Implementation and Assessment of an Augmented Surgical Training Curriculum with a *daVinci* robot: an experimental study

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Context

Robot-assisted interventions:

- Wrist dexterity
- Hand-eye coordination
- Motion stability

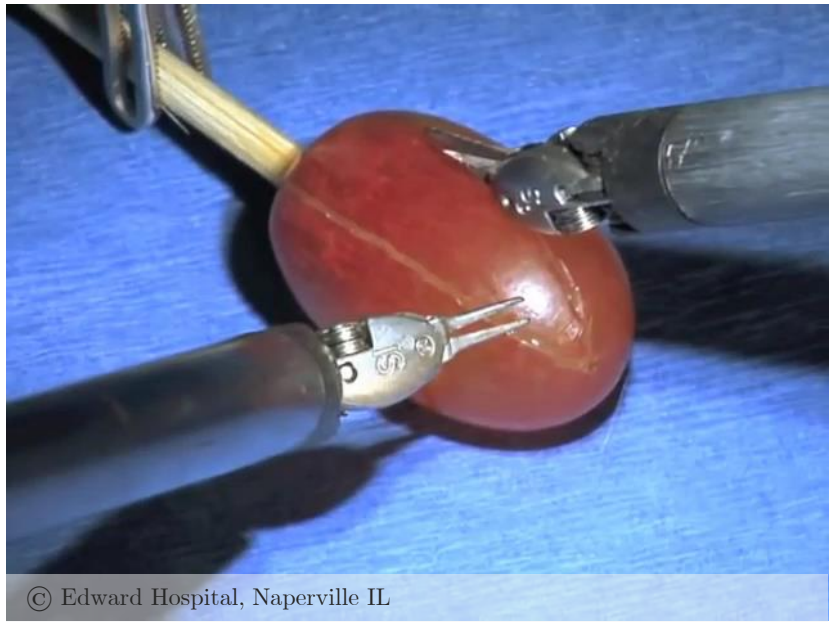
13 million yearly laparoscopic procedures

→ Only 4% is robot-assisted

→ Necessity for trained surgeons

Market increase by 2026: +**21%**

Surgical Robotics Training programs for establishing **comprehensive** and **robust** skillsets in aspiring surgeons



Virtual Reality Simulators

Before:

