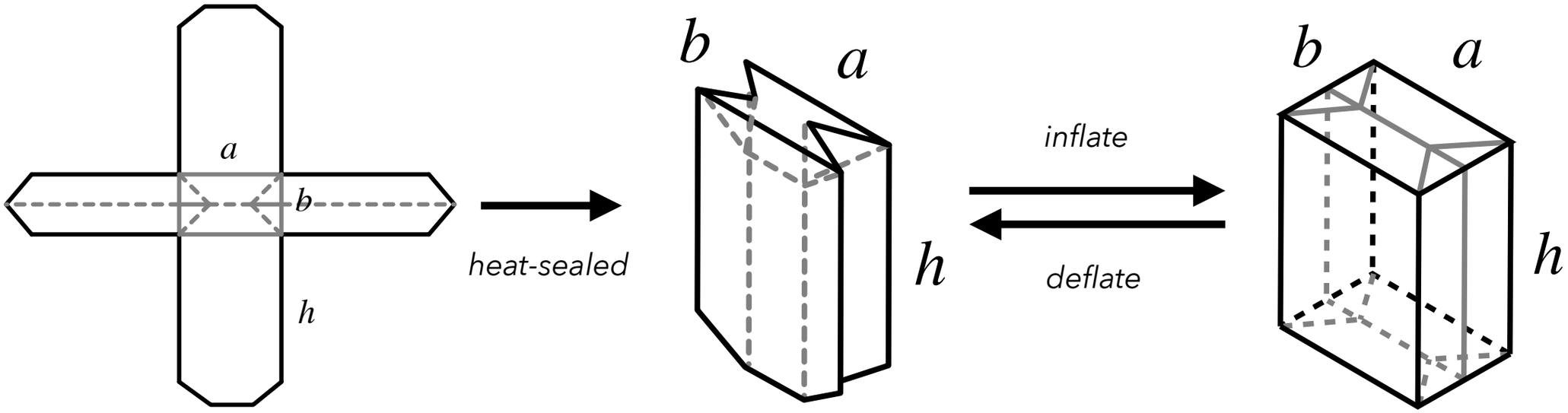


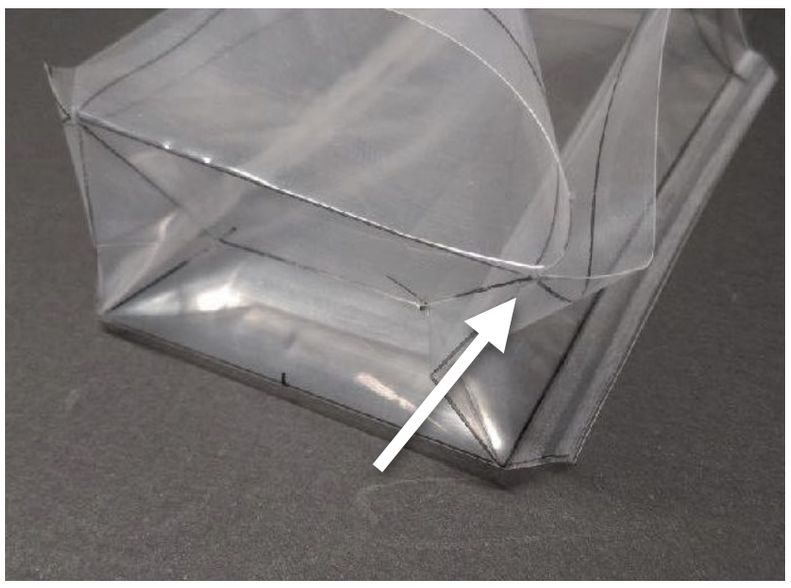
Fabrication detail



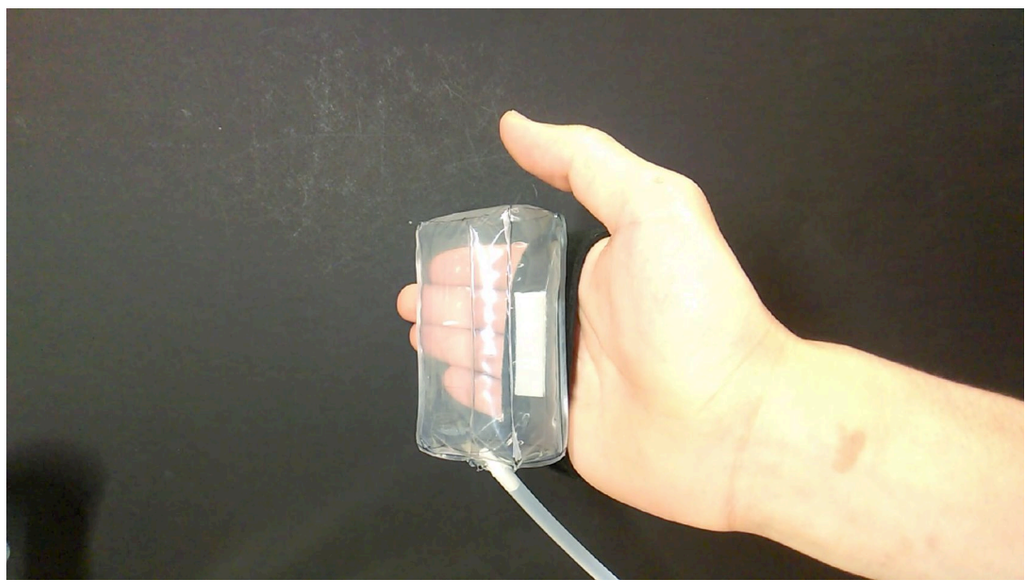
Inflation video

Rectangular Box





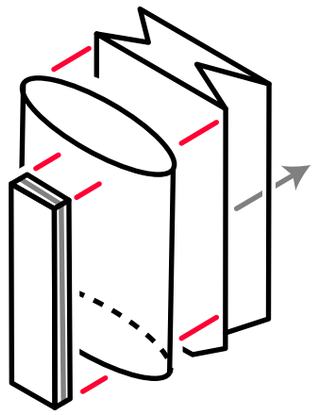
Fabrication detail



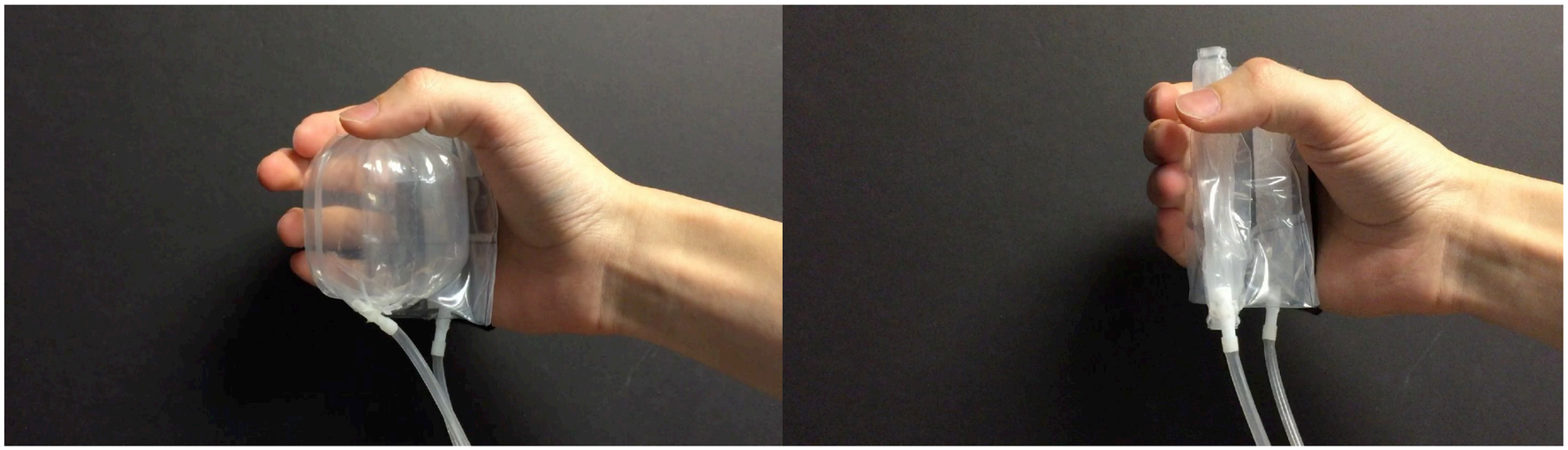
Inflation video

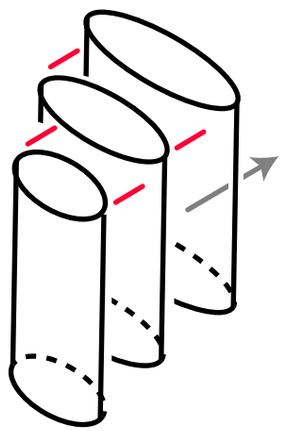
Props on Palm

Prop Stacking

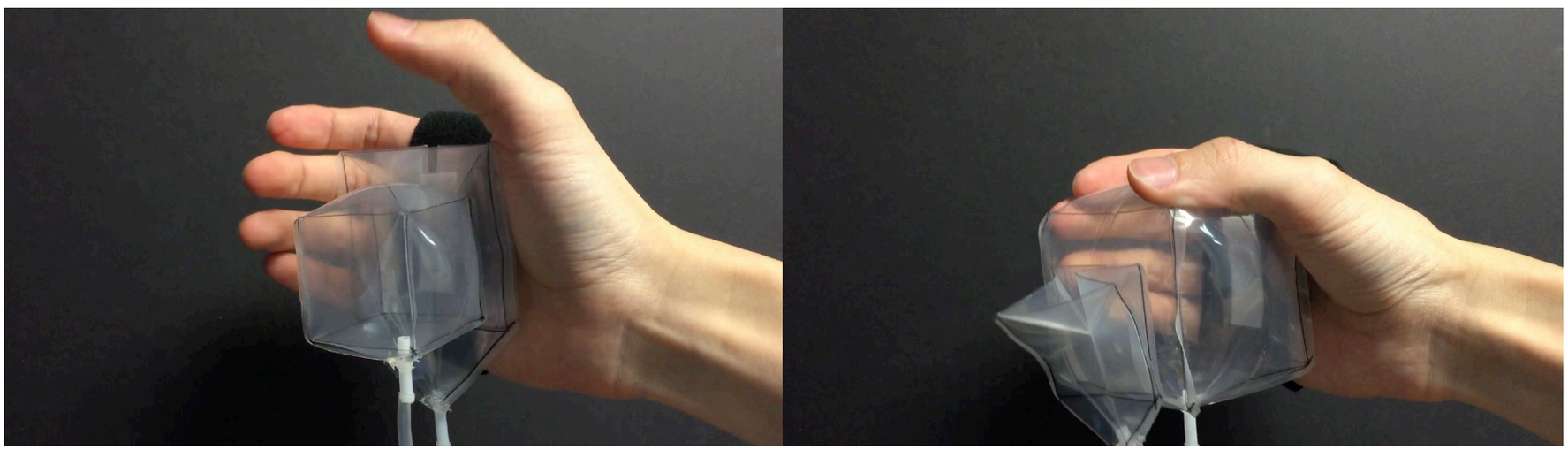


