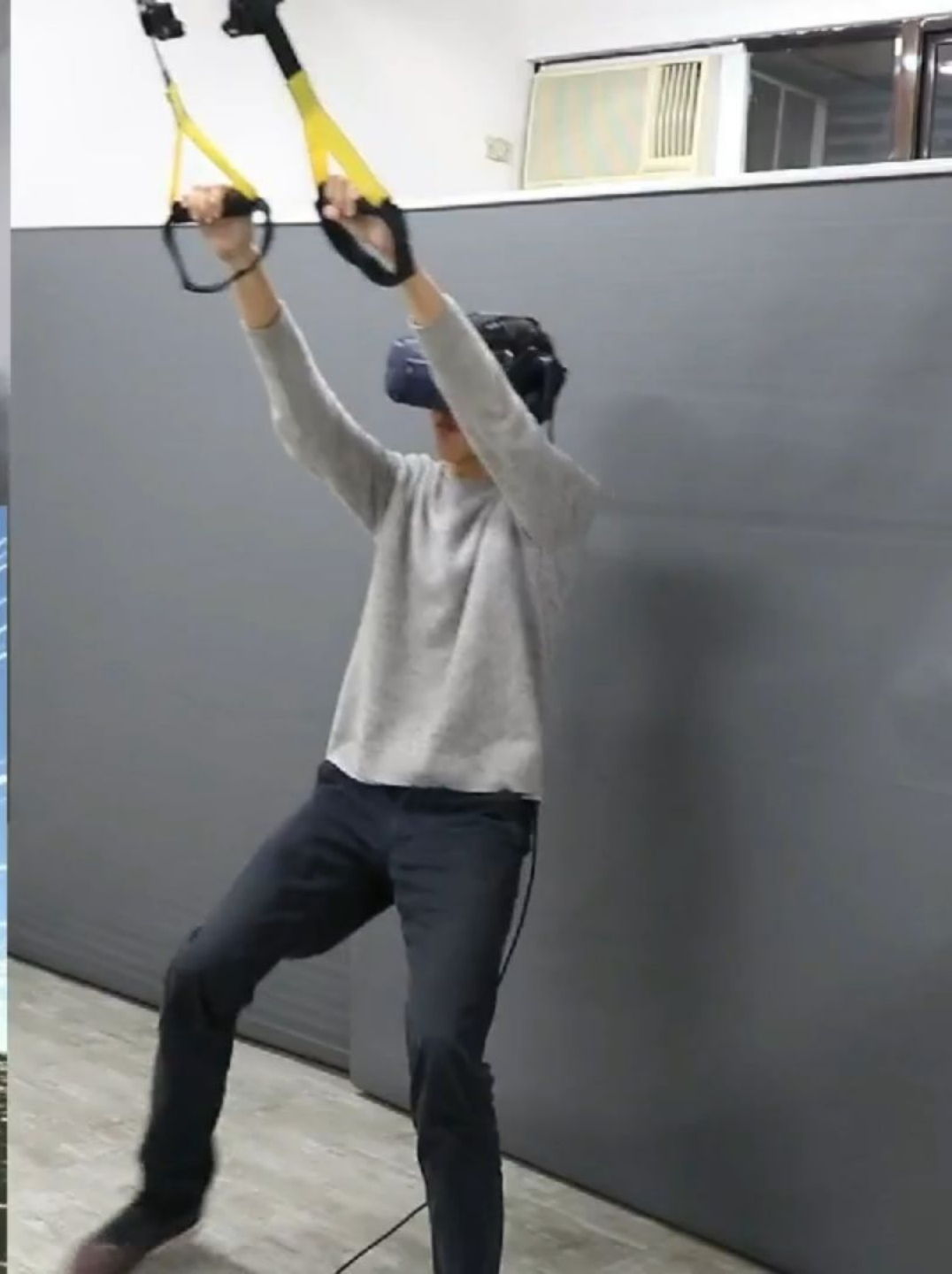
Pull-Ups

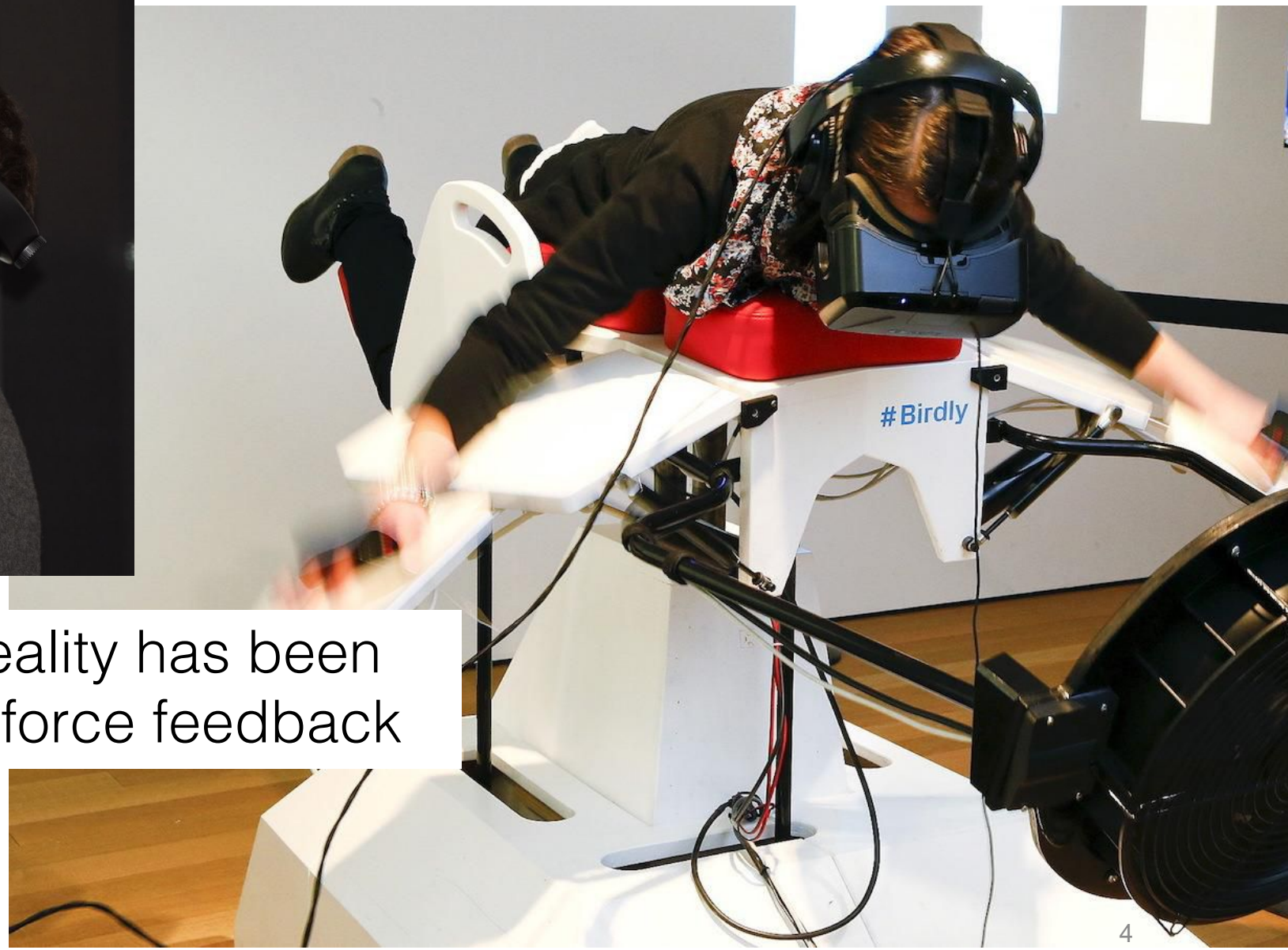
Enhancing Suspension Activities with Body-Scale Kinesthetic Force Feedbacks for Virtual Reality

Yuan-Syun Ye, Hsin-Yu Chen, Liwei Chan
National Chiao Tung University, Taiwan


3
2
1
0
speeding on small wave

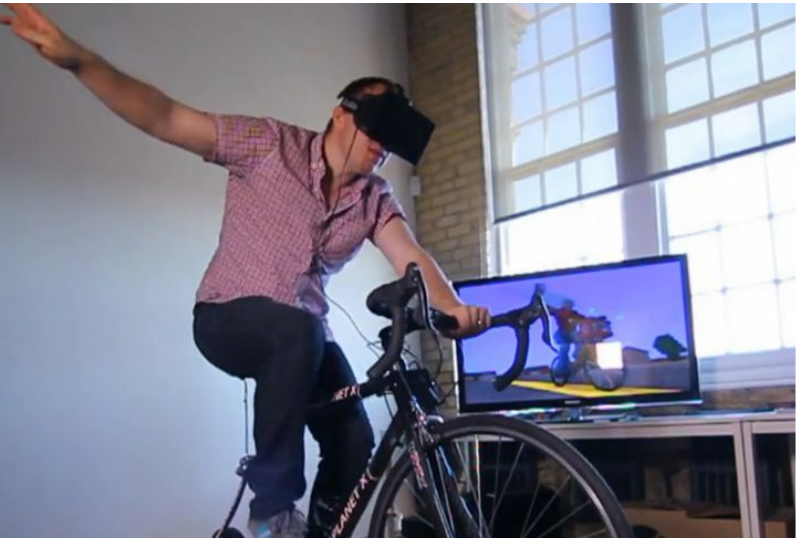


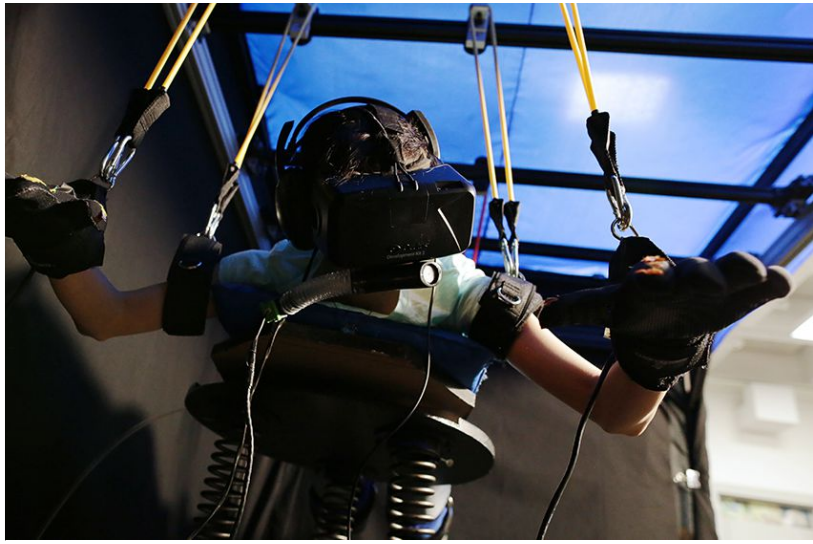
Motivation



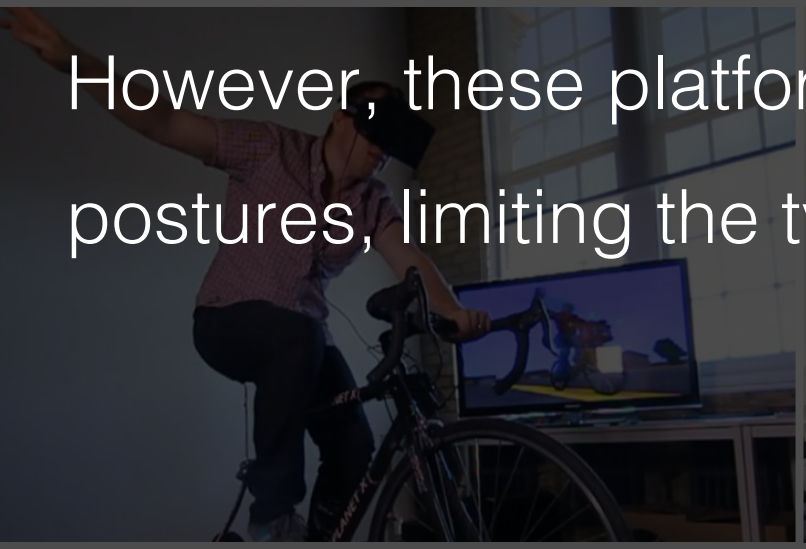
Simulated sport in virtual reality has been increasingly explored with force feedback

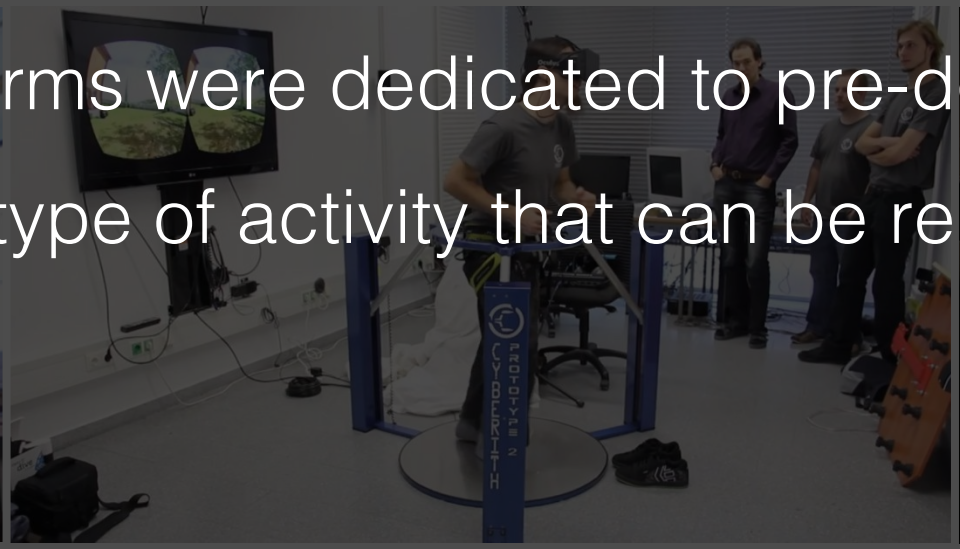
Examples include…





Examples include…

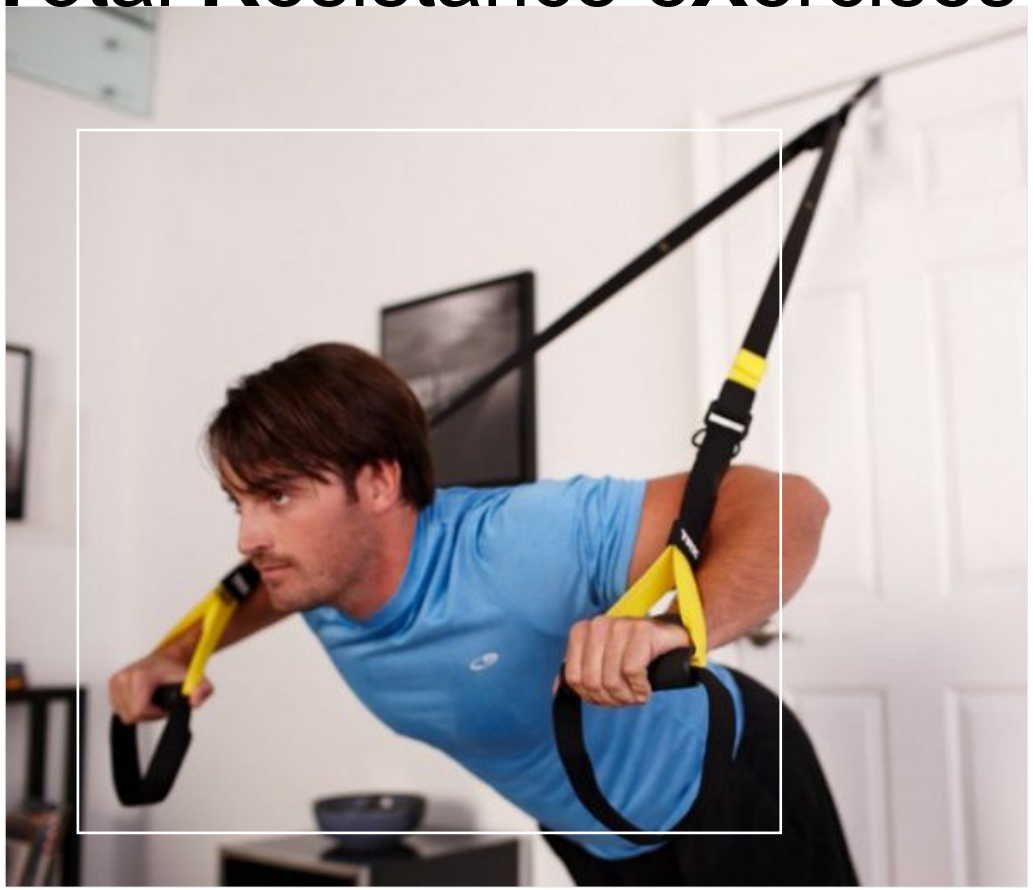




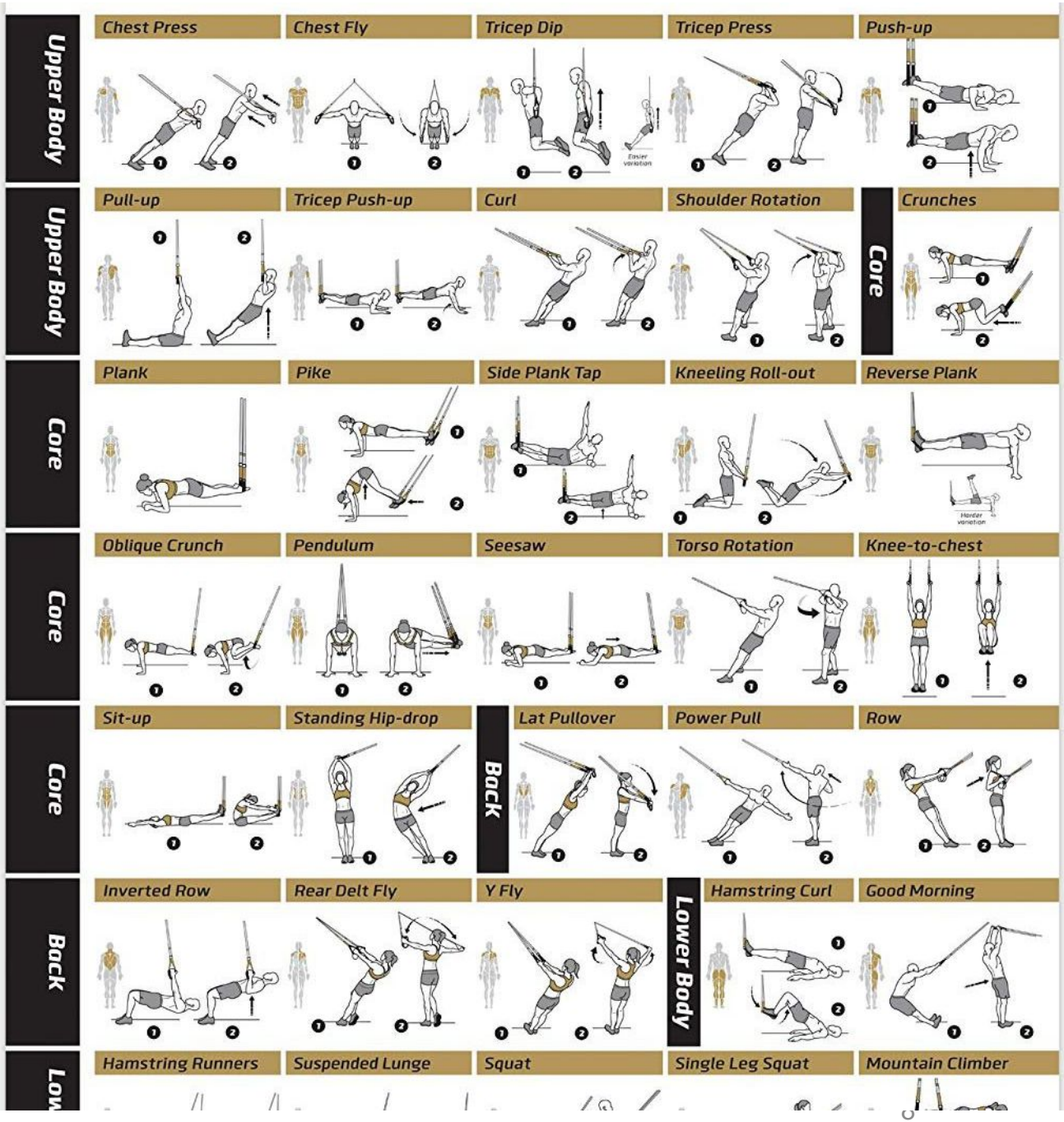
However, these platforms were dedicated to pre-determined exercise postures, limiting the type of activity that can be represented in VR.