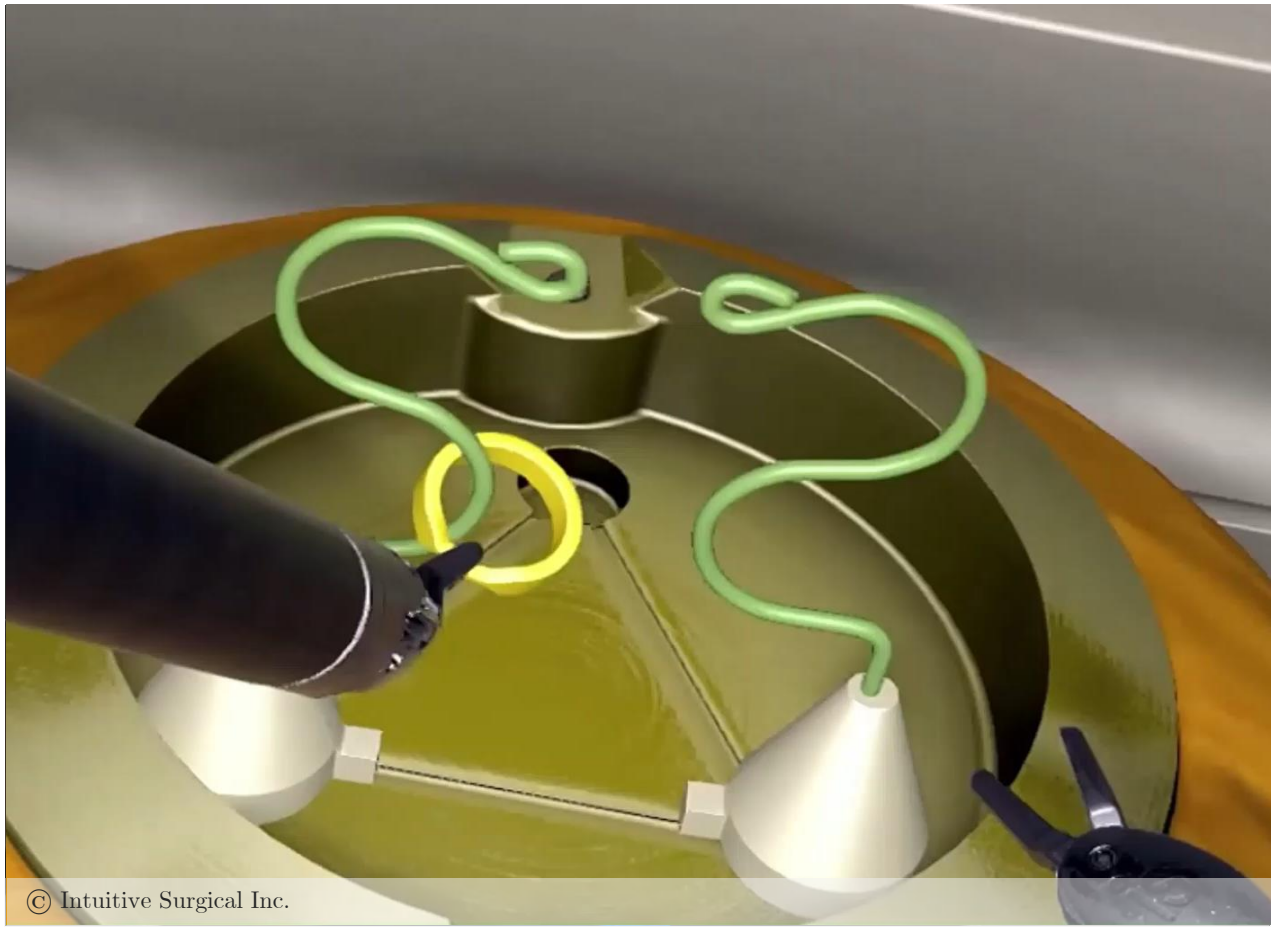
- Dry-lab phantoms
- Animal models

Nowadays:

- **Simulated Environments**

Infinite repetitions
Customizability
$ Low costs
Progress tracking

Performance in VR simulators is **correlated to clinical performance**[1]