Shape Stacking

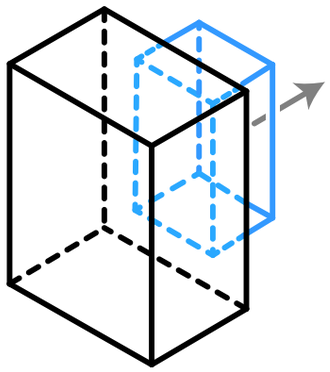




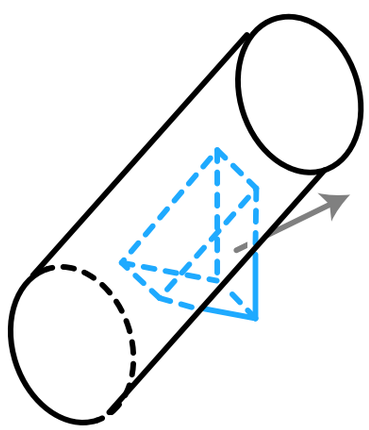
Size Stacking



Prop Extension



Parallel Extension

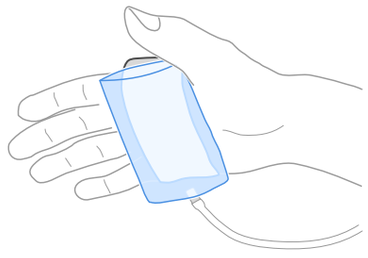


Tilt Extension

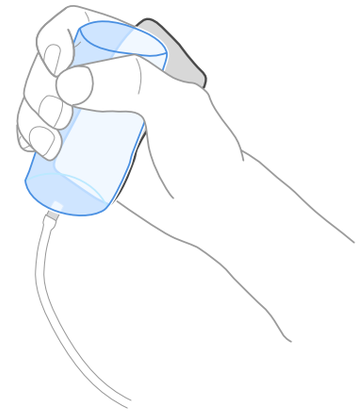
Prop Sensing

Finger Operation

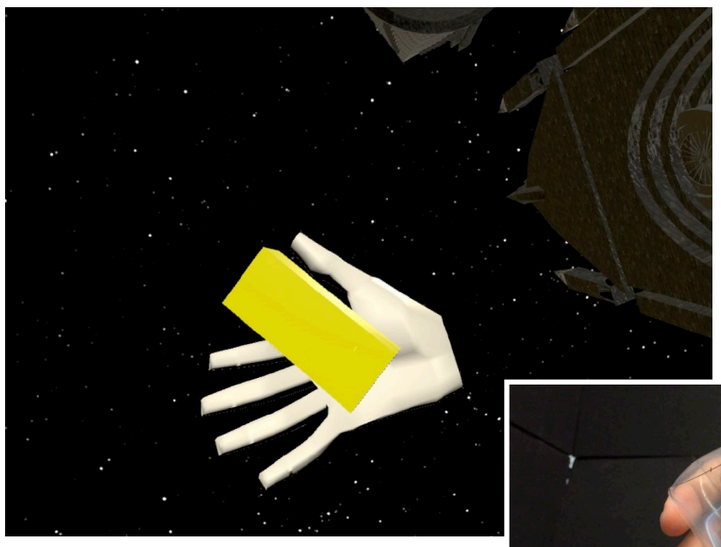
Leap Motion



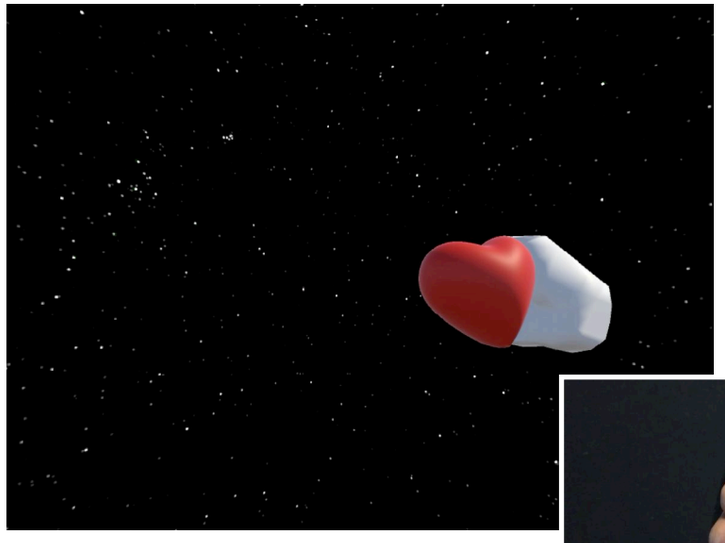
Force-Sensitive Resisters (FSRs)