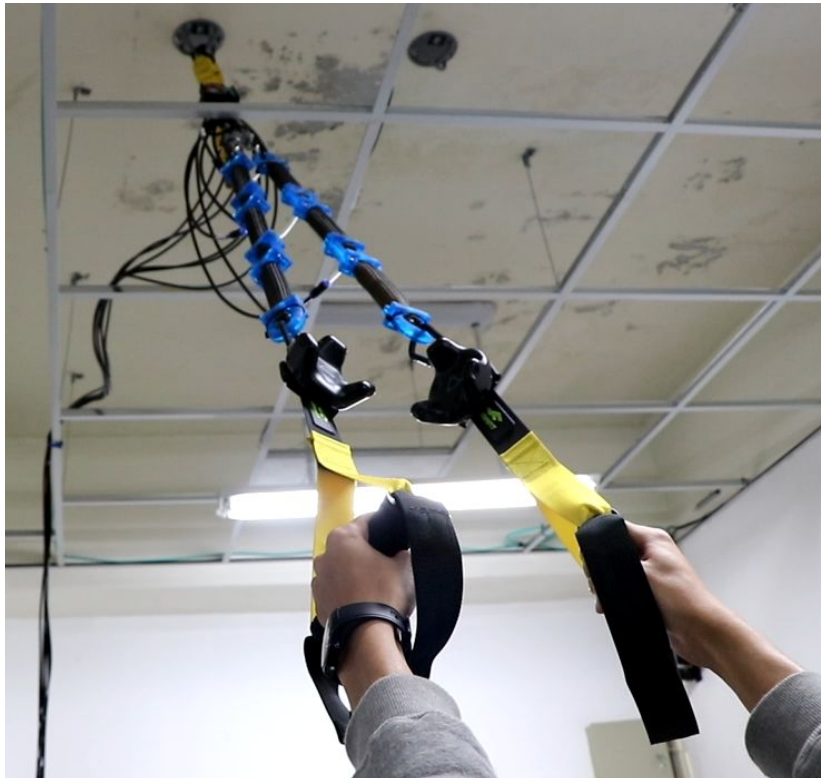
New fitness equipment supports a wider range of exercise styles and easy adoption at home

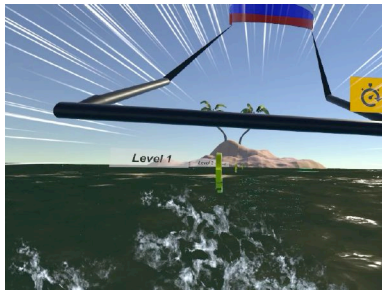
Total **R**esistance e**X**ercises

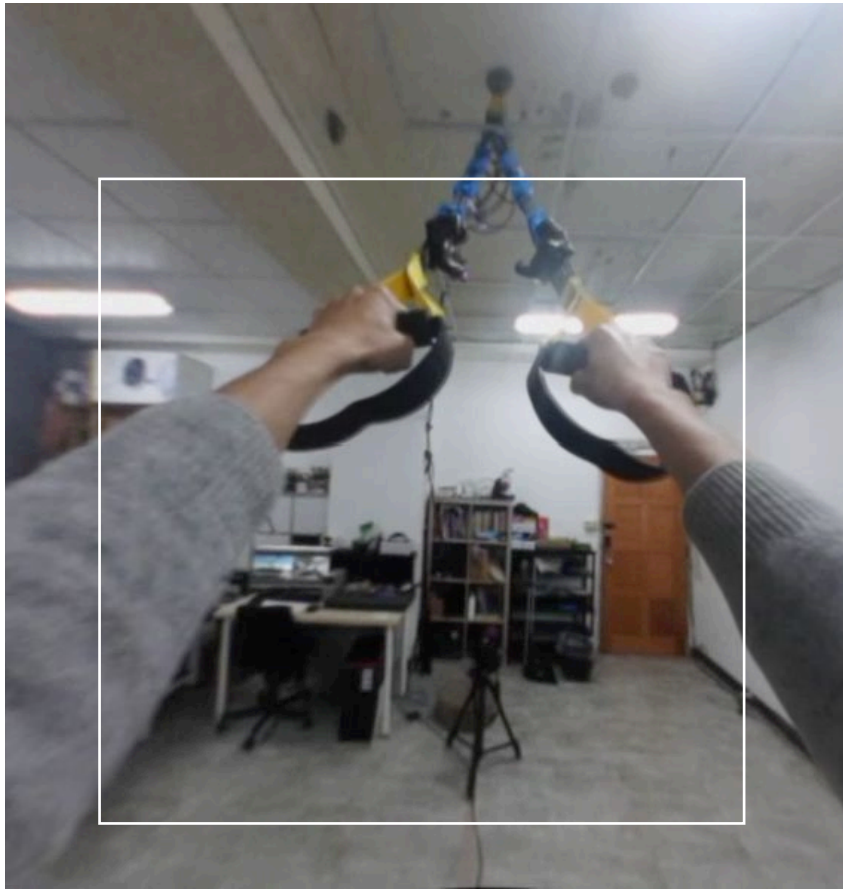


many postures
suggested by TRX









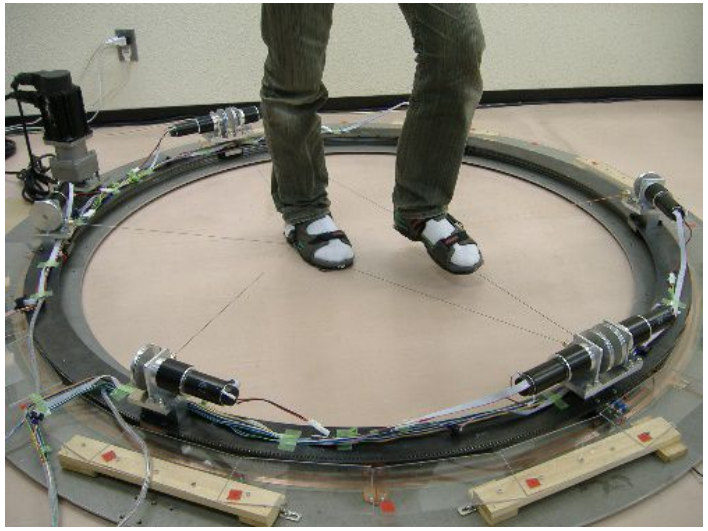
Pull-Ups, modified from TRX, can support a variety of body postures with **bodily kinesthetic feedback.**

Related Work

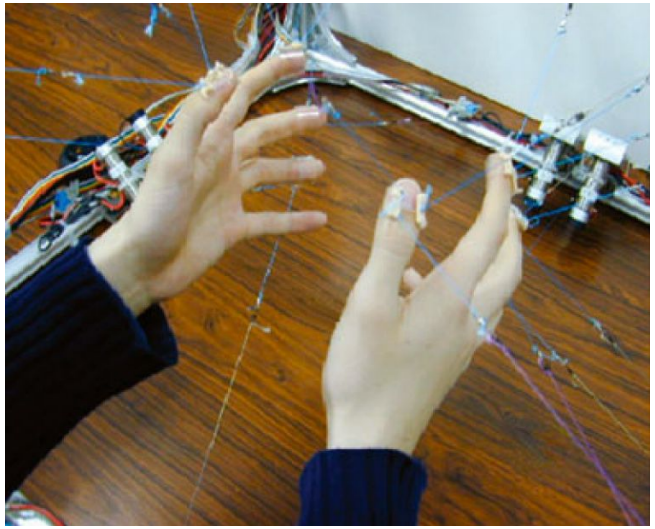
- Cable-Driven Haptic Feedback
- Suspension Systems for Vertical Body Motion VR

Cable-Driven Haptic Feedback

Active Feedback



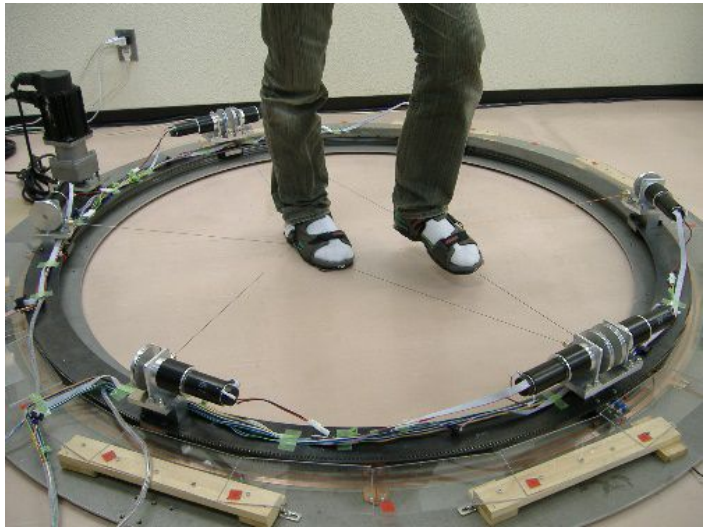
String Walker,
SIGGRAPH Etech ‘07



SPIDAR-8,
Springer ‘13

Cable-Driven Haptic Feedback

Active Feedback



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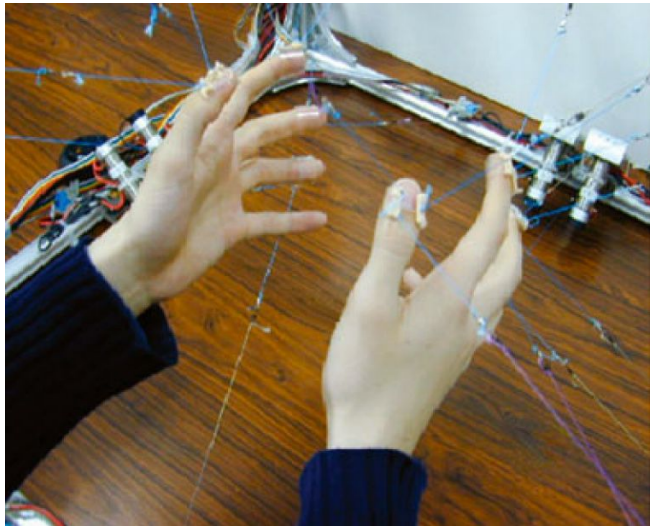
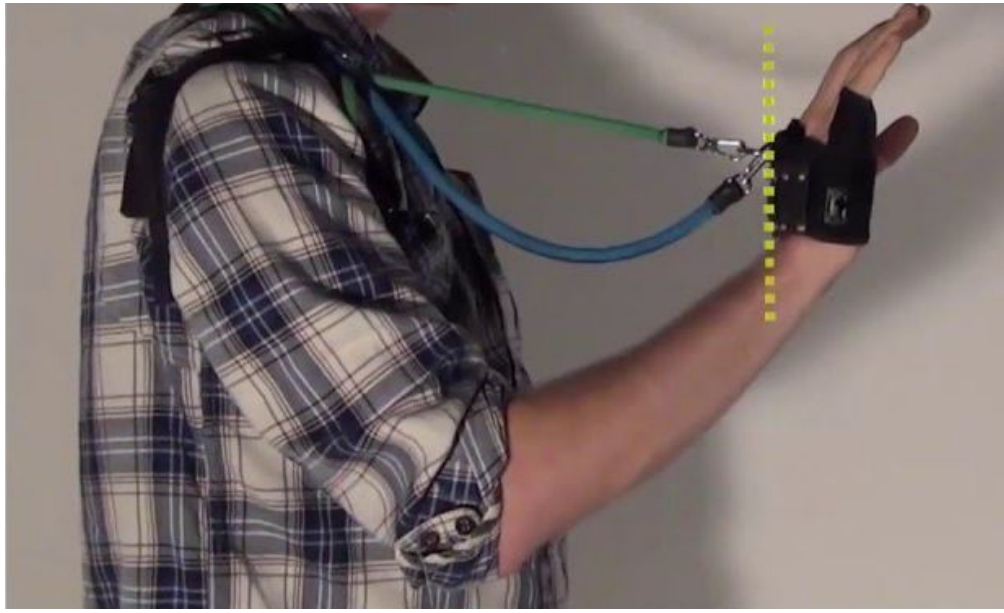