State of the Art

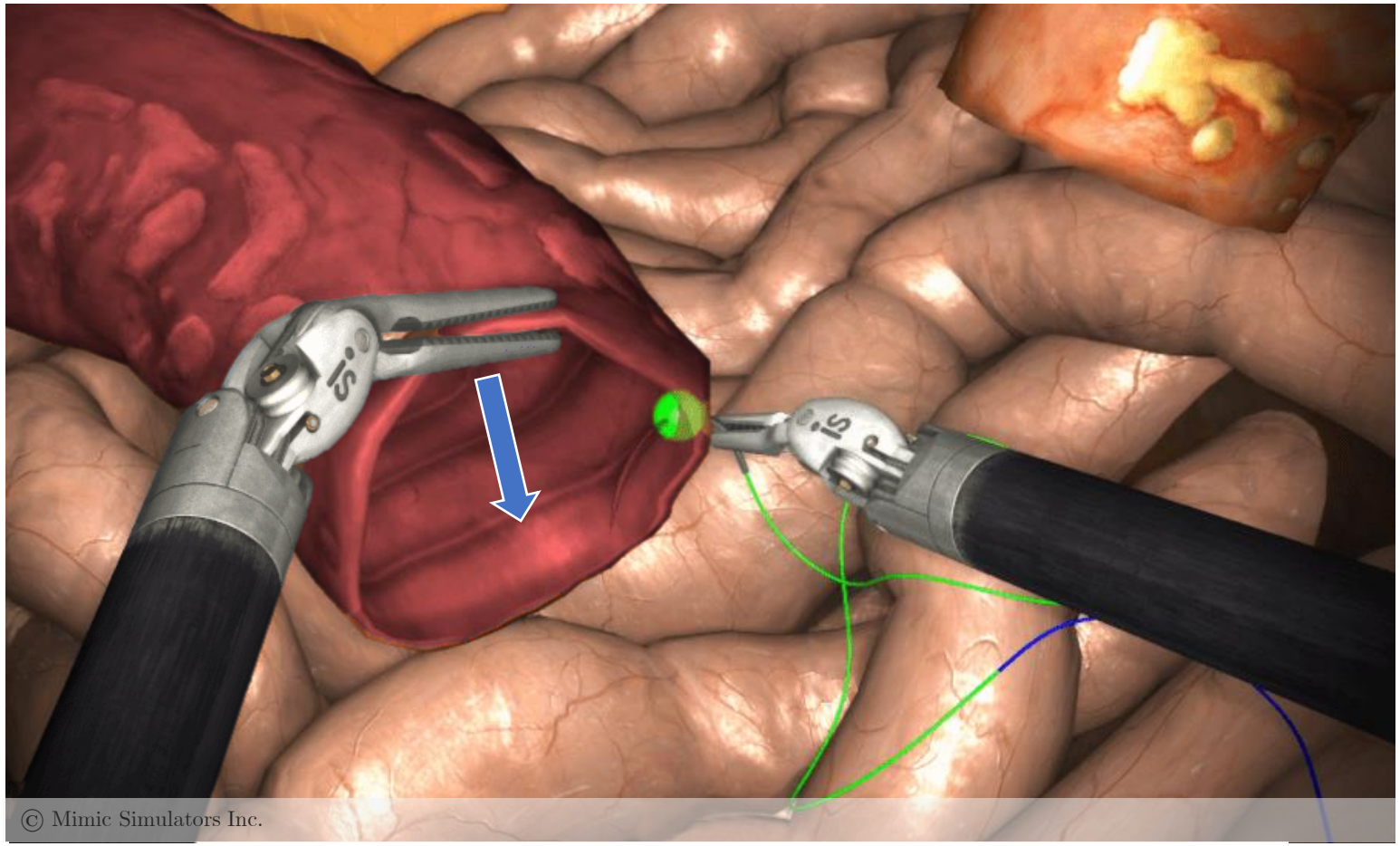
Commercial Solutions: examples

daVinci SimNow – Intuitive Inc.

Mimic dV-Trainer: Mimic Inc.

Requirements

1. Error identification
2. Computation of a desired position
3. Repositioning cues



Objectives

1 Develop a surgical simulator featuring **assistance strategies**

- Visual Assistance
- **Haptic assistance**

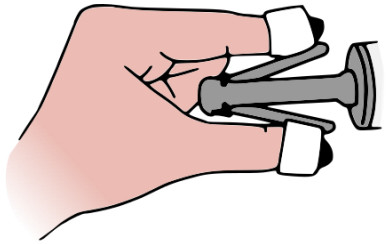
2 Validate the simulator in a **clinical context**