Object Properties Emulation



Elasticity

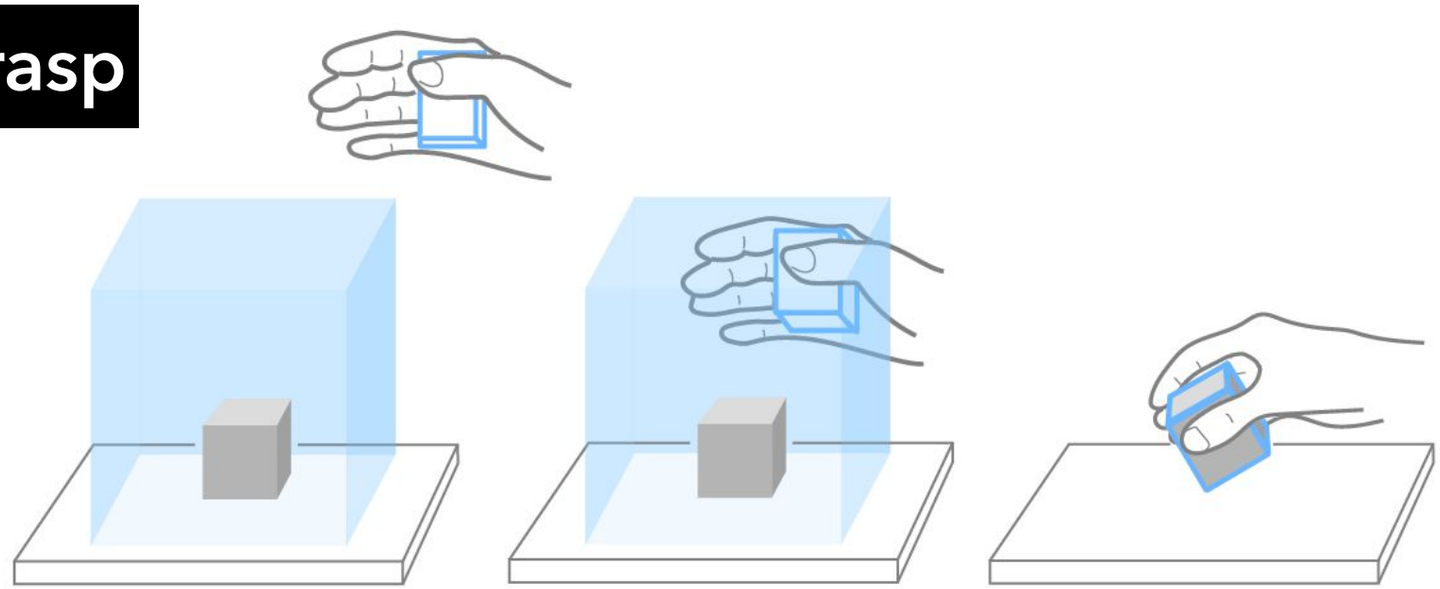


Heartbeat

Incorporation into VR

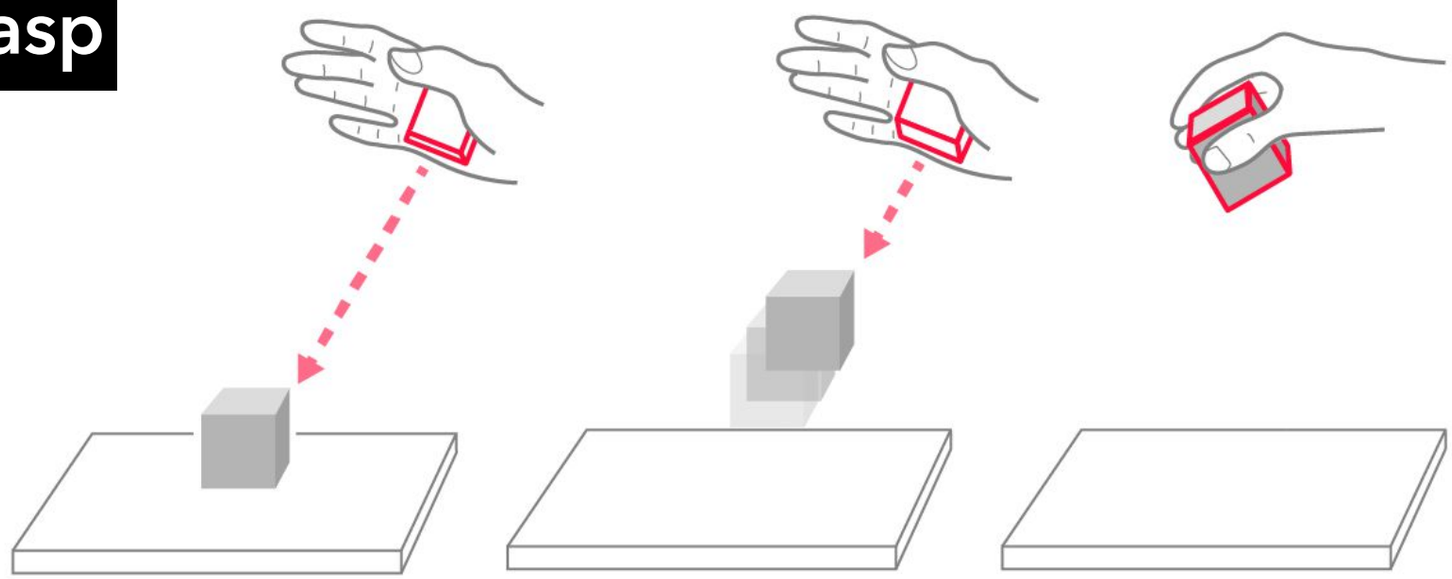
Natural Grasp

Grasp in place.



Magic Grasp

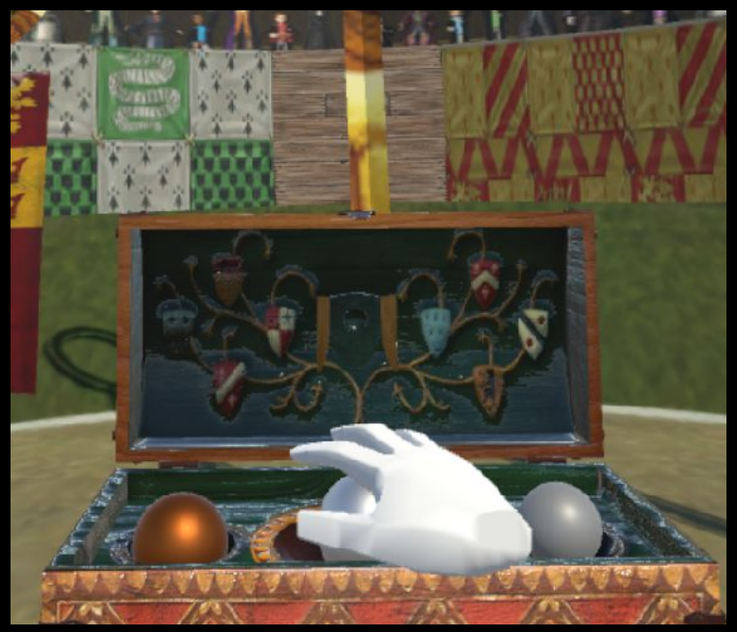
“Summoning.”