SPIDAR-8,
Springer ‘13

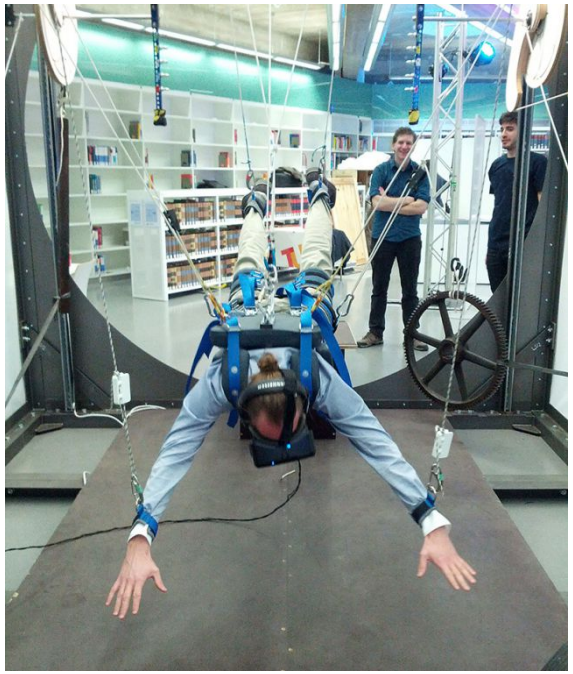
Passive Feedback



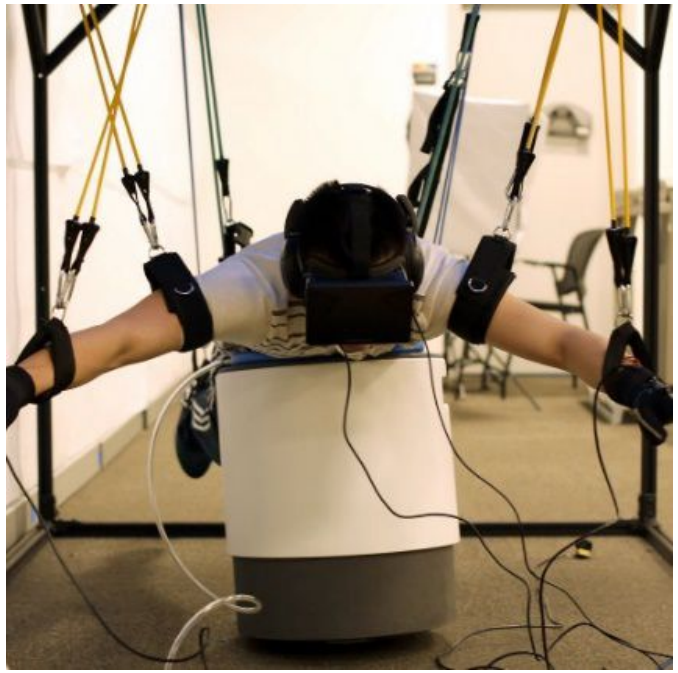
Elastic-Arm,
IEEE VR ’15

Suspension Systems for Body Motion VR

Pre-determined Platform



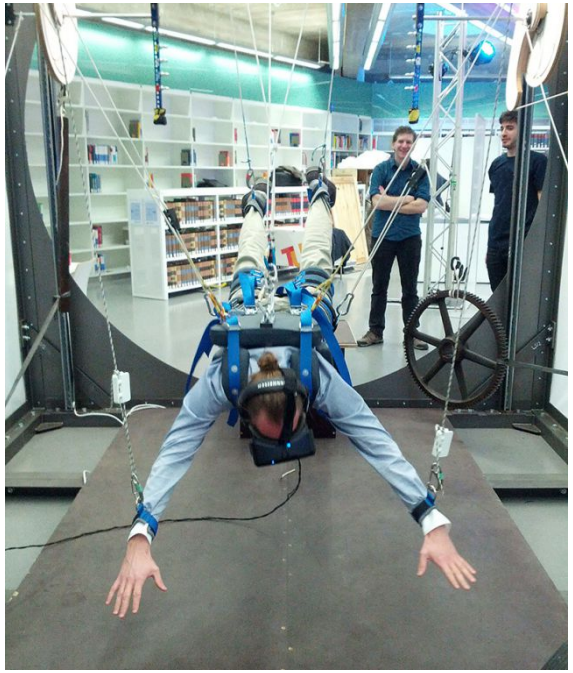
Indoor Skydiving,
VRST ‘15



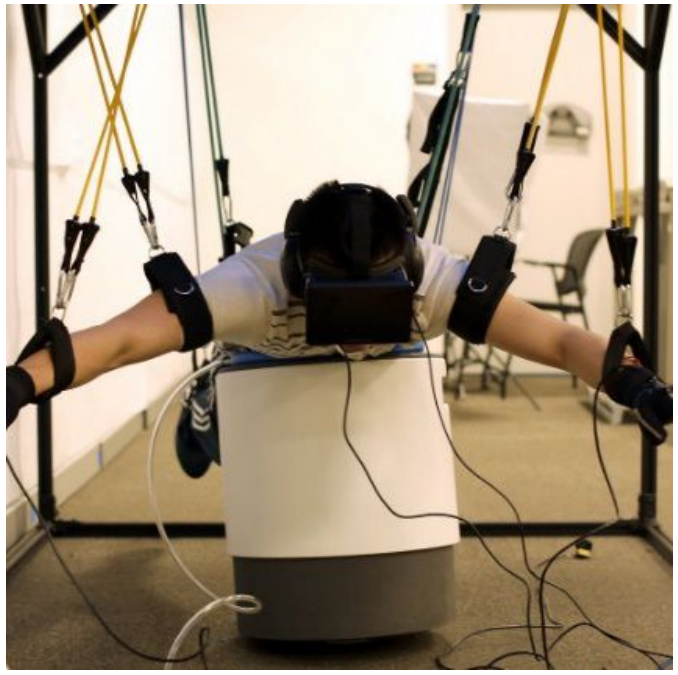
Scuba Diving,
UIST ‘16

Suspension Systems for Body Motion VR

Pre-determined Platform

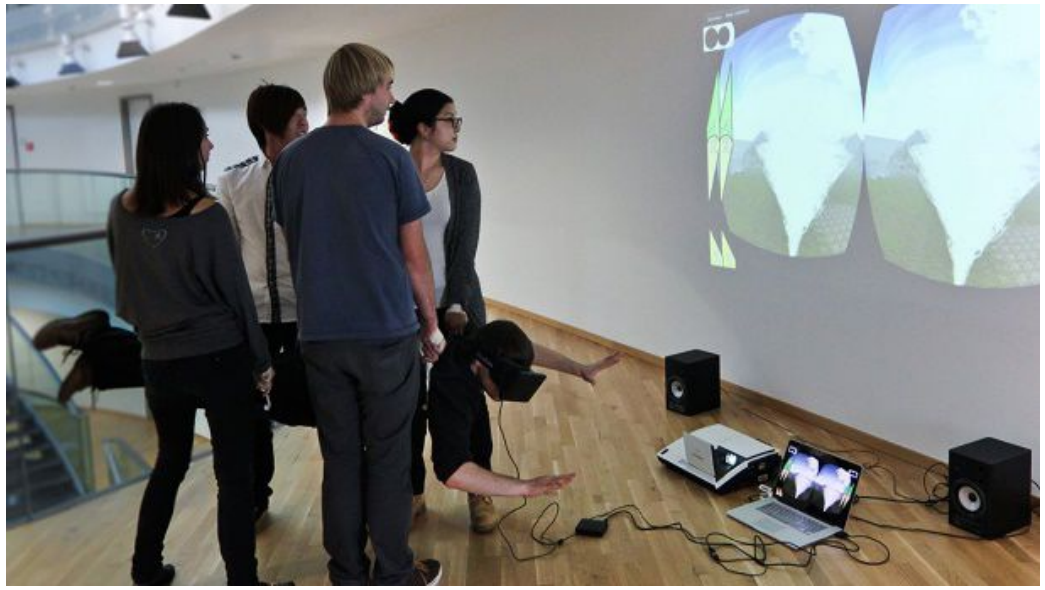


Indoor Skydiving,
VRST ‘15



Scuba Diving,
UIST ‘16

Temporary Platform



Haptic Turk,
CHI ‘14

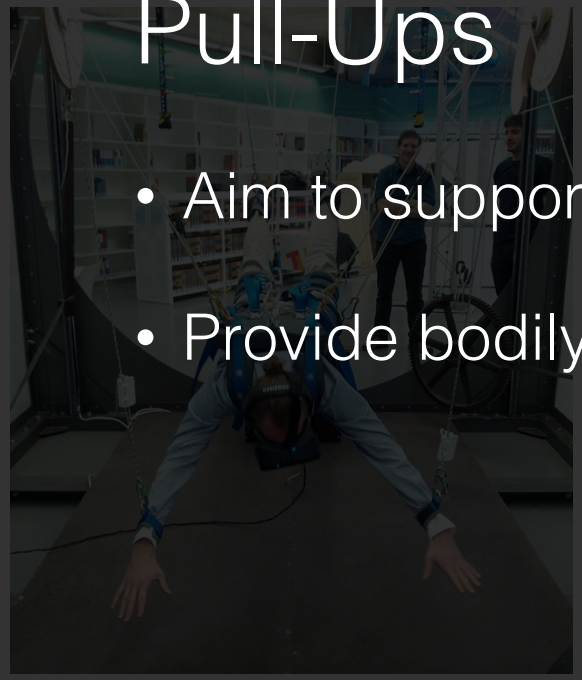
Suspension Systems for Body Motion VR

Pre-determined Platform

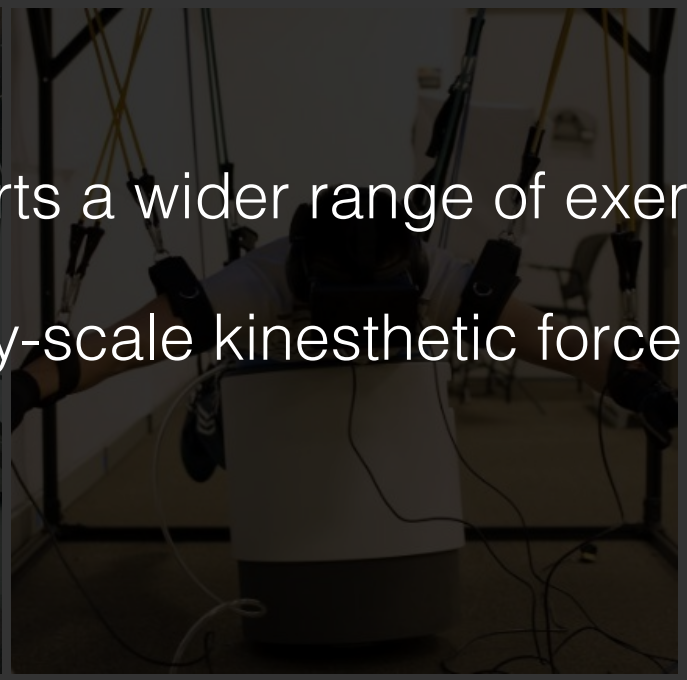
Temporary Platform

Pull-Ups

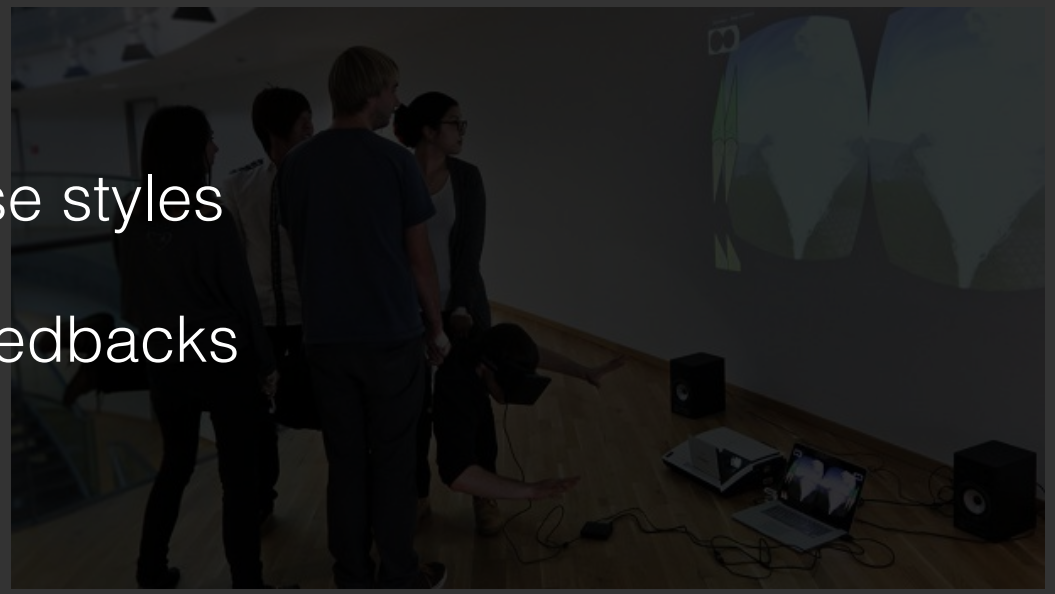
- Aim to supports a wider range of exercise styles
- Provide bodily-scale kinesthetic force feedbacks



Indoor Skydiving,
VRST ‘15



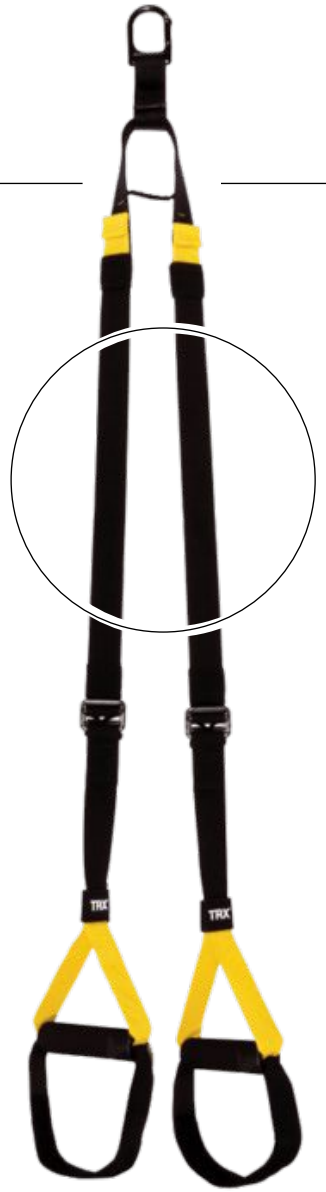
Scuba Diving,
UIST ‘16



Haptic Turk,
CHI ‘14

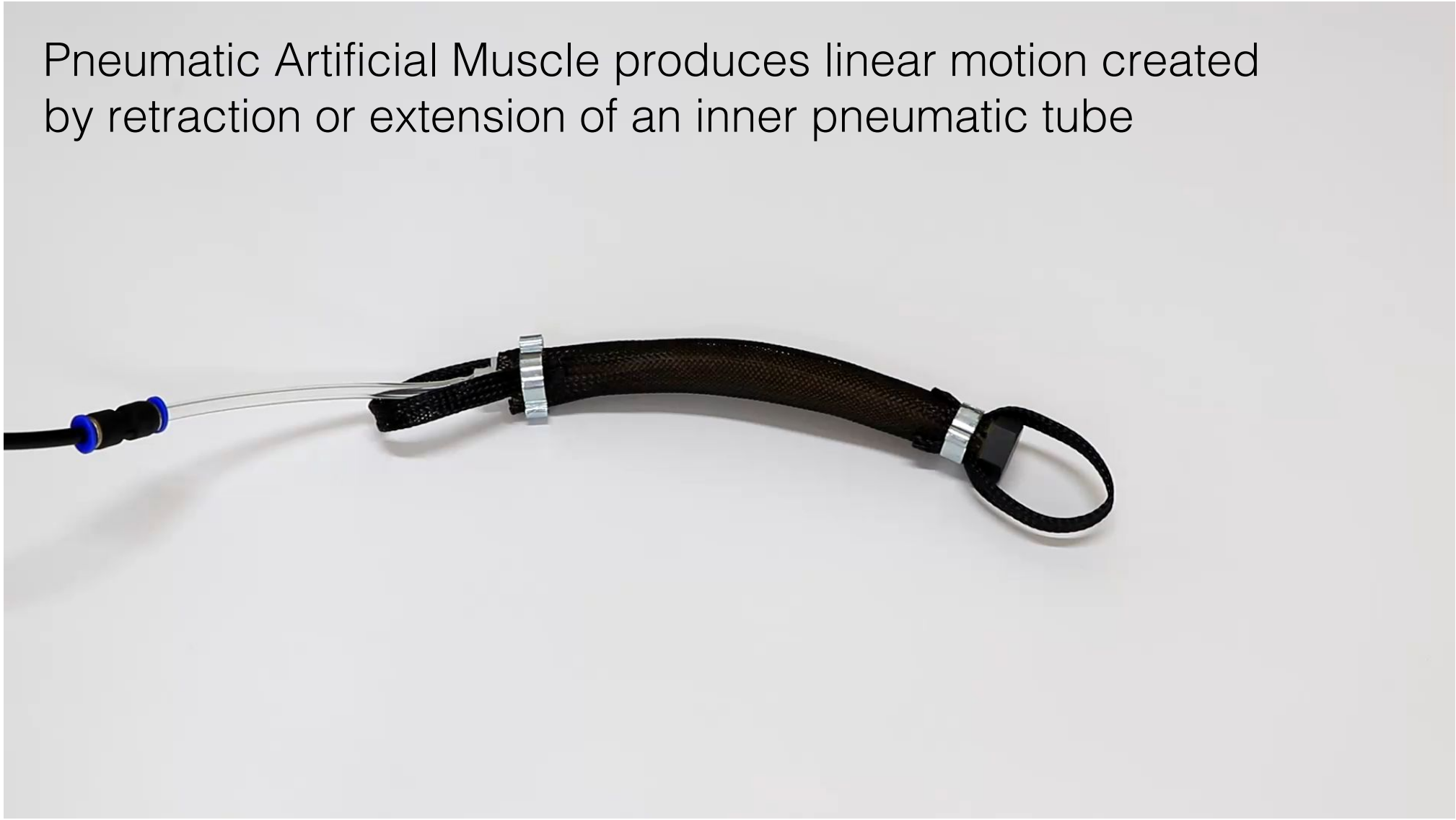
Implementation


TRX
TRX



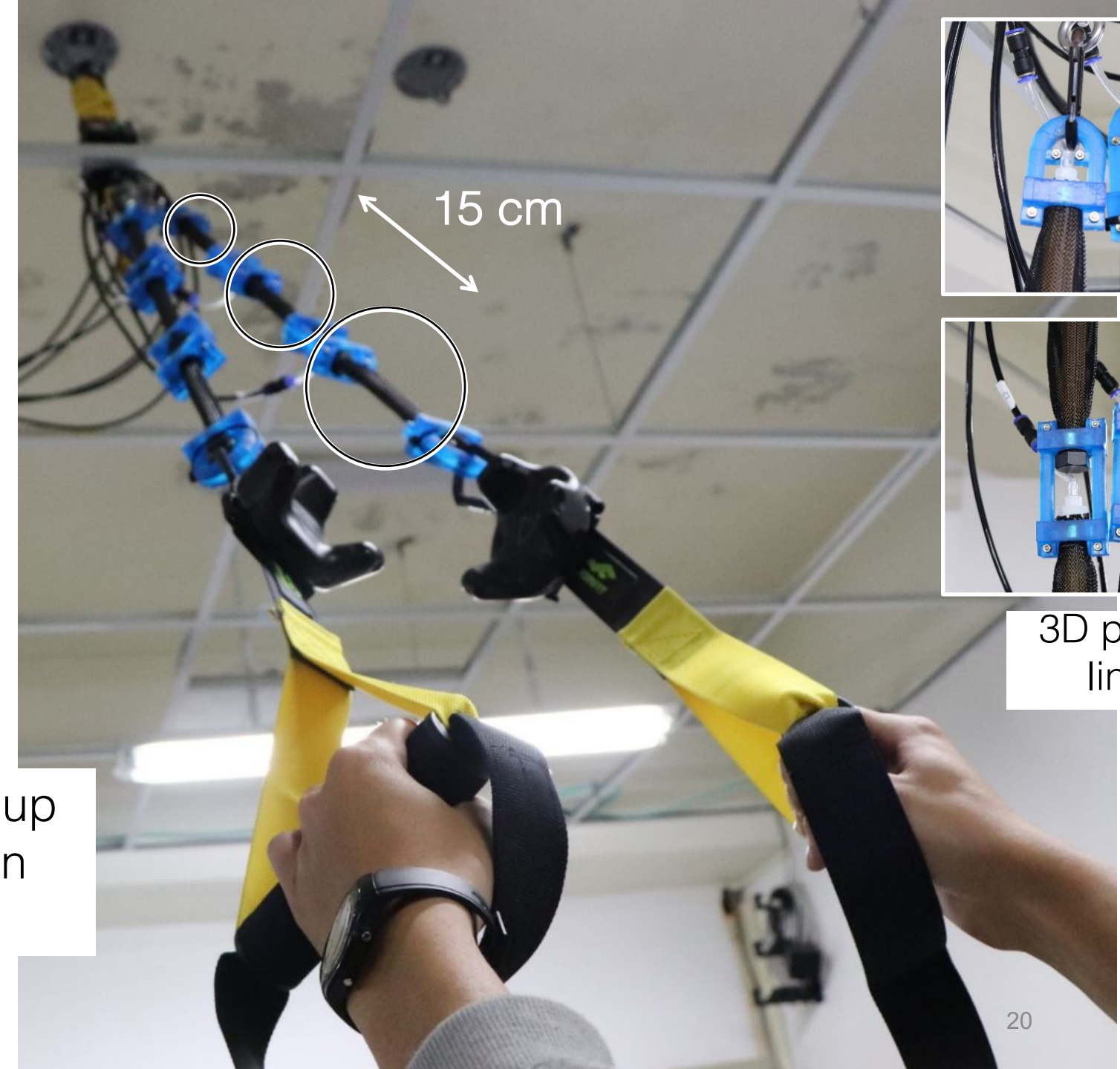
Suspension training was replaced the strap with pneumatic artificial muscle (PAM) or air muscles for enabling active feedback

Pneumatic Artificial Muscle produces linear motion created by retraction or extension of an inner pneumatic tube