→ **Istituto Europeo di Oncologia**

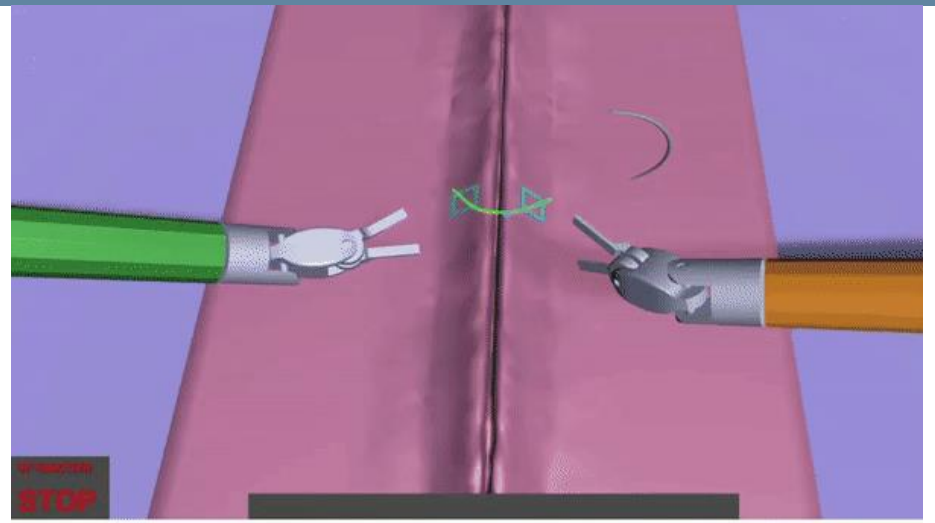
3 **Experimental phase**

- **Improved performance**
- **Skill transfer**

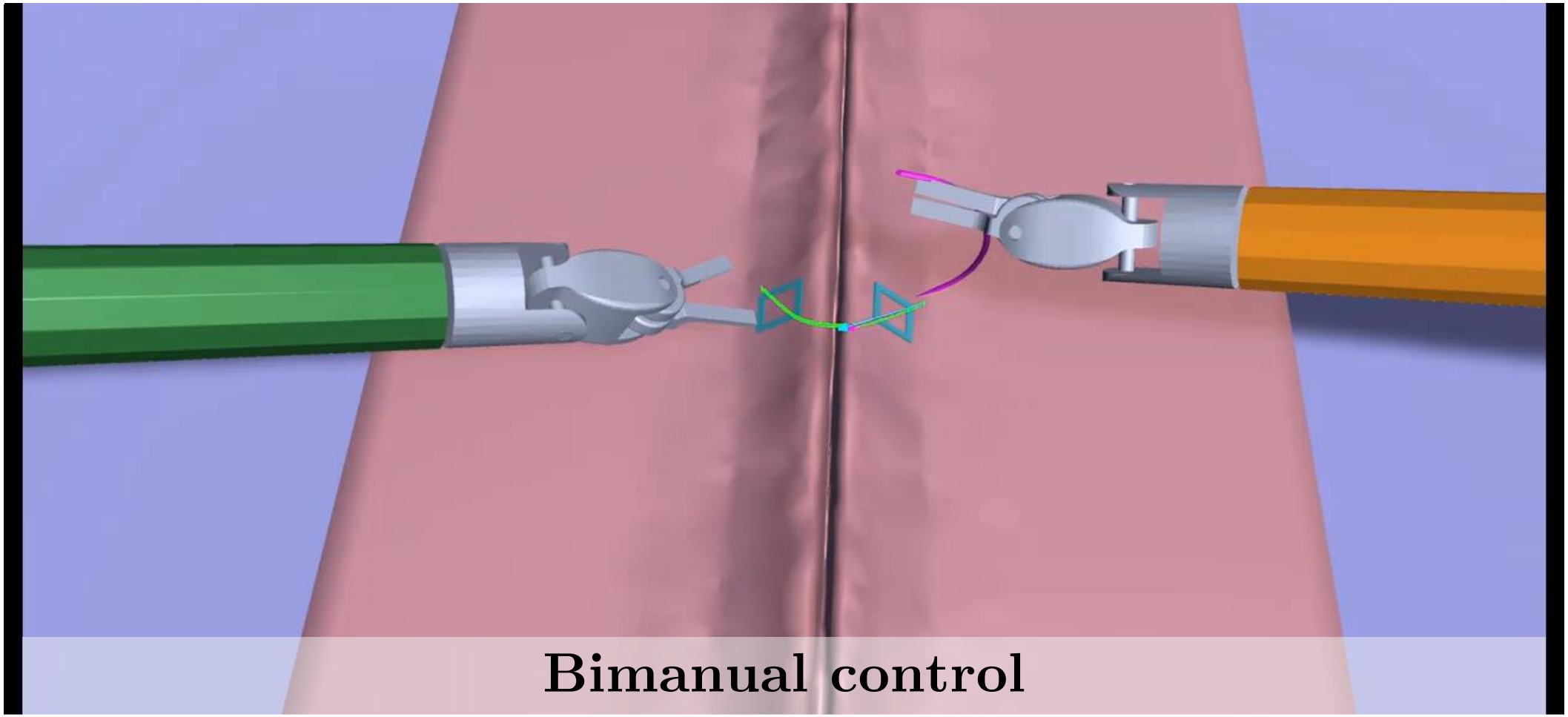
The Surgical Simulator



Teleoperation commands