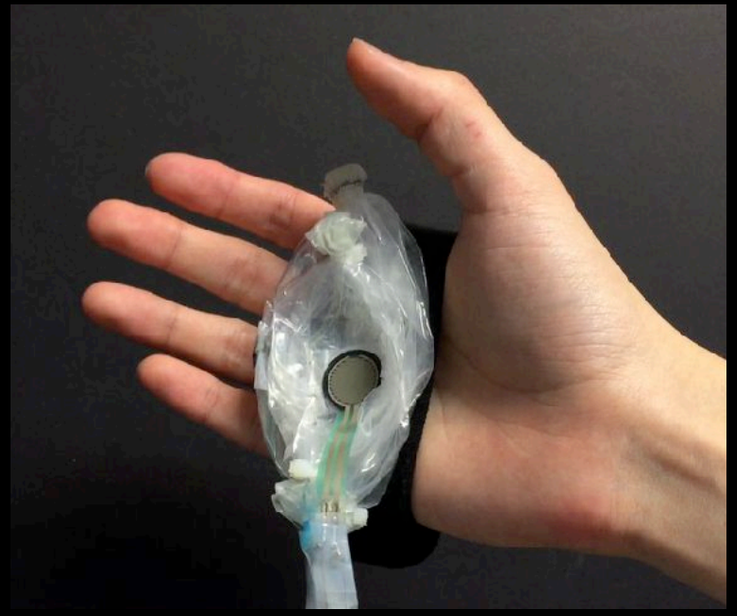


Demo Applications

Demo Application

Quidditch Sports Training





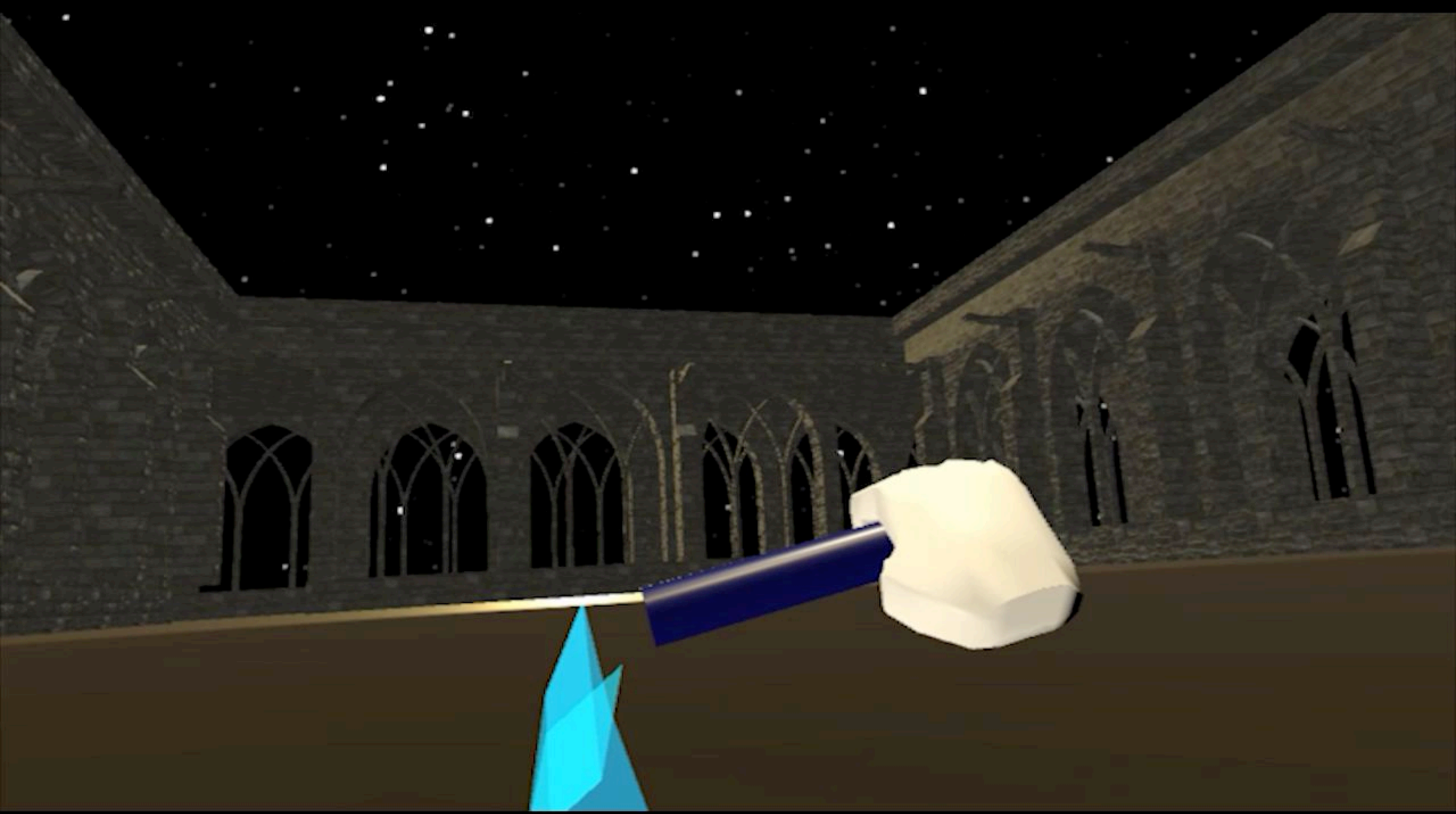
Flat State

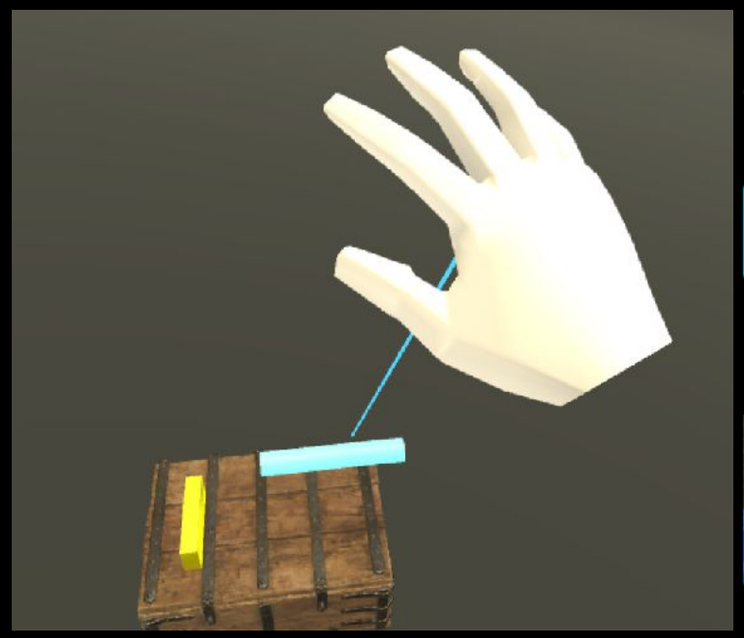
Ball (Large Sphere)

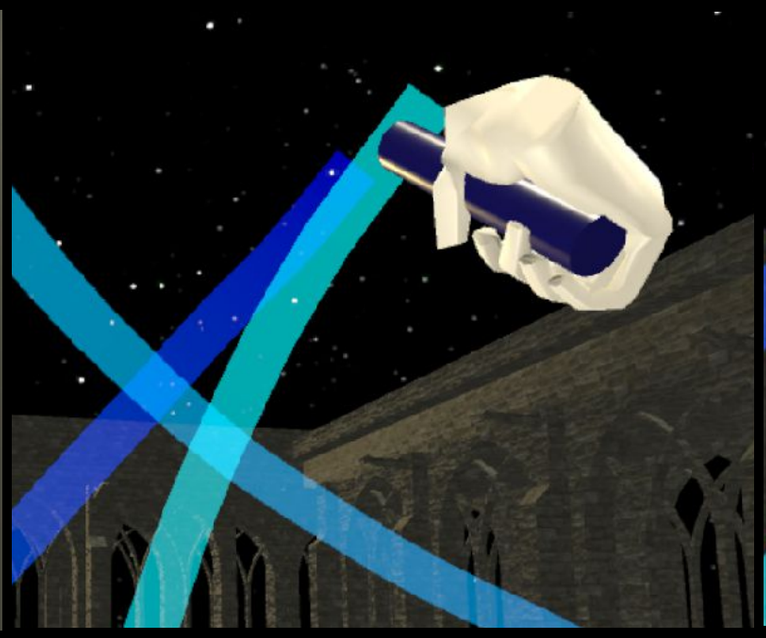
Snitch (Small Sphere)