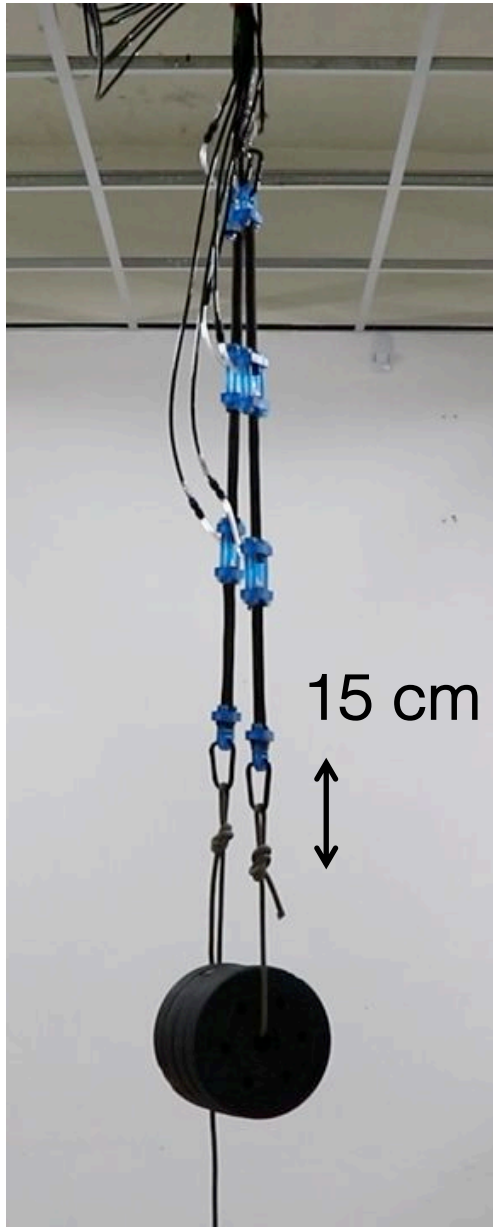


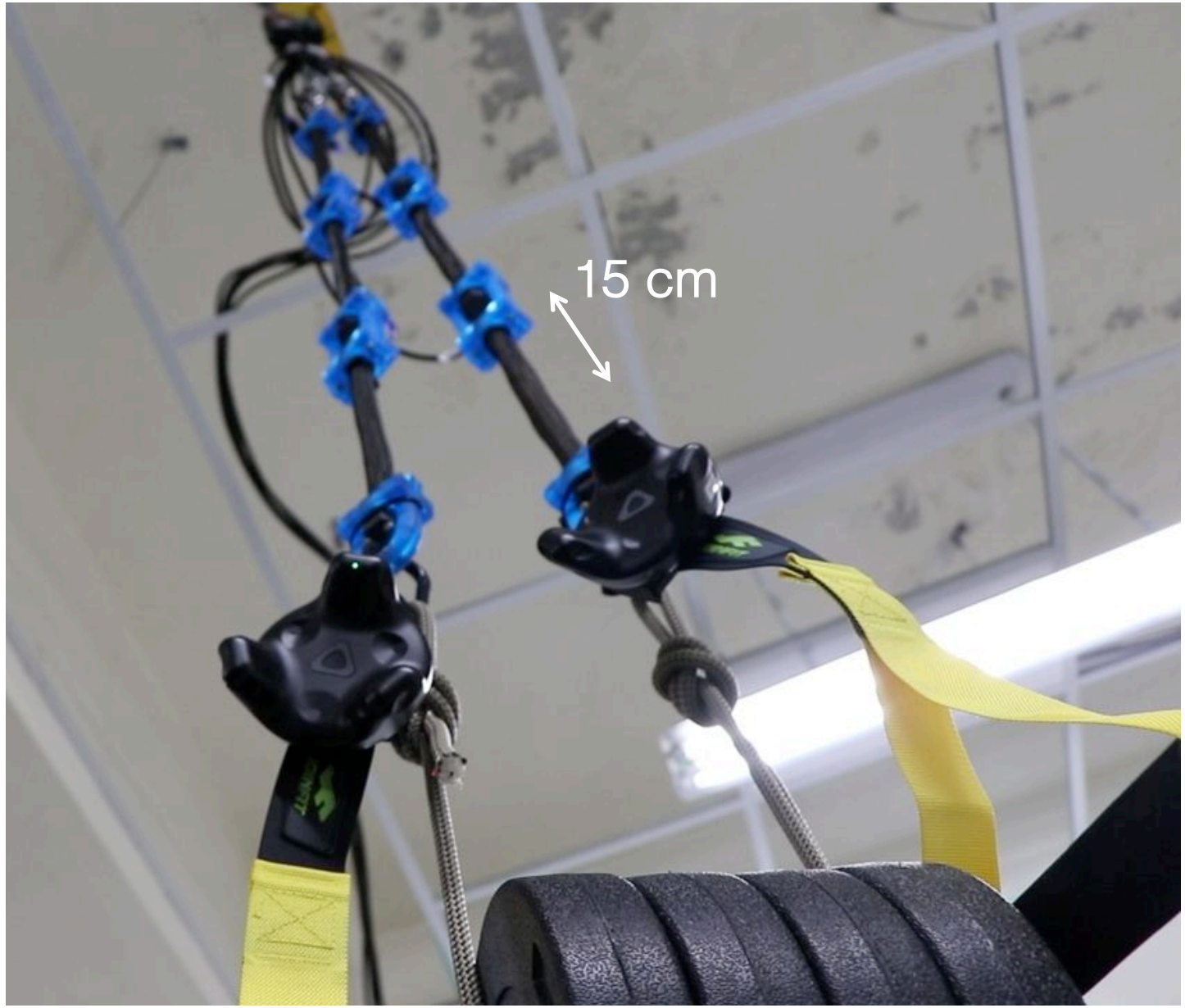
Each air muscle shrinks 5 cm when contraction.

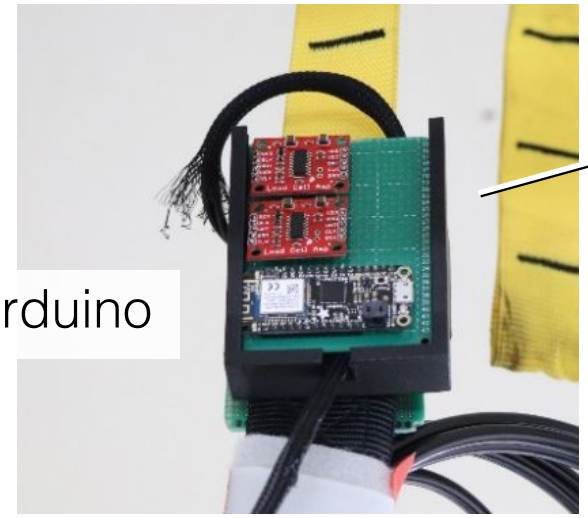
Three air muscles linked up allow 15 cm **contraction** in total **for each strap**