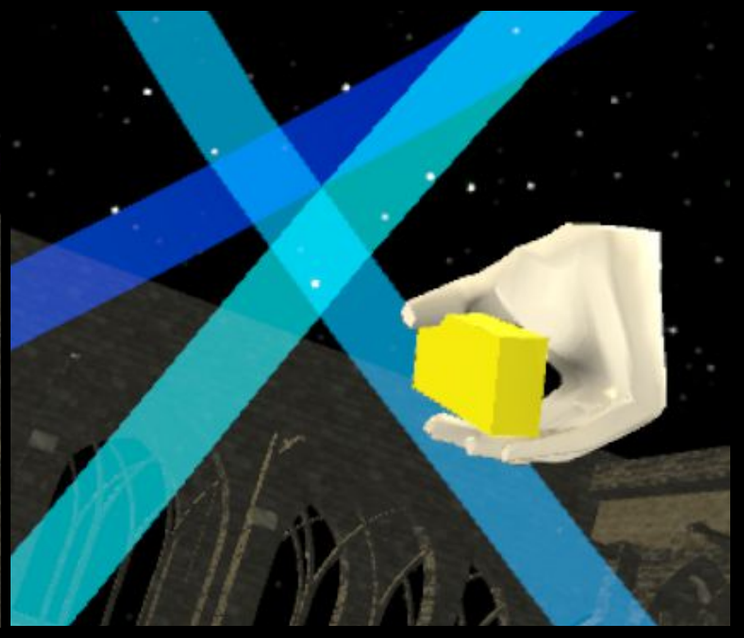
Demo Application

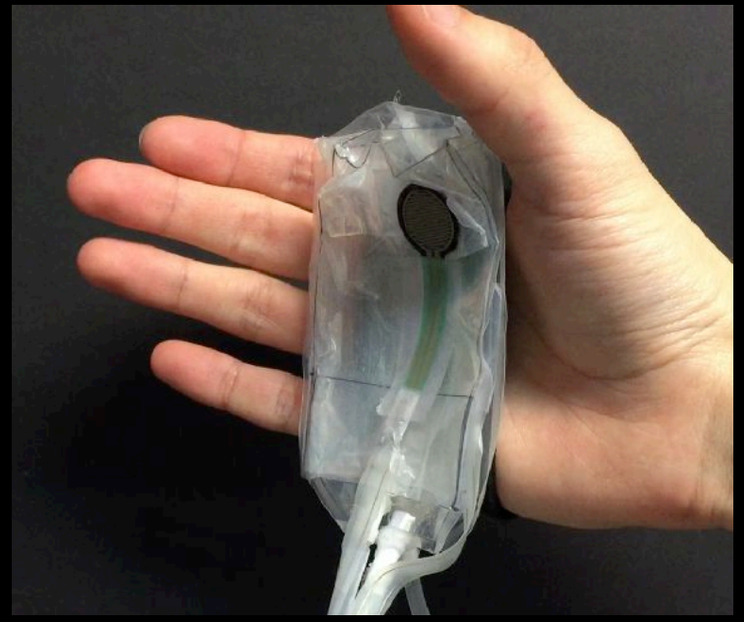
Magic Brush Painting











Flatten State

Brush (Cylinder)

Eraser (Extended Box)

User Studies

User Study 1

Visual Size Acceptance Range

Can PuPoP leverage visual dominance effect to allow a single prop to represent a range of similar visual sizes?

Physical Prop

≈

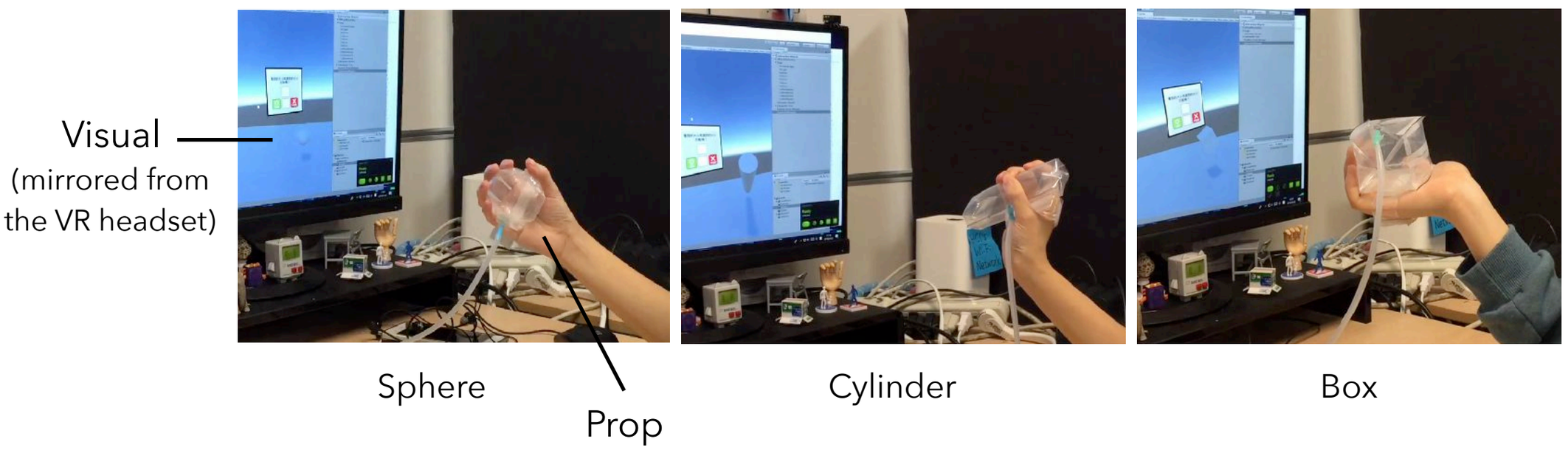
Acceptance Range

Visual Counterpart

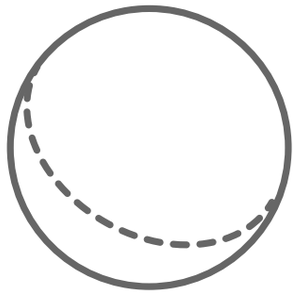
User Study 1

Visual Size Acceptance Range

Can PuPoP leverage visual dominance effect to allow a single prop to represent a range of similar visual sizes?

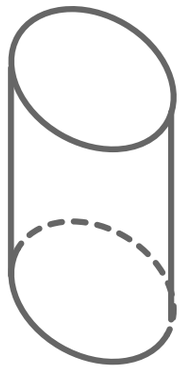


Using one-up-one-down adaptive staircase method. Participants answered YES or NO on whether the visual size matches the physical one.



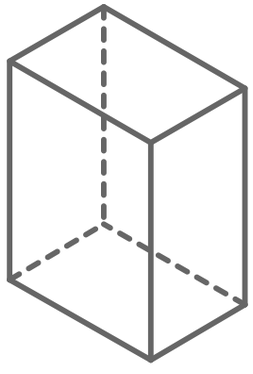
Sphere

Physical Size	***Small***	***Medium***	***Large***
Visual Size Upper Bound	63.2	75.5	95.3
Visual Size Lower Bound	46.0	60.5	73.4



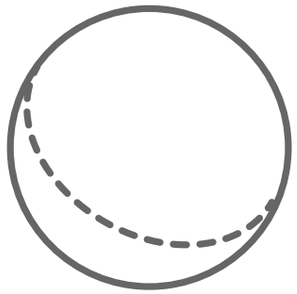
Cylinder

Physical Size	***Small***	***Medium***	***Large***
Visual Size Upper Bound	38.0	54.4	70.8
Visual Size Lower Bound	28.7	42.4	54.1



Box

Physical Size	***Small***	***Medium***	***Large***
Visual Size Upper Bound	59.2	69.7	88.7
Visual Size Lower Bound	43.7	53.4	68.2



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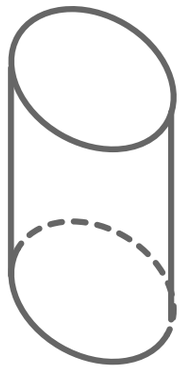

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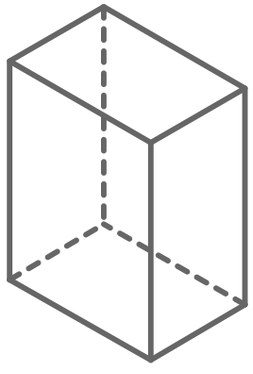

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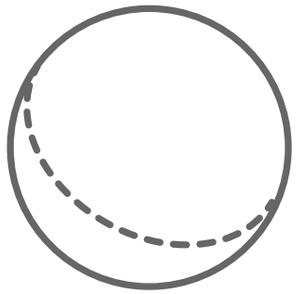

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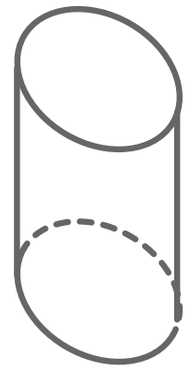

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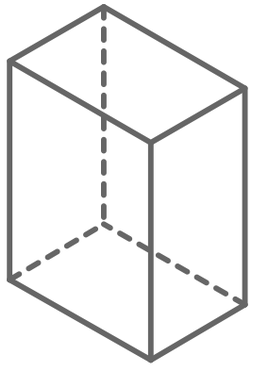

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Average Upper Bound

36.2%

Larger than the physical size

Average Lower Bound

≈

The physical size

User Study 2

VR Enjoyment & Object Realism

What is effect of PuPoP on VR application enjoyment and object realism, compared to other interfaces?

User Study 2

VR Enjoyment & Object Realism

What is effect of PuPoP on VR application enjoyment and object realism, compared to other interfaces?

PuPoP

Controller
(HTC VIVE)

Free-hand Manipulation
(Leap Motion)

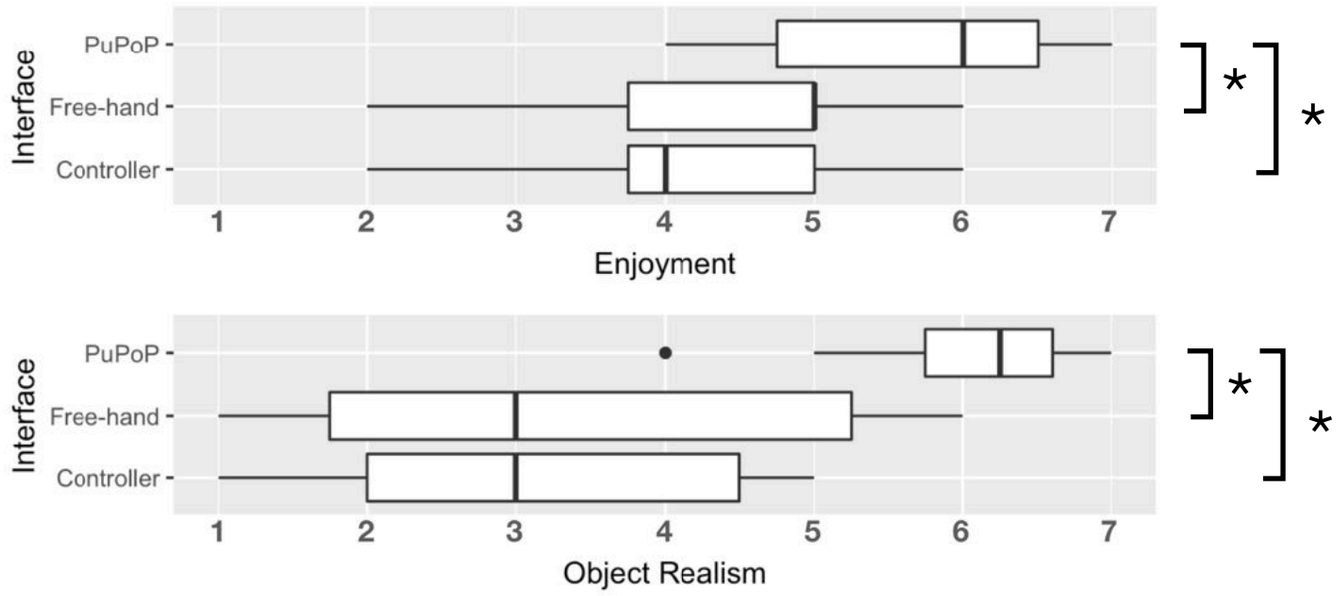
Participants rated enjoyment and object realism in a continuous 7-point Likert Scale.

VR Enjoyment & Object Realism

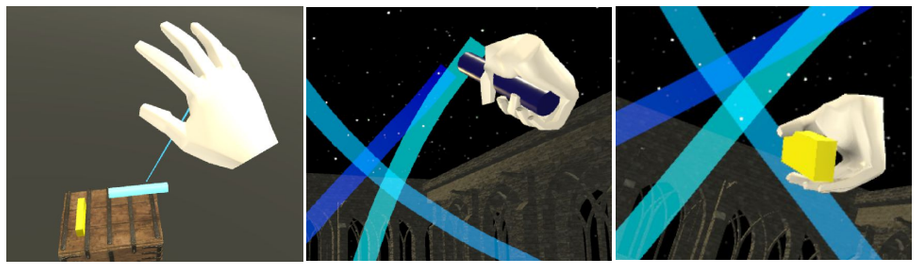
Quidditch

“I felt like throwing a real ball!”

“I could physically catch the Snitch!”

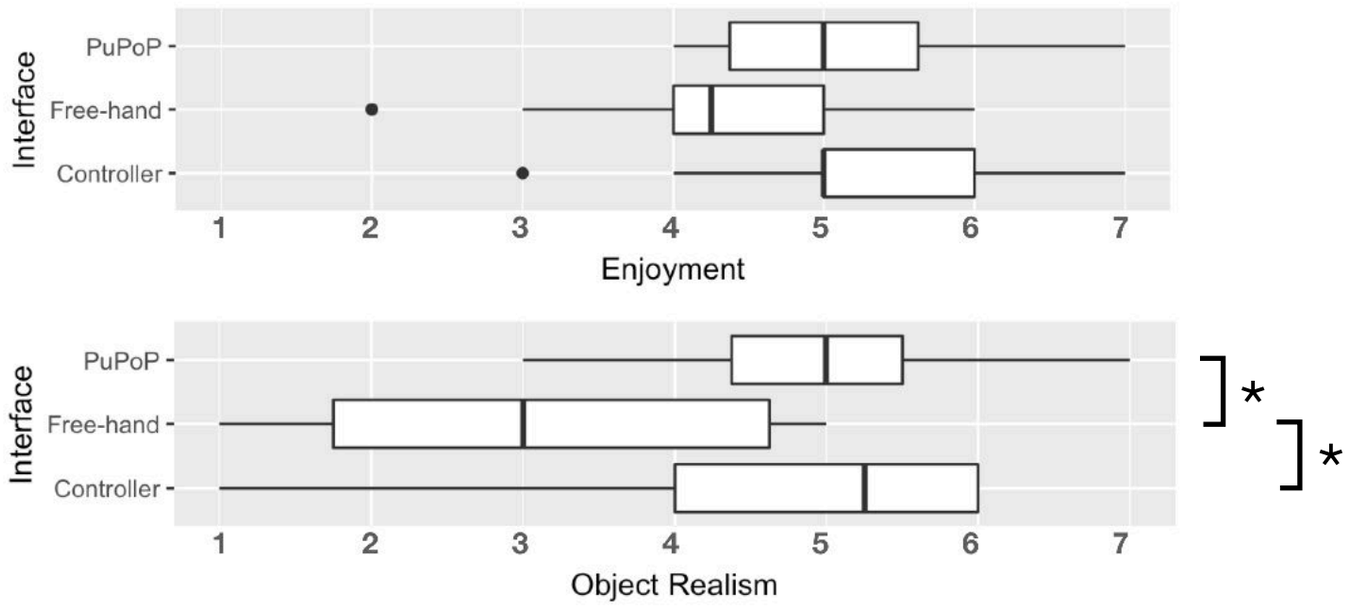


Painting



“The brush felt too soft.” 😢

“The eraser was definitely an eraser!”