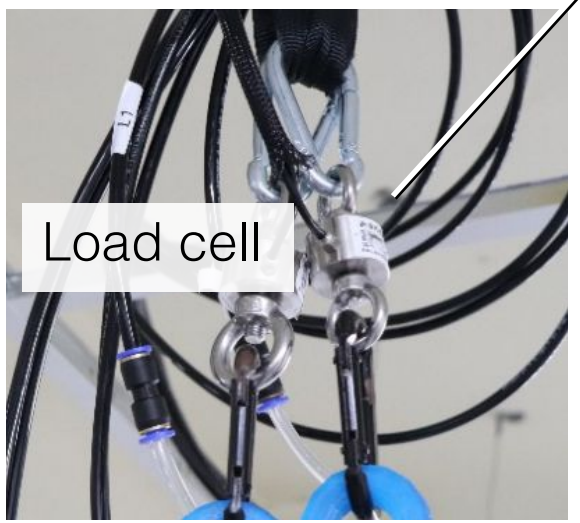
3D printing linkages


15 cm

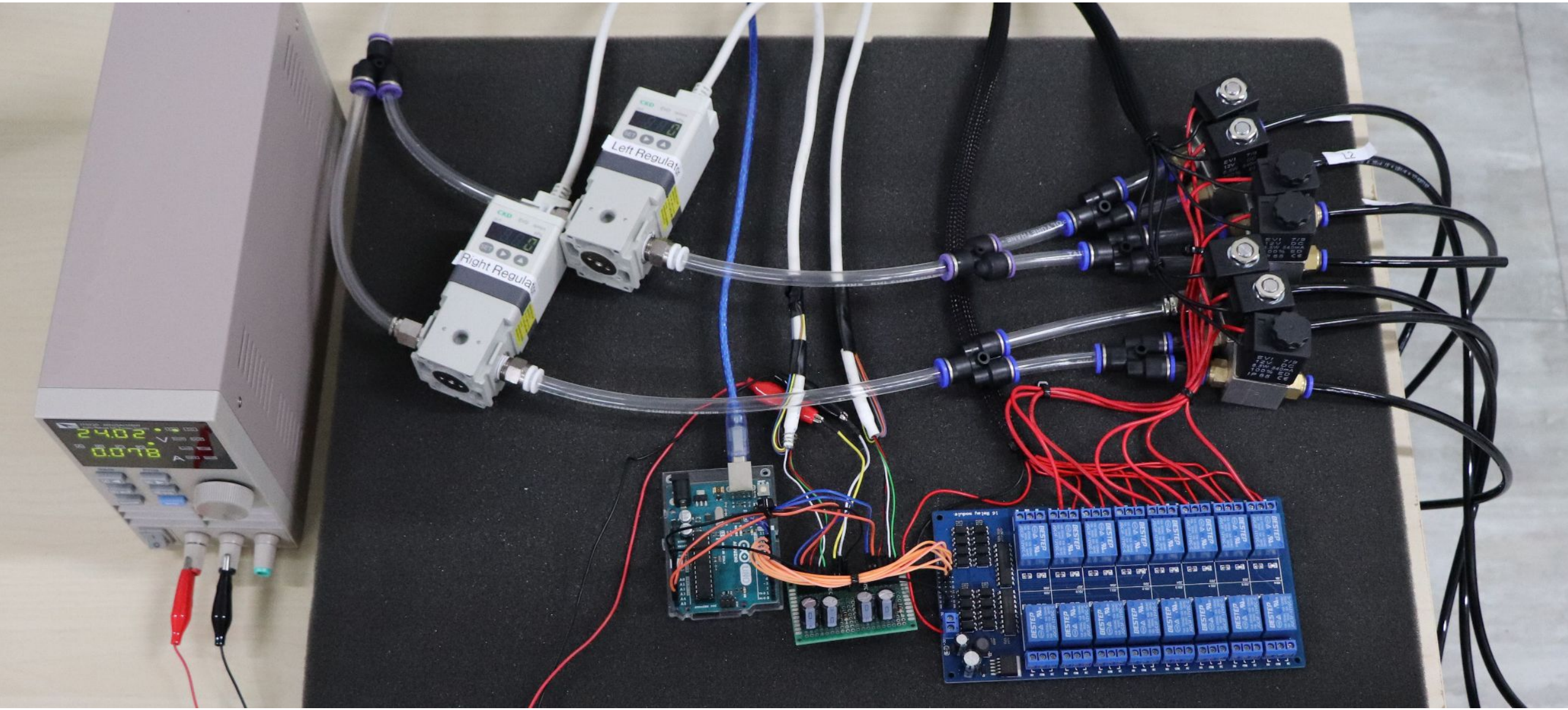

15 cm

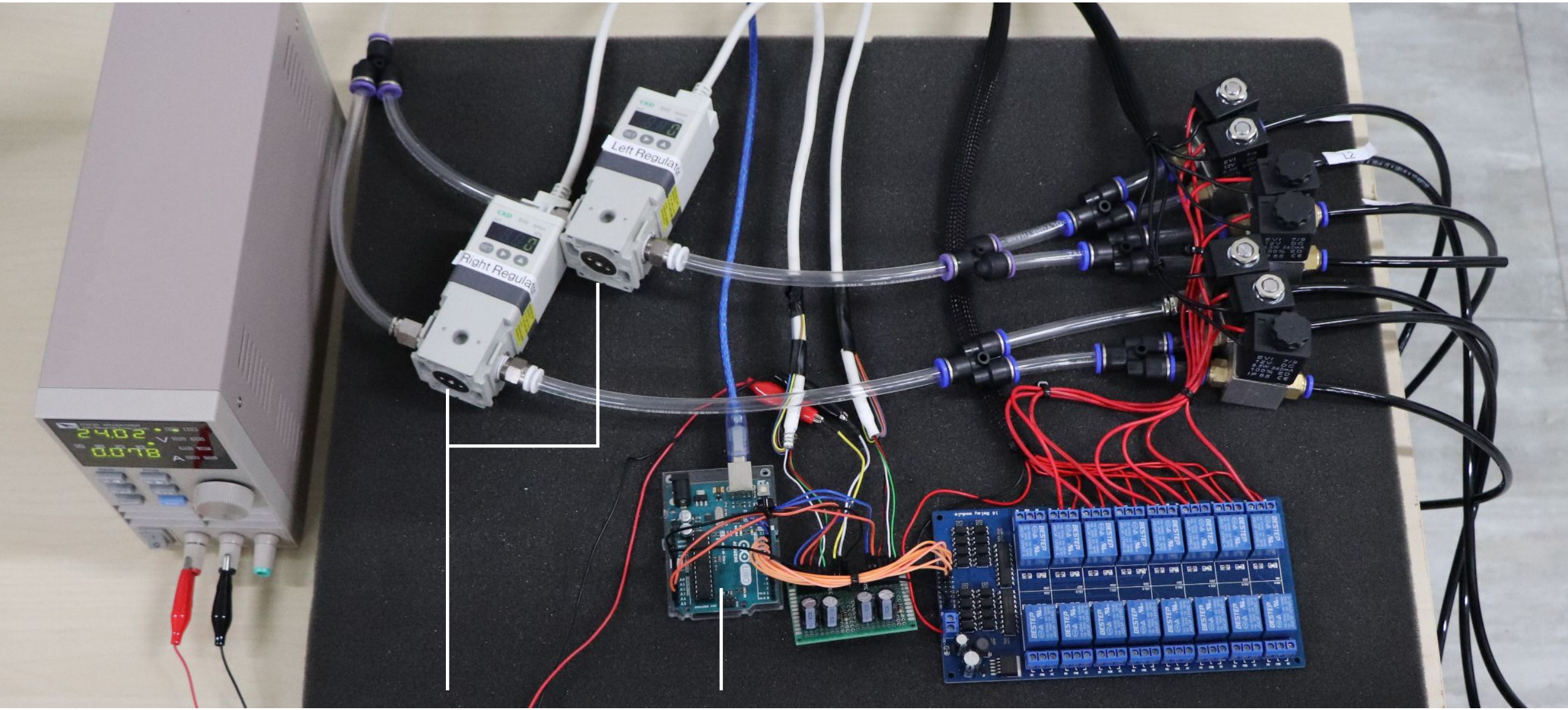


Arduino



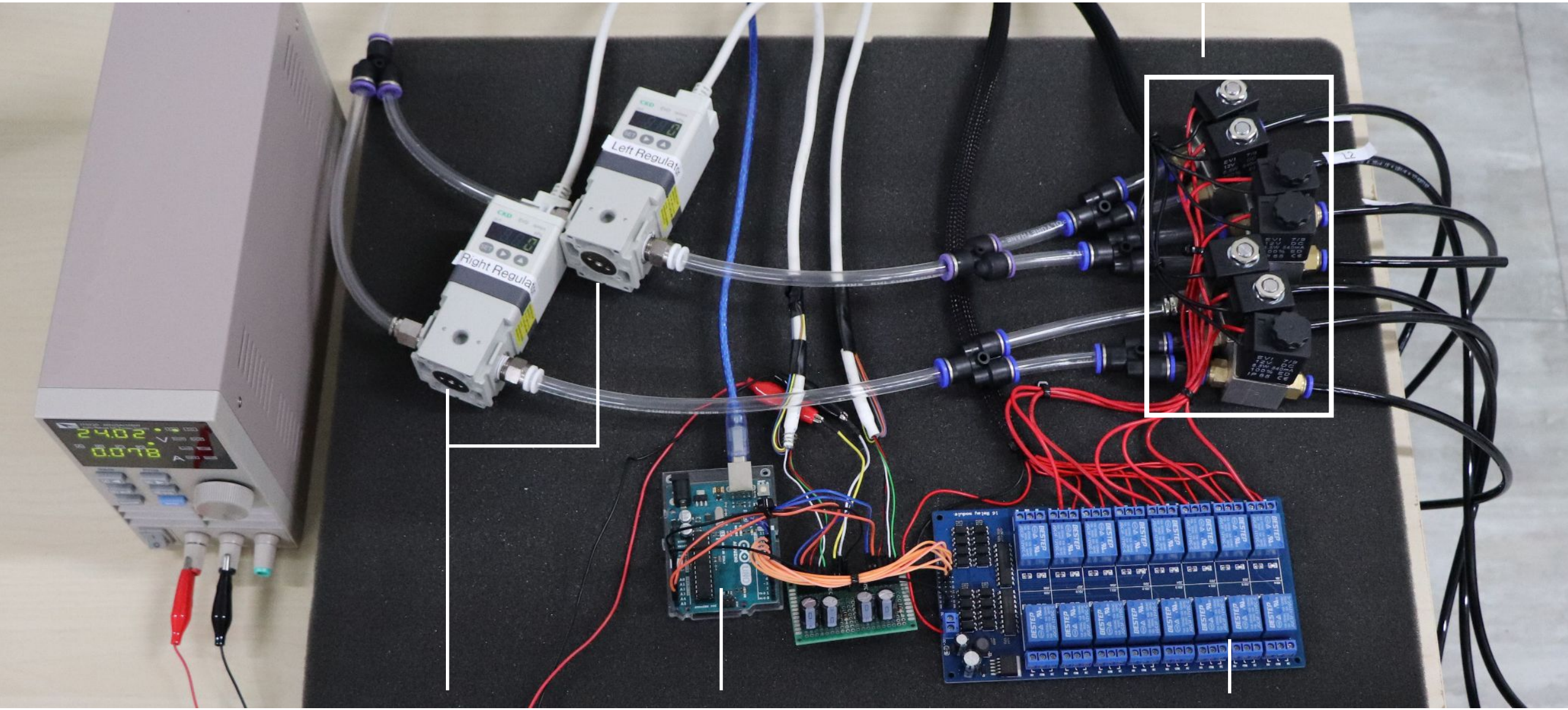
Load cell

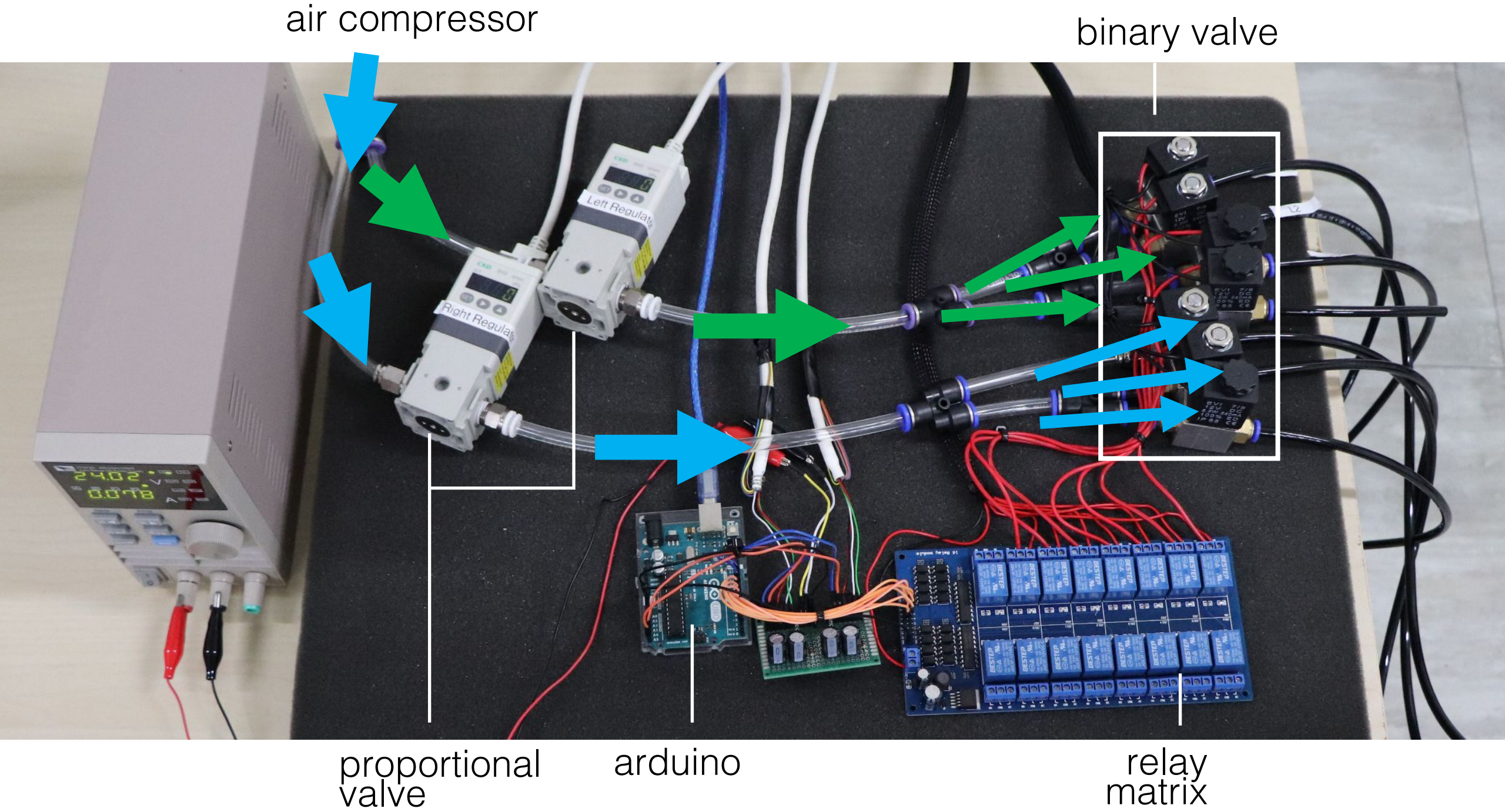

Left Regulat
Right Regulat
24.02
0.078

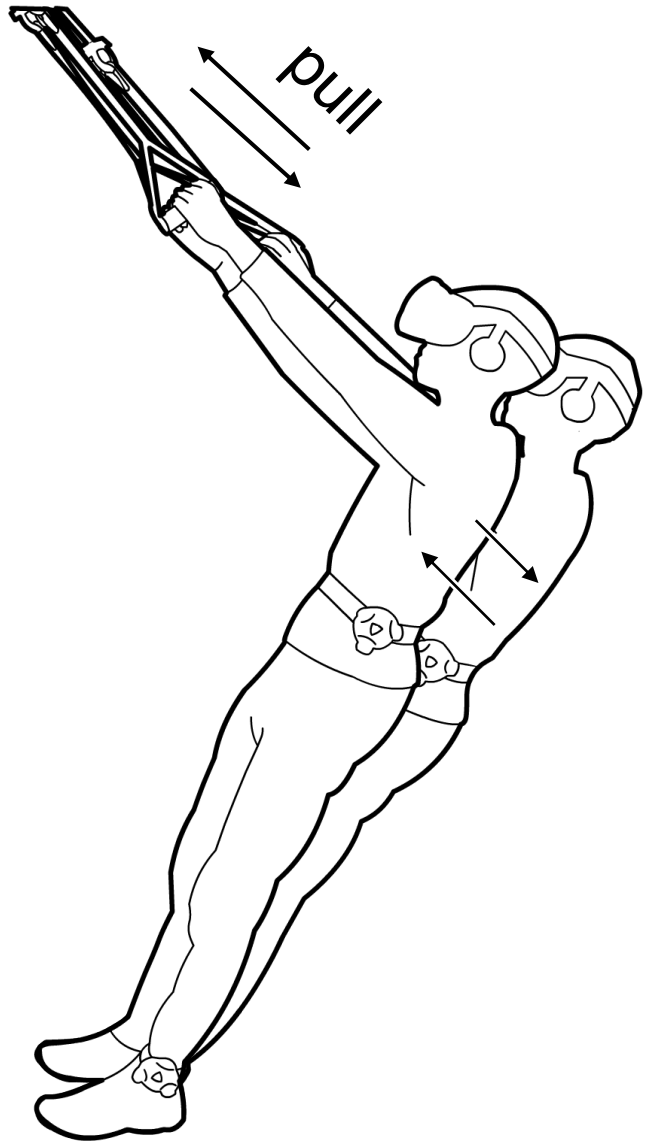


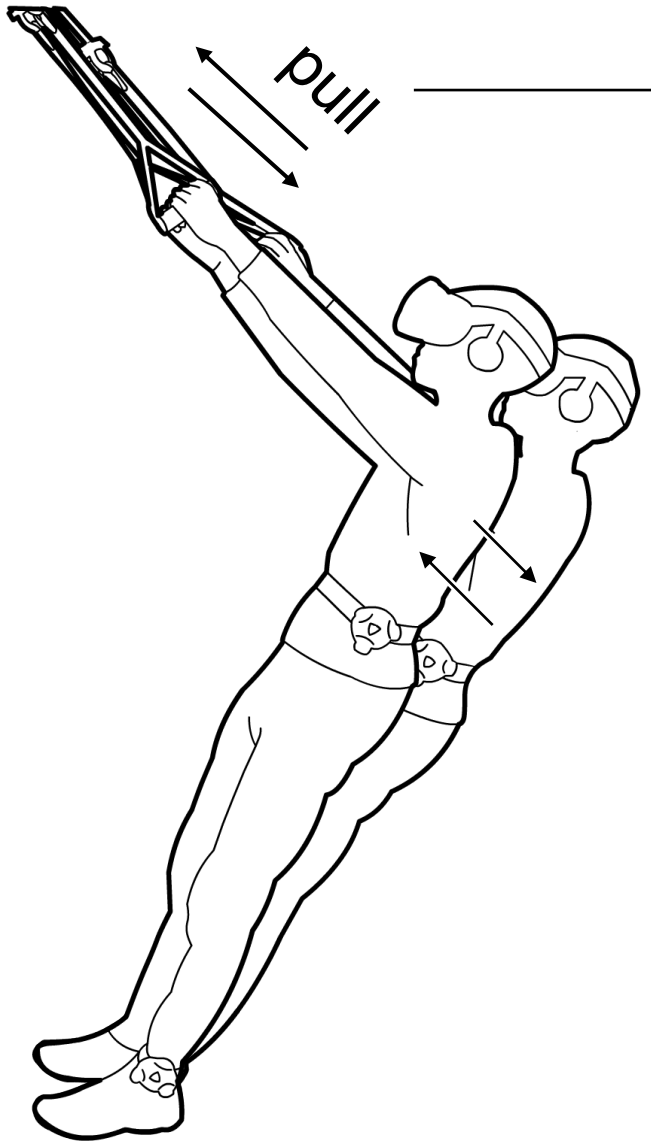
proportional valve

arduino


binary valve
proportional valve
arduino
relay matrix


air compressor
binary valve
proportional valve
arduino
relay matrix

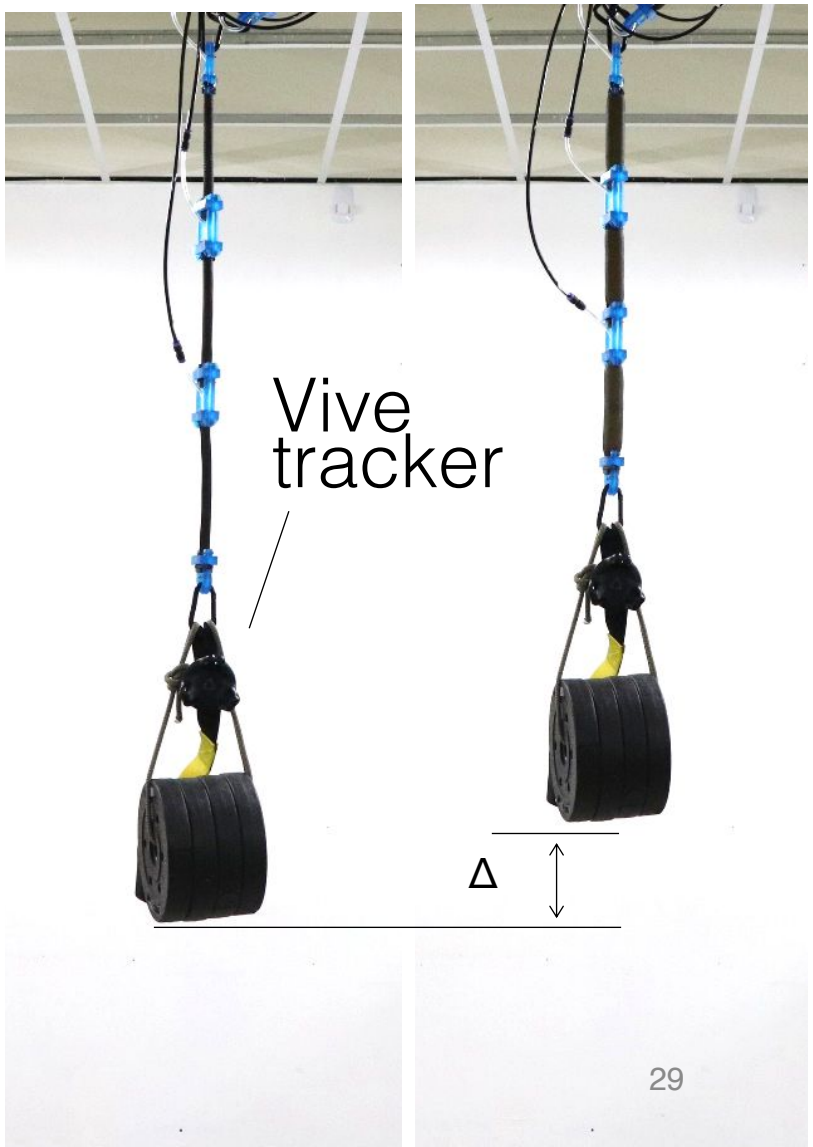

pull



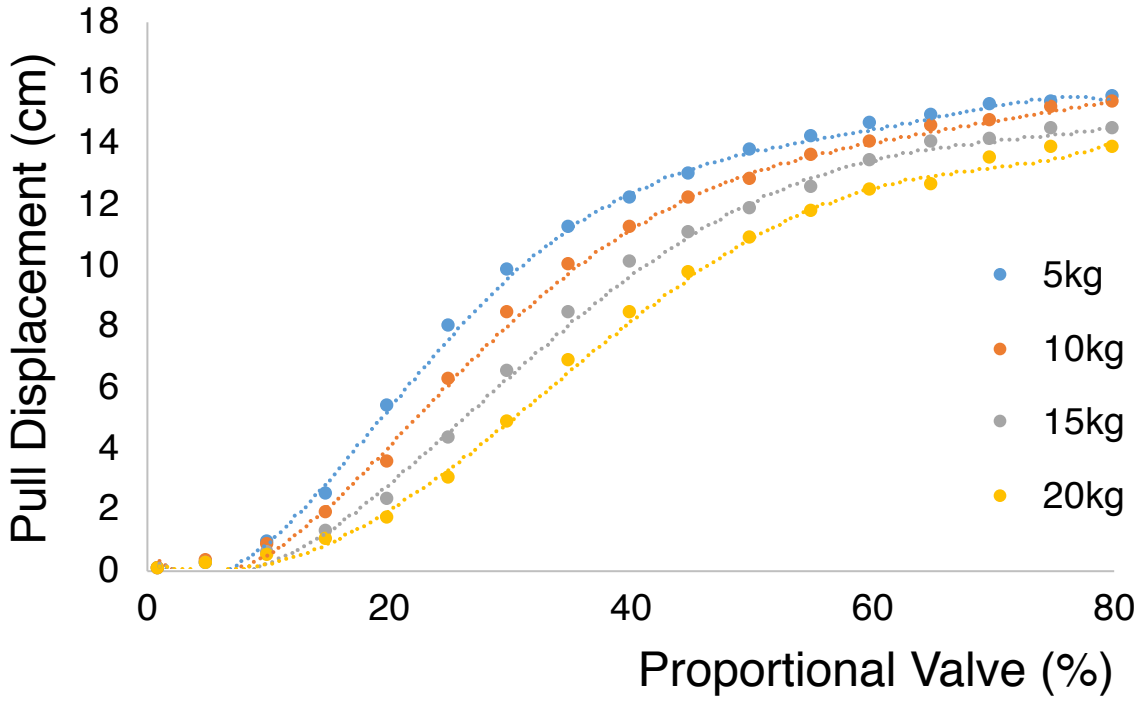
Active Kinesthetic Force Feedback
:: up to 15 cm

Regulating Pulling Distance

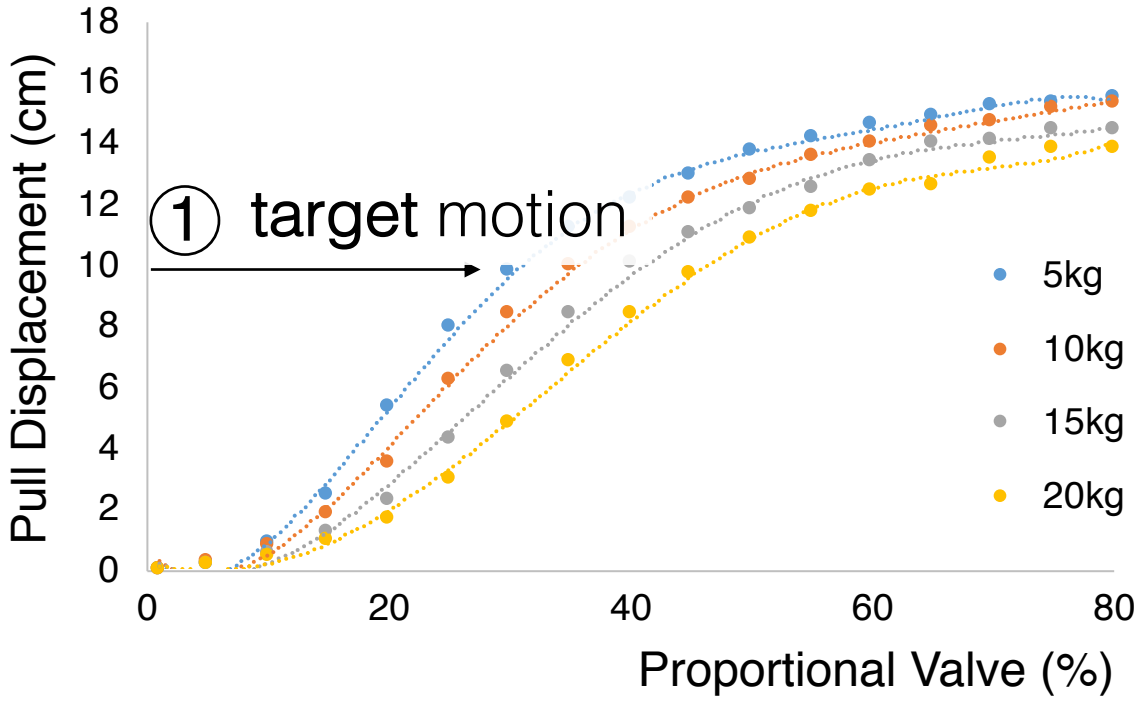
- To formulate an end-to-end function
- Four different loads (5 kg, 10kg, 15 kg, 20 kg)
- Sampled 16 displacements (0 to 700KPa)



- Fitted each profile with a **quartic** equation



- Fitted each profile with a **quartic** equation
- By **interpolating** the corresponding air pressures needed for the motion



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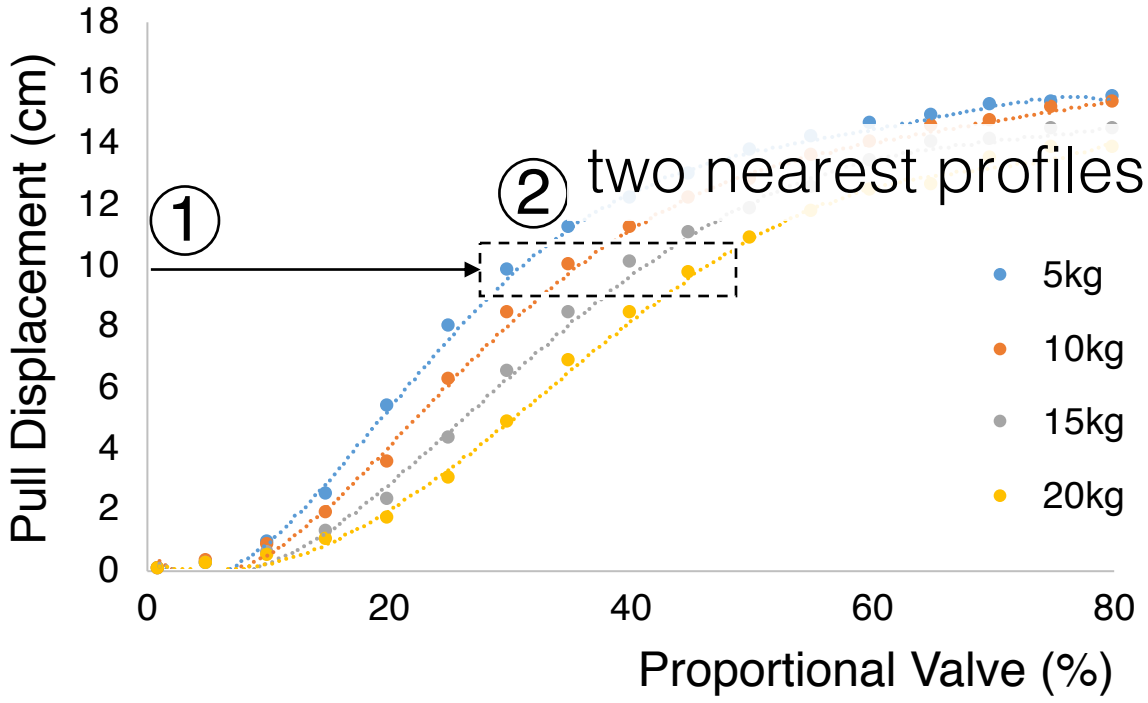