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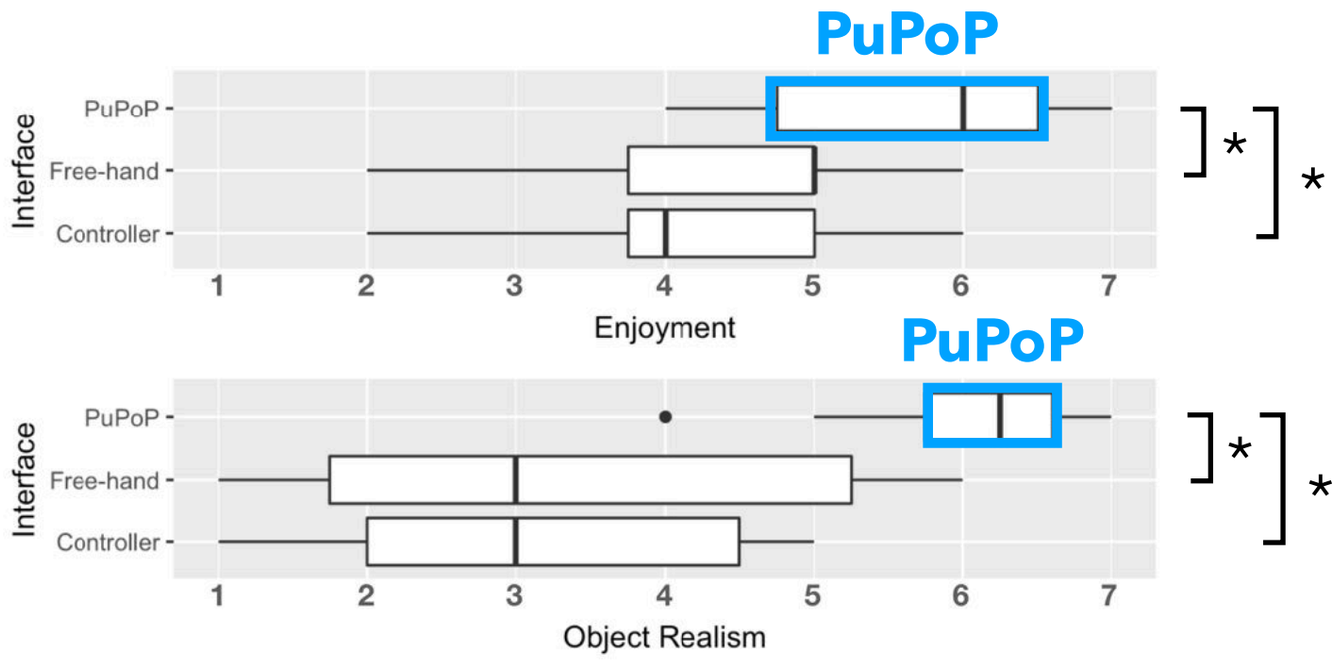

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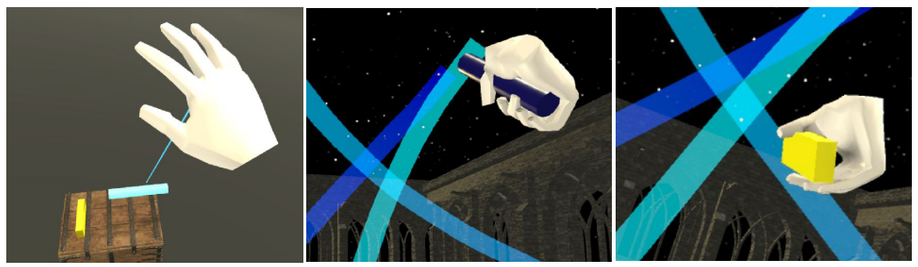

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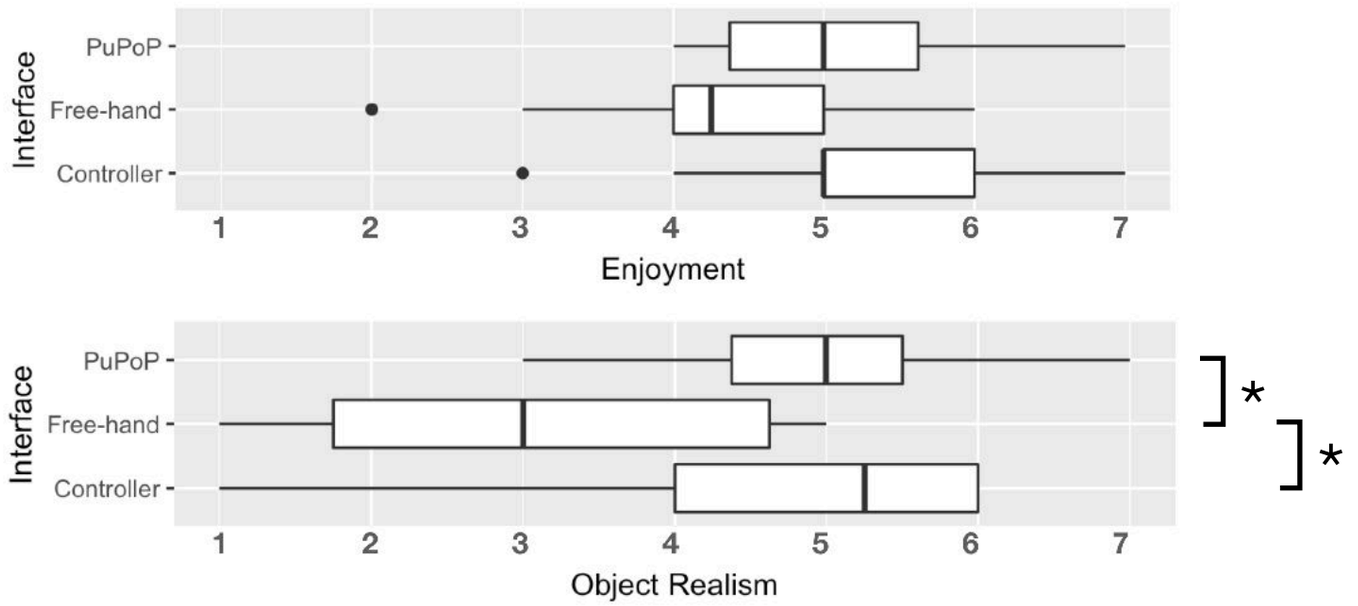