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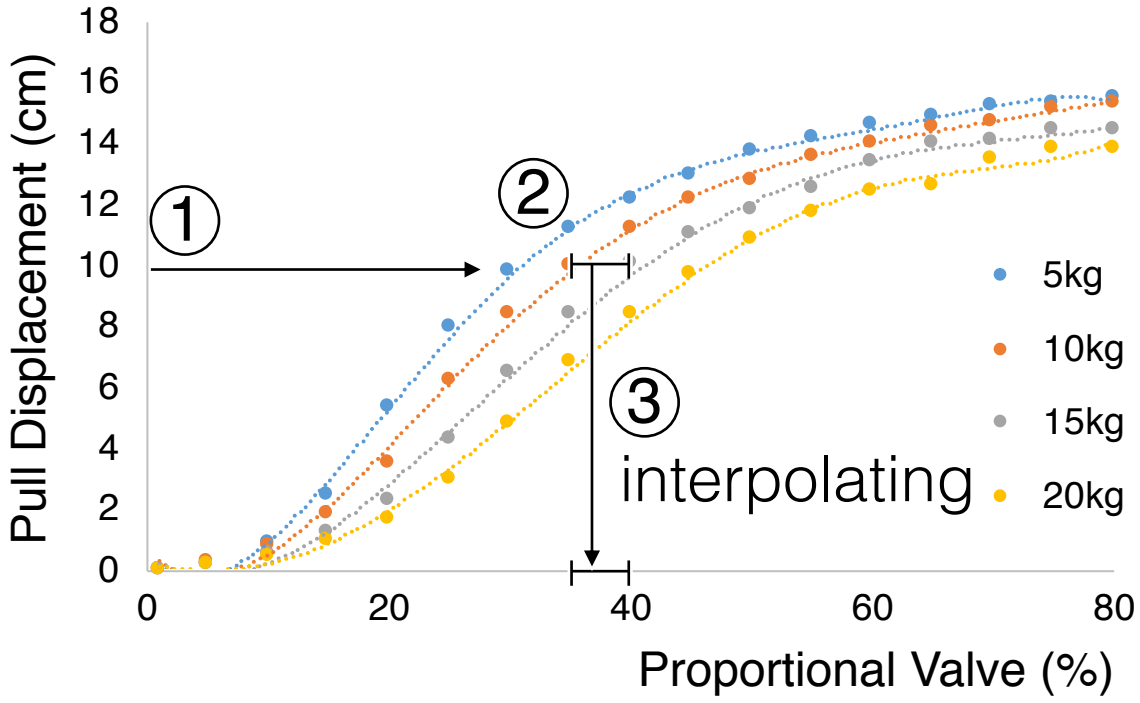
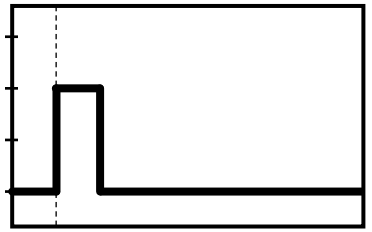
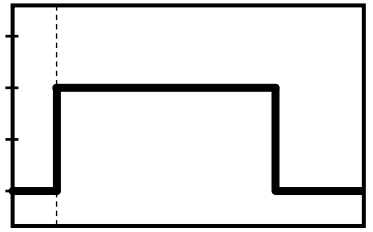


Symmetric Force Feedbacks

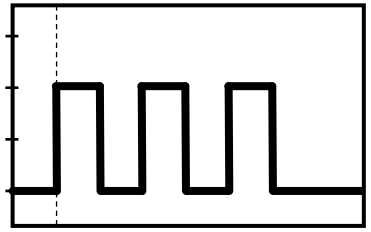
Impulse



Pull-Up

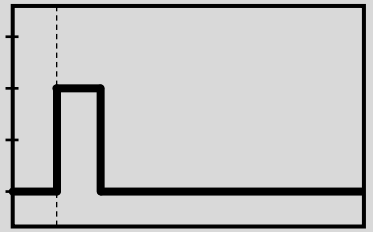


Oscillation
(Vibration)

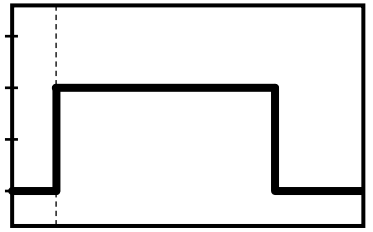


Symmetric Force Feedbacks

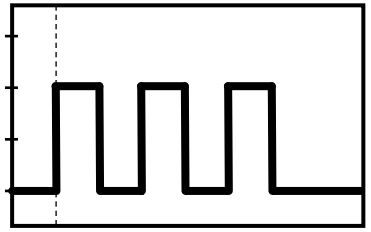
Impulse



Pull-Up



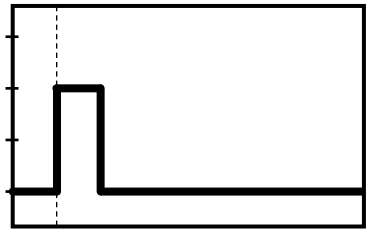
Oscillation
(Vibration)



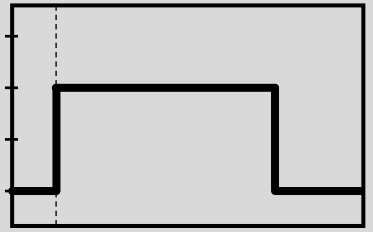
pulling up and setting down in sequence

Symmetric Force Feedbacks

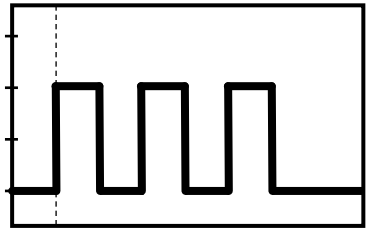
Impulse



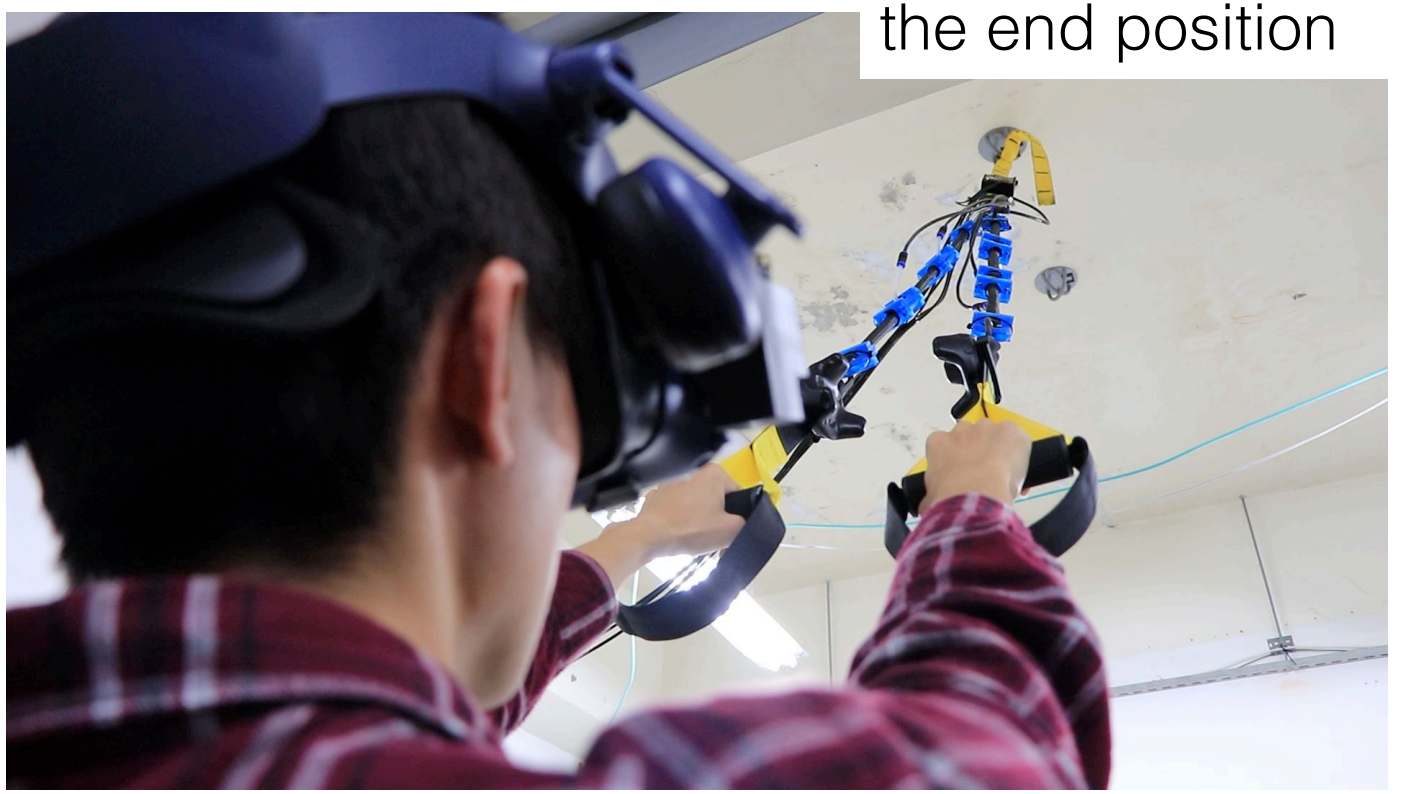
Pull-Up



Oscillation
(Vibration)

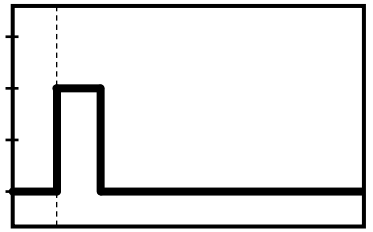


keeps the user at the end position

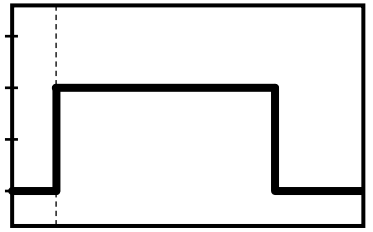


Symmetric Force Feedbacks

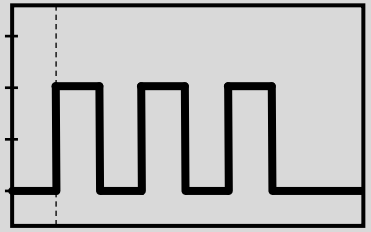
Impulse



Pull-Up



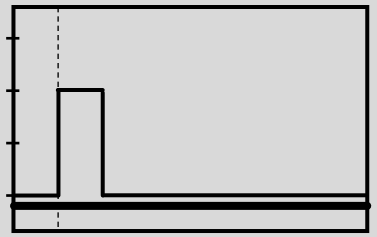
Oscillation
(Vibration)



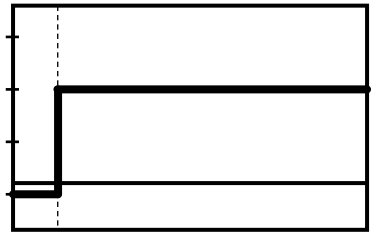
continuous impulses in long and short pull displacements

Asymmetric Force Feedbacks

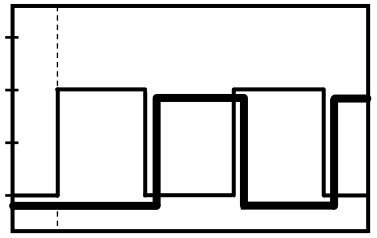
Tilt-Impulse



Tilt-Lift



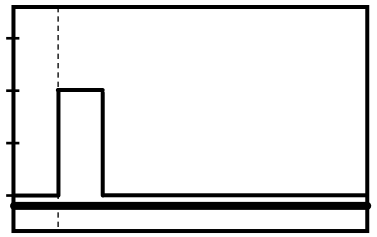
Alternating Tilts



Only the left or right strap contracts

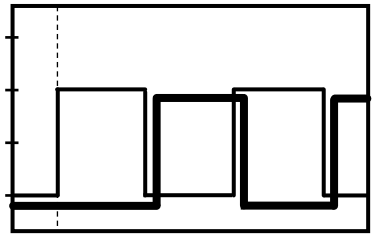
Asymmetric Force Feedbacks

Tilt-Impulse



Tilt-Lift

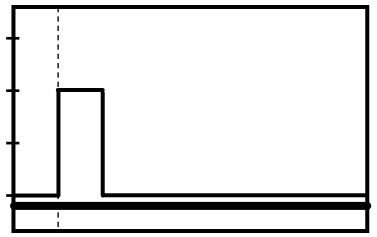
Alternating-Tilts



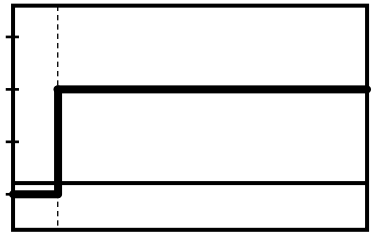
Keeps the user on one side at the end position

Asymmetric Force Feedbacks

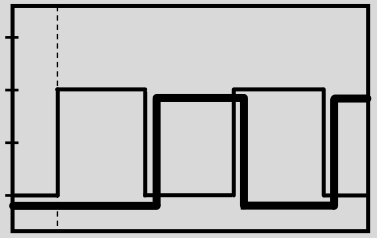
Tilt-Impulse



Tilt-Lift



Alternating-Tilts



Asymmetric body oscillation

Applications

- Kitesurfing
- Paragliding Landing
- Space Invader

Kitesurfing

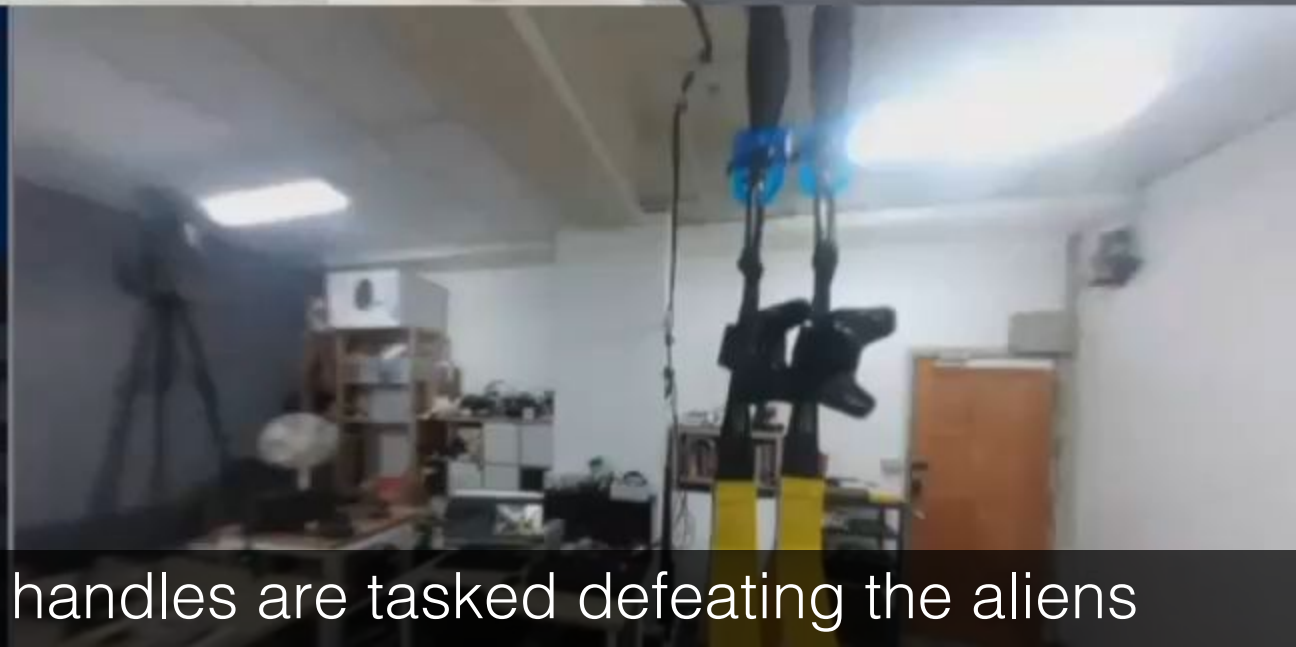
This experience focuses on the sensation of wave riding by oscillation

smooth transition from reality to virtual reality

Paragliding

Users were maneuvering the paragliding to a landing zone with a squatting pose

Space Invader



Users laying back and holding the two handles are tasked defeating the aliens

Four weapons are provided with distinct haptic feedbacks

User Studies

Study 1: Discernible Kinesthetic Force Feedback

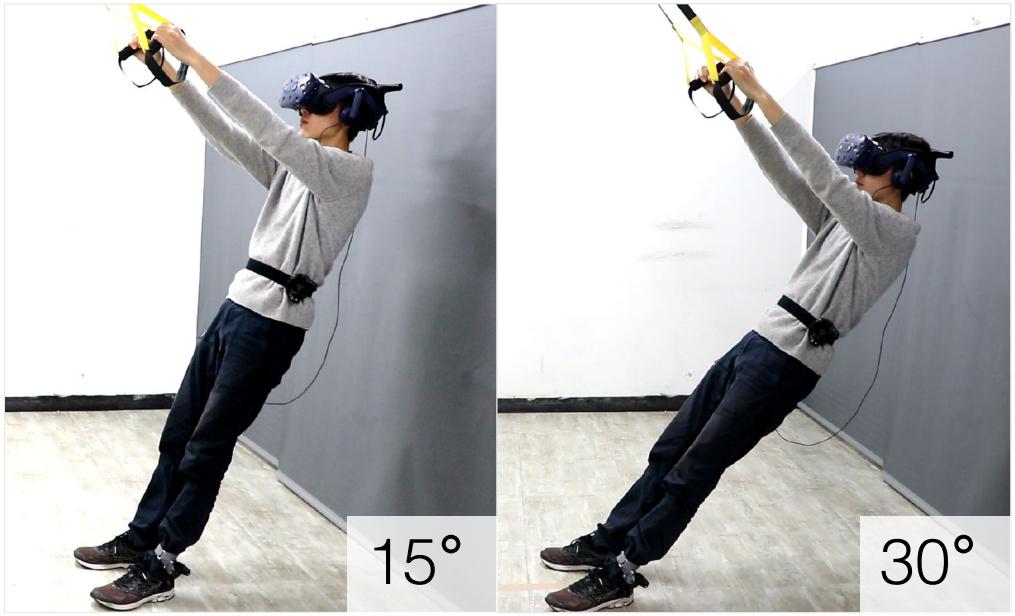
how users perceive kinesthetic force stimuli with two different postures