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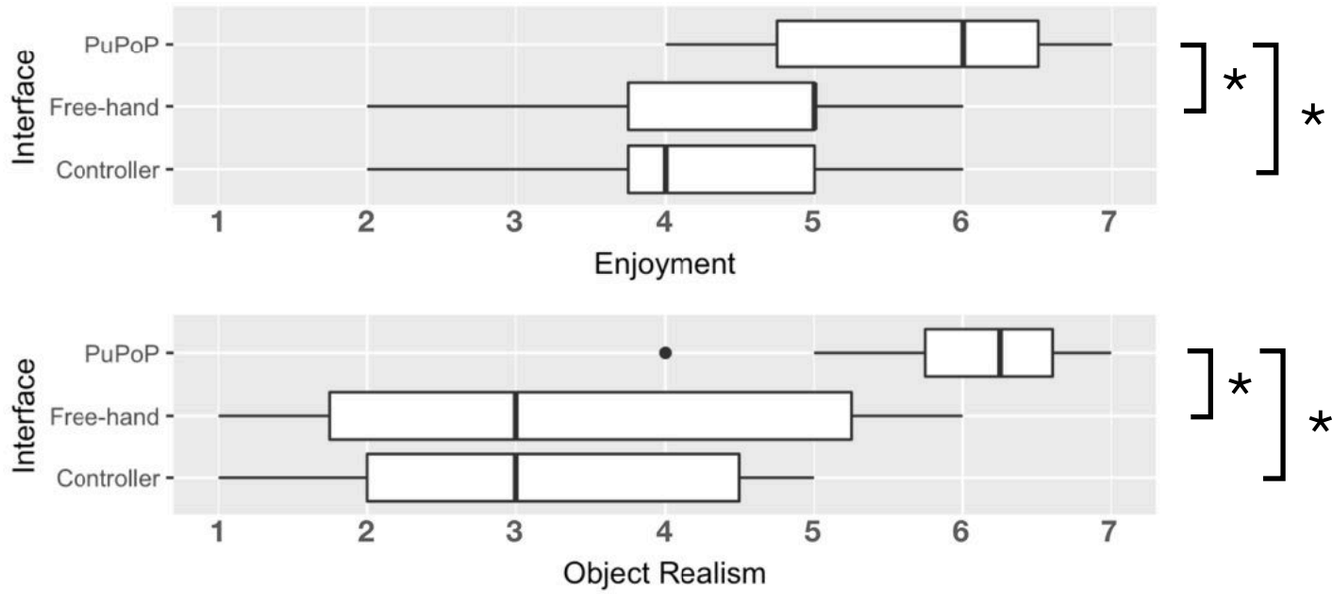

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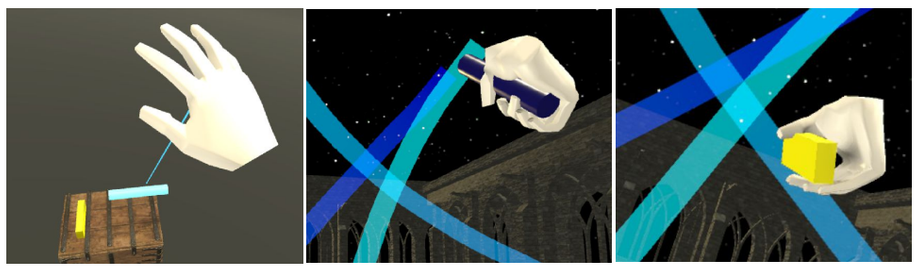

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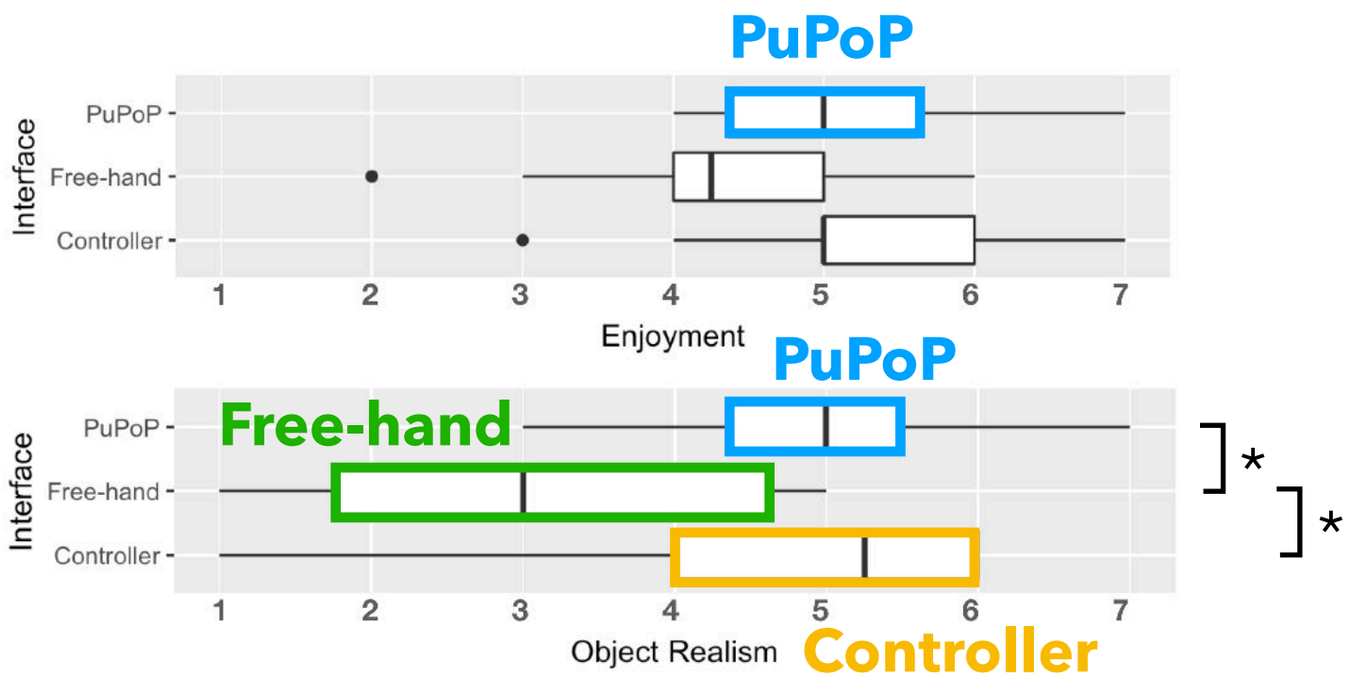

Limitations & Future Work

1. Grounding.
2. Illusion.
3. Portability & Inflation time.
4. Stiffness.
5. Complex shapes.

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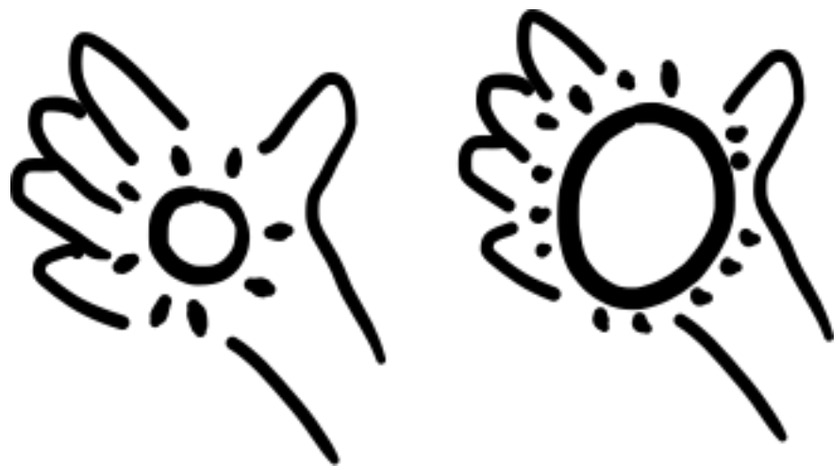

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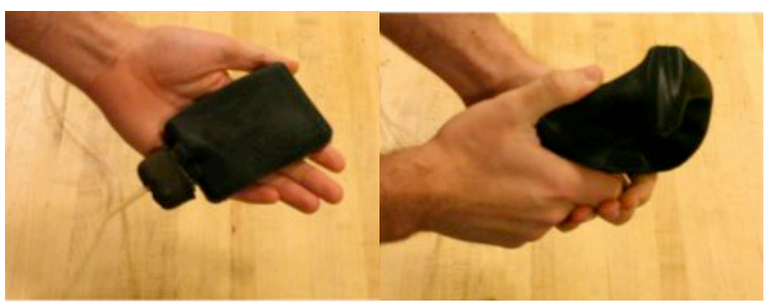

Follmer, et al. UIST ‘12

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Skouras, et al. SIGGRAPH ’14

Conclusions

1. The concept of a light-weight wearable Pop-up Prop on Palm (PuPoP) for VR.
2. The design and implementation of a set of PuPoP shape structures, including stacking, extension and sensing.
3. Two user studies to understand visual size acceptance range of PuPoP and evaluate the interface.