Study 2: User Experience

how Pull-Ups enhances user experience and alleviate the motion sickness

Study 1: Discernible Threshold (JND)

- Two Angled body postures : 15° / 30°
- Constant stimuli
  - Base motions: 1, 2, 4, 8 cm
  - Offset motions (ΔM) : 0, 1, 2, 4 cm
- 64 trials in total
  - 2 postures x 16 motions x 2 repetitions



Study Process (speedup 1x)

Target Angle : 30
Now Angle : -0.7

Start Trial

Trial : 2/32

Please lean back

Discernible Percentage

15°

Offset Distance (cm)	1	2	4	8
0	0.04	0.13	0.17	0.00
1	0.79	0.42	0.21	0.13
2	1.00	0.92	0.38	0.25
4	1.00	1.00	0.96	0.75

Base Stimulus Distance (cm)

30°

Offset Distance (cm)	1	2	4	8
0	0.04	0.16	0.12	0.12
1	0.76	0.56	0.24	0.12
2	0.96	0.92	0.56	0.40
4	1.00	1.00	0.96	0.84

Base Stimulus Distance (cm)

Discernible Percentage

15°

Offset Distance (cm)	1	2	4	8
0	0.04	0.13	0.17	0.00
1	0.79	0.42	0.21	0.13
2	1.00	0.92	0.38	0.25
4	1.00	1.00	0.96	0.75

Base Stimulus Distance (cm)

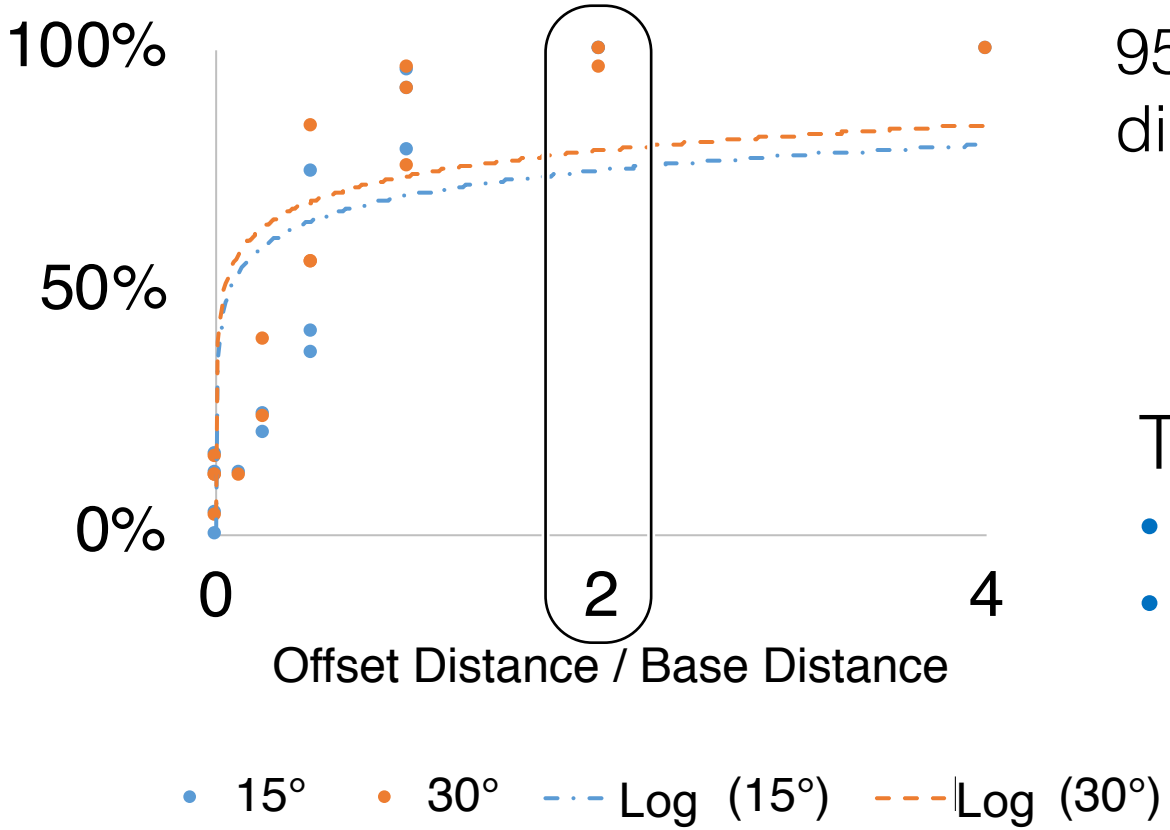
30°

Offset Distance (cm)	1	2	4	8
0	0.04	0.16	0.12	0.12
1	0.76	0.56	0.24	0.12
2	0.96	0.92	0.56	0.40
4	1.00	1.00	0.96	0.84

Base Stimulus Distance (cm)

Greater base motions paired with greater offset motions

Weber Contrast



95% of the user were able to distinguish two stimuli apart

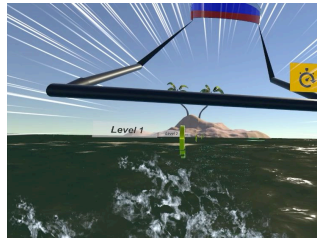
Two sets of kinesthetic forces:

- Light feedback : 1, 3, 9 cm
- Strong feedback : 2, 6, 15 cm (~~18cm~~)

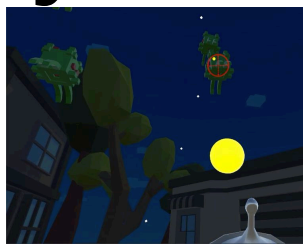
Study 2: User Experience

- Within-subject design
  - **Activity**: kitesurfing / space invader / paragliding
  - **Feedback**: passive / light / strong

Activity



Kitesurfing


Space Invader


Paragliding

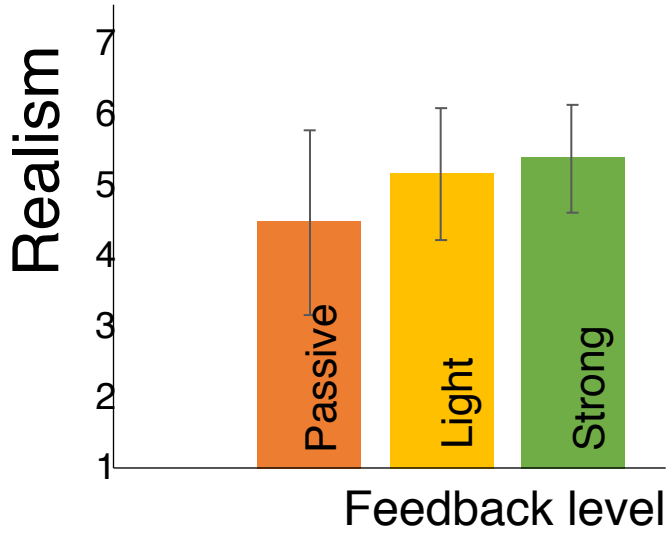
X

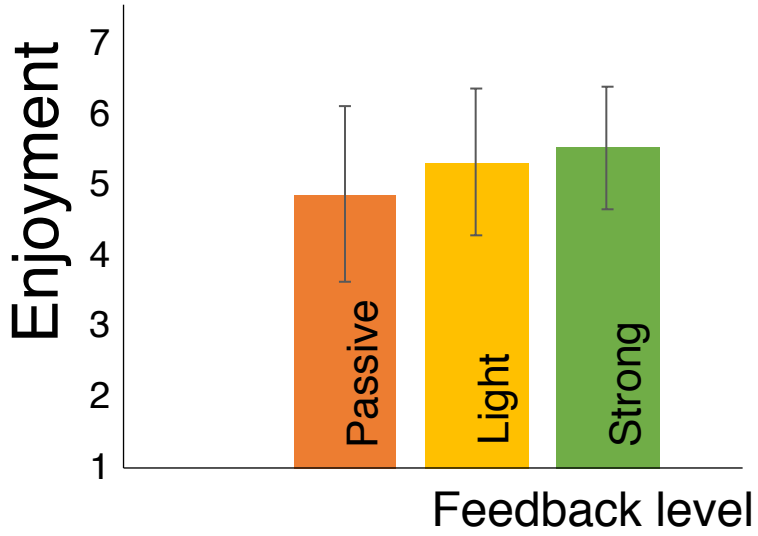
Feedback

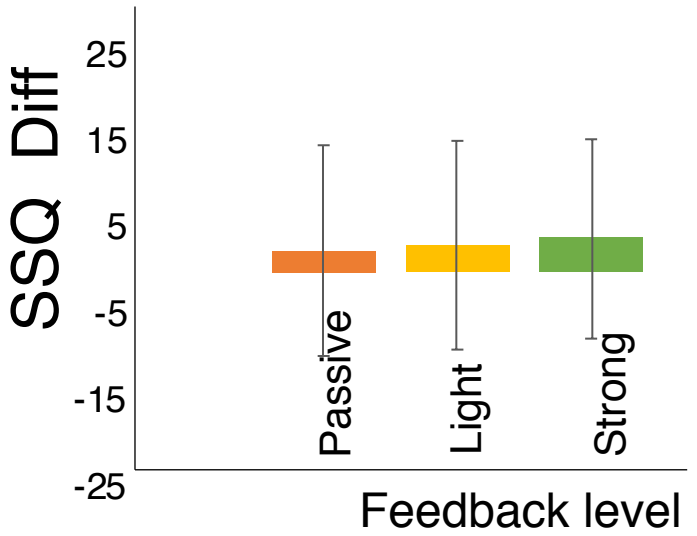
Passive feedback
Light feedback set (1, 3, 9 cm)
Strong feedback set (2, 6, 15 cm)

Study 2: User Experience

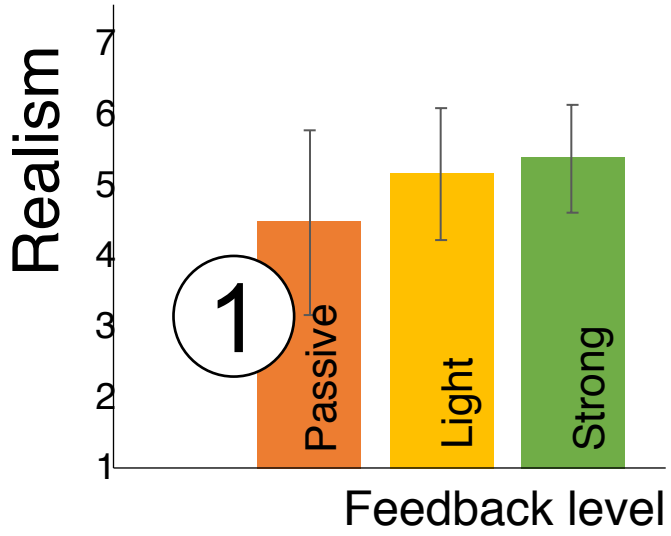
- Within-subject design
  - **Activity**: kitesurfing / space invader / paragliding
  - **Feedback**: passive / light / strong
- Measurement
  - Realism & Enjoyment (7-point Likert scale)
  - Simulator Sickness Questionnaire (SSQ)
  - Open-ended interview

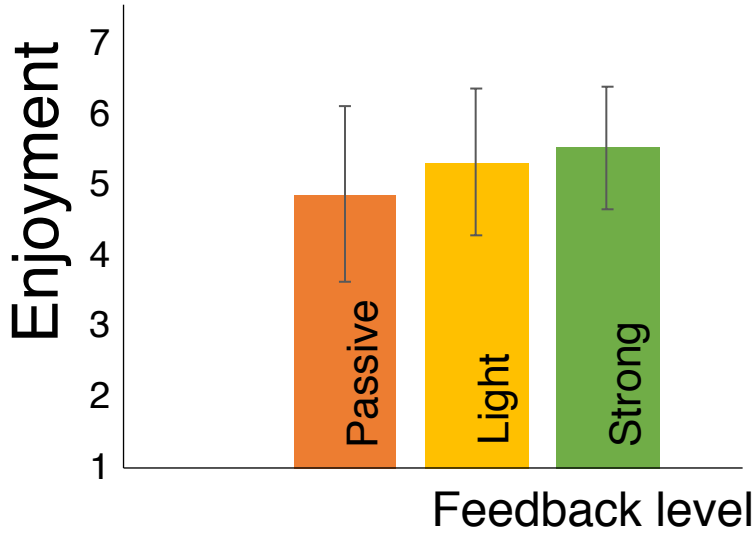

Realism
7
6
5
4
3
2
1
Passive
Light
Strong
Feedback level

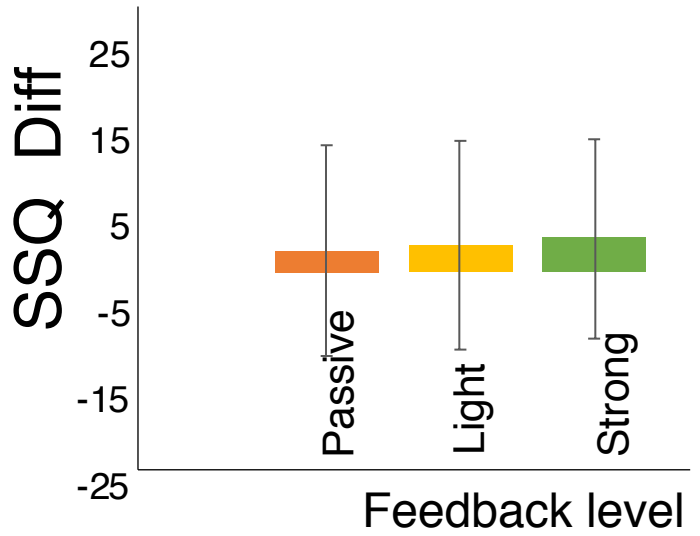

Enjoyment
7
6
5
4
3
2
1
Passive
Light
Strong
Feedback level


SSQ Diff
25
15
5
-5
-15
-25
Passive
Light
Strong
Feedback level

1 Passive feedback alone had positive effects on enjoyment and realism.

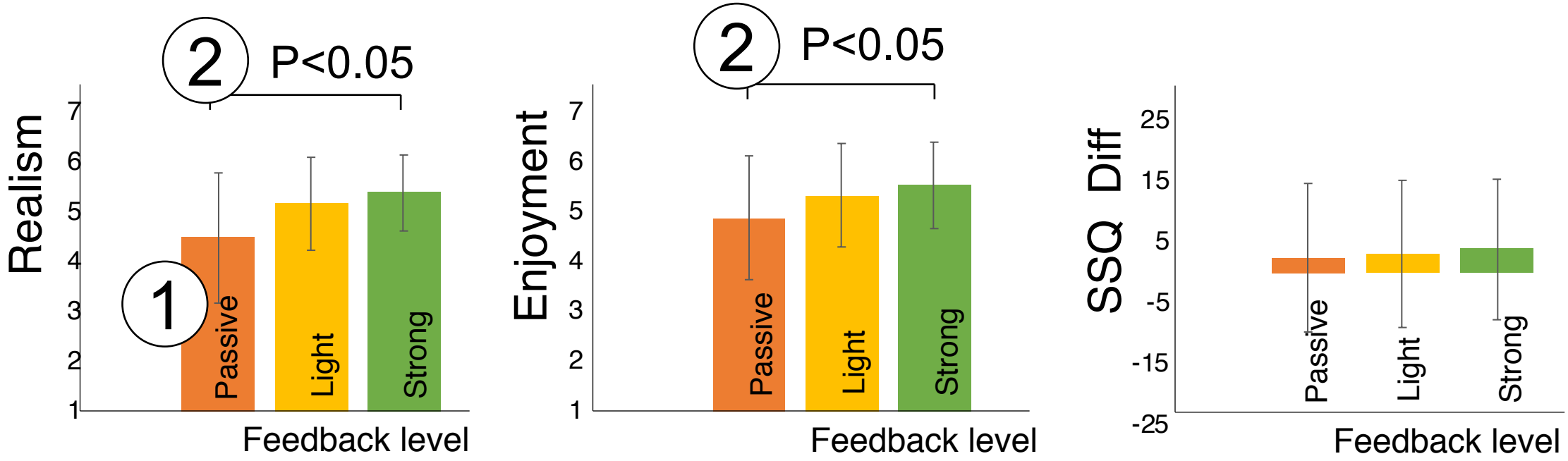






1 Passive feedback alone had positive effects on enjoyment and realism.

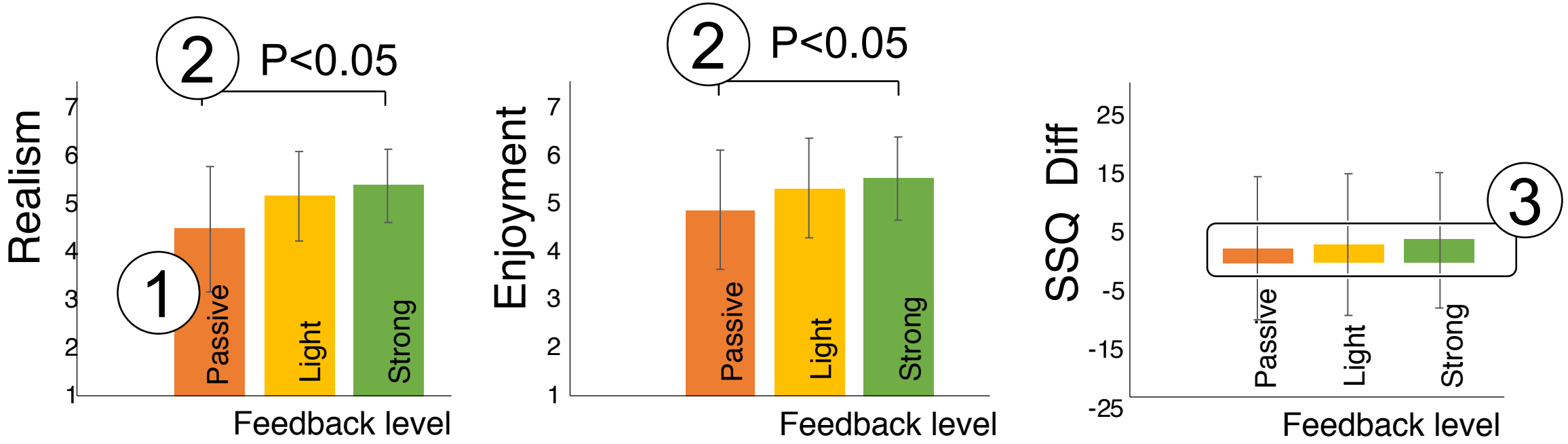
2 Only **Strong** was found significantly higher enjoyment and realism than **Passive**.



1 Passive feedback alone had positive effects on enjoyment and realism.

2 Only **Strong** was found significantly higher enjoyment and realism than **Passive**.

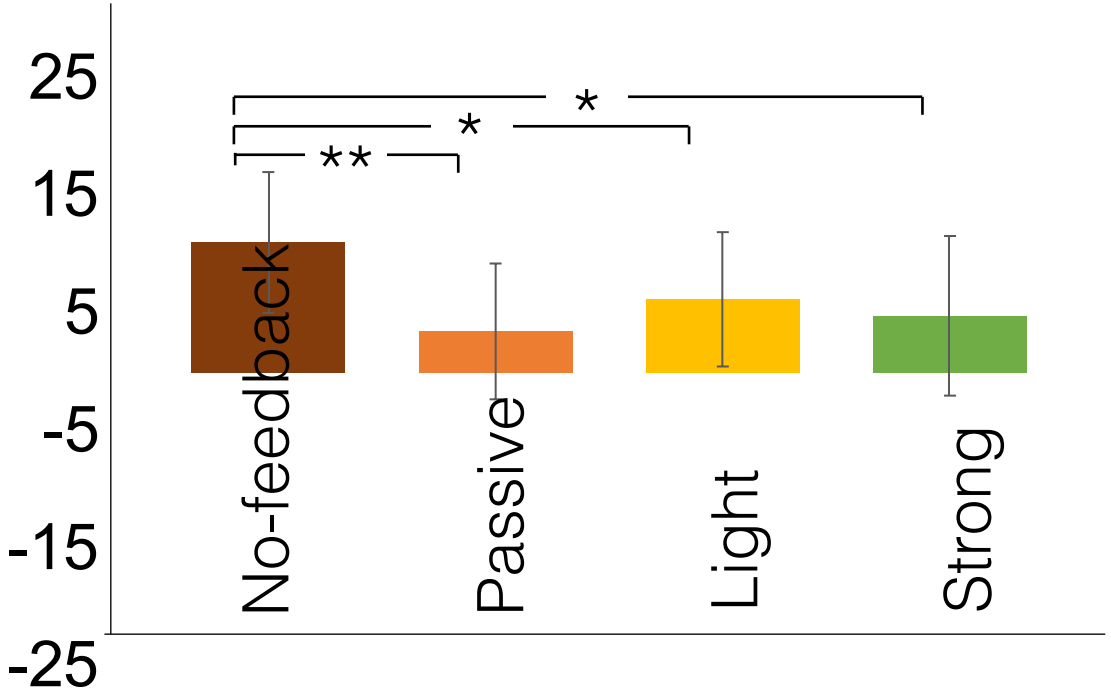
3 No difference in activity or feedback was found for relative SSQ.



No-Feedback Condition

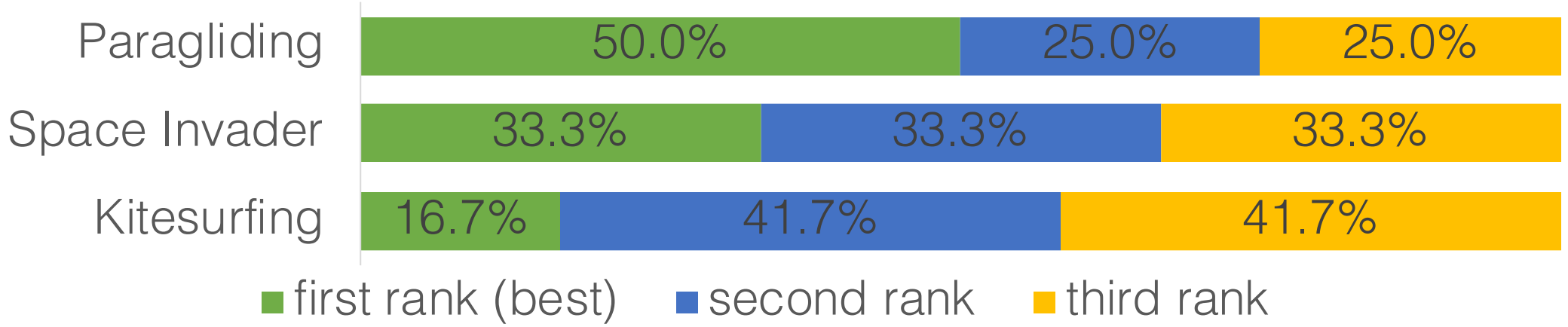
- Sitting posture
- Hand controllers
- Simulator Sickness Questionnaire
  - Kitesurfing
  - Paragliding

SSQ Difference



Both **passive** and **active** feedback of the suspension kit significantly reduced motion sickness

User Preferences



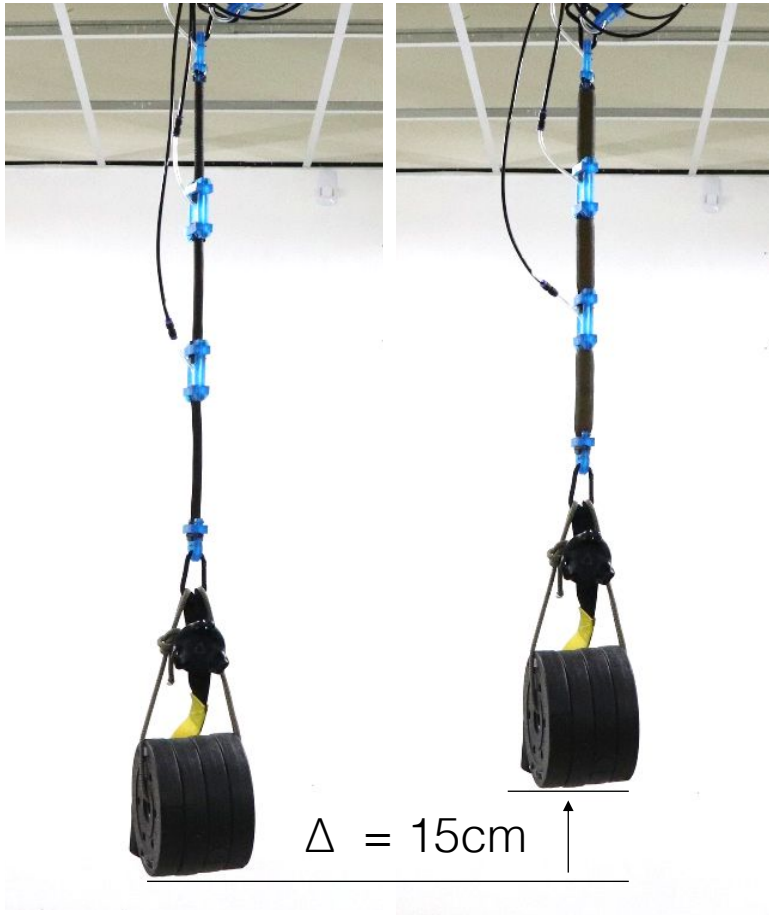
User Feedbacks

- "*While the [pull] feedbacks were on the hands instead of on the feet on landing, I still felt it realistic, which surprised me* (P6)"
- "*Cannon is most impressive that I felt it really pulled my body away* (P2, P4)"

Limitation

Limited and Upper-bound Actuation

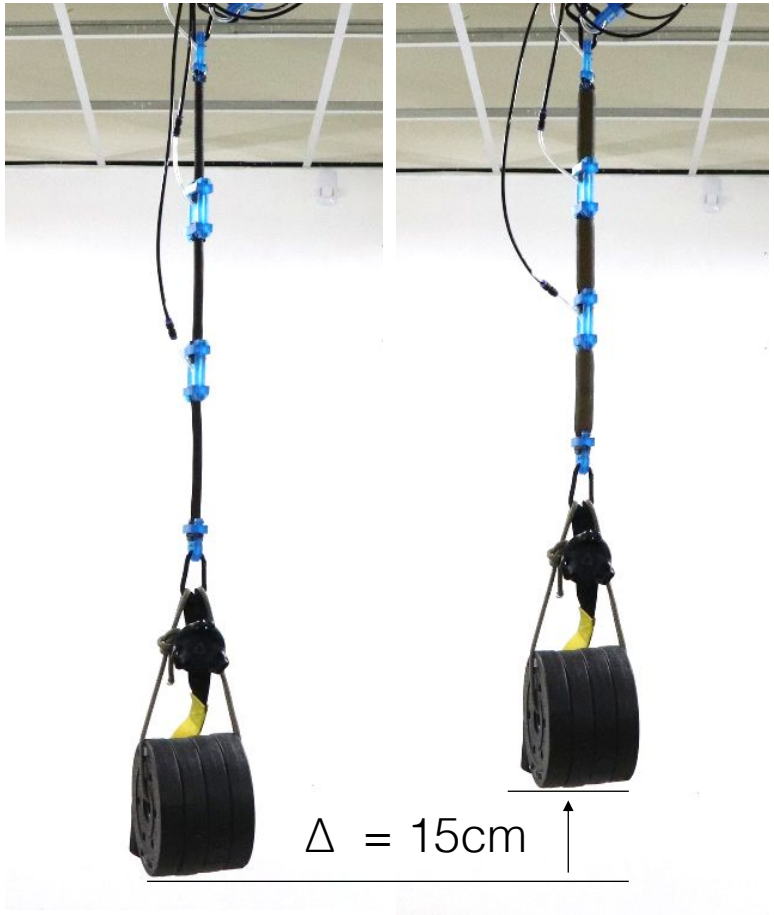
- The advanced set should be expected to be 18 cm for the greatest level.



Limited and Upper-bound Actuation

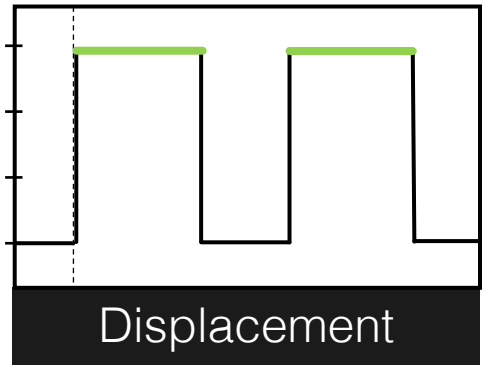
- The advanced set should be expected to be 18 cm for the greatest level.

- For the safety issue may need to identify the upper-bound of the feedback in the future.

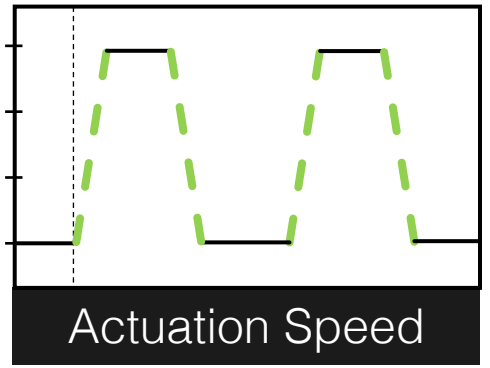


Further Enrich the Feedback Design

- The current feedback design only explores the level of actuation displacements.

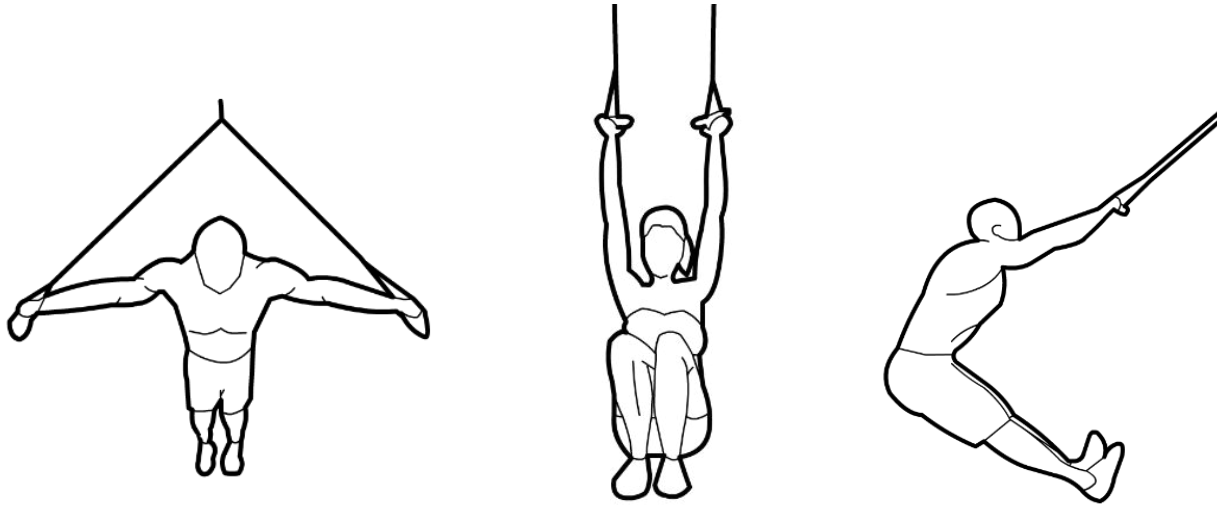


- It may be possible to add factors to actuation speed as a second factor to increase design space.



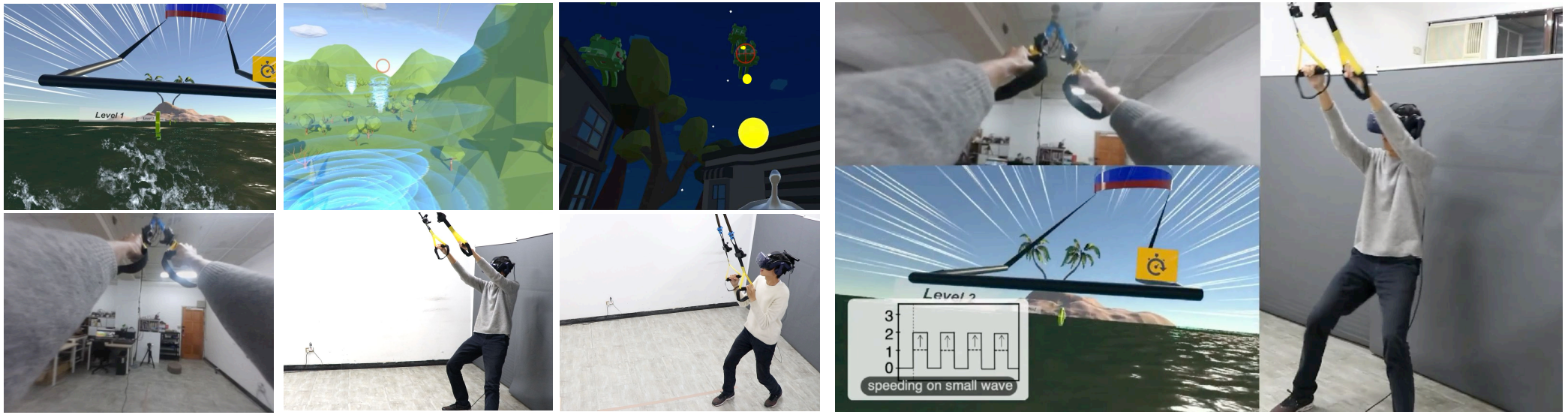
Wider Postures and Safety Concerns

- Special care about safety must be taken when involving advanced exercise postures that pose user balance.



Conclusion

- We presented **Pull-Ups**, a **suspension kit** that enhances suspension activities in virtual reality with **active kinesthetic force feedback.**
  - **Passive feedback** with TRX alone helps to **reduce motion sickness**.
  - **Active feedback** (e.g., strong feedback) **further enhance enjoyment / realism**.
- Pull-Ups aims to provide a new option for designing **rich exertion interaction** in virtual reality at home.

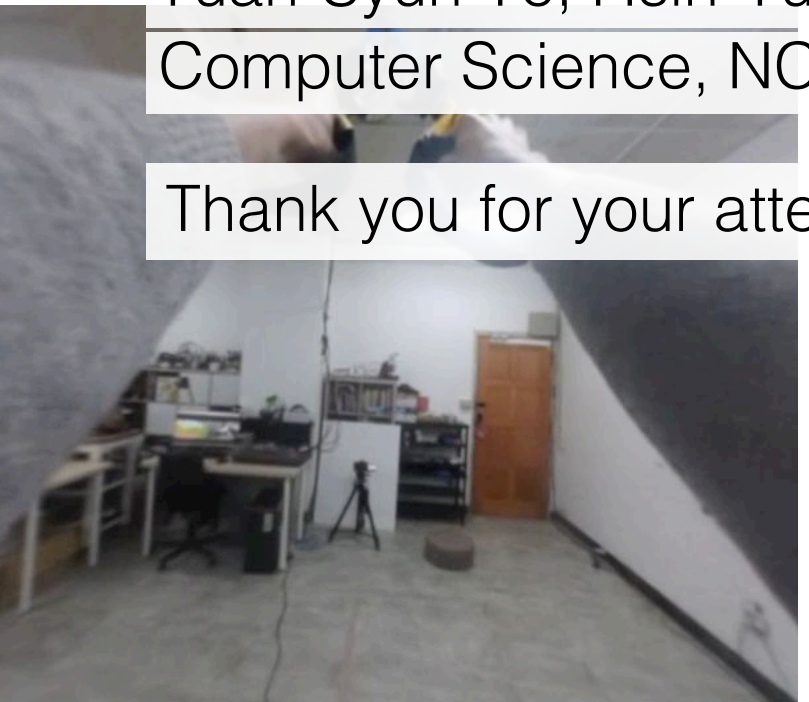




Pull-Ups:
Enhancing Body-Scale Physical Activities with Force-Motion Feedbacks for Virtual Reality

Yuan-Syun Ye, Hsin-Yu Chen, Liwei Chan
Computer Science, NCTU, Taiwan

Thank you for your attention



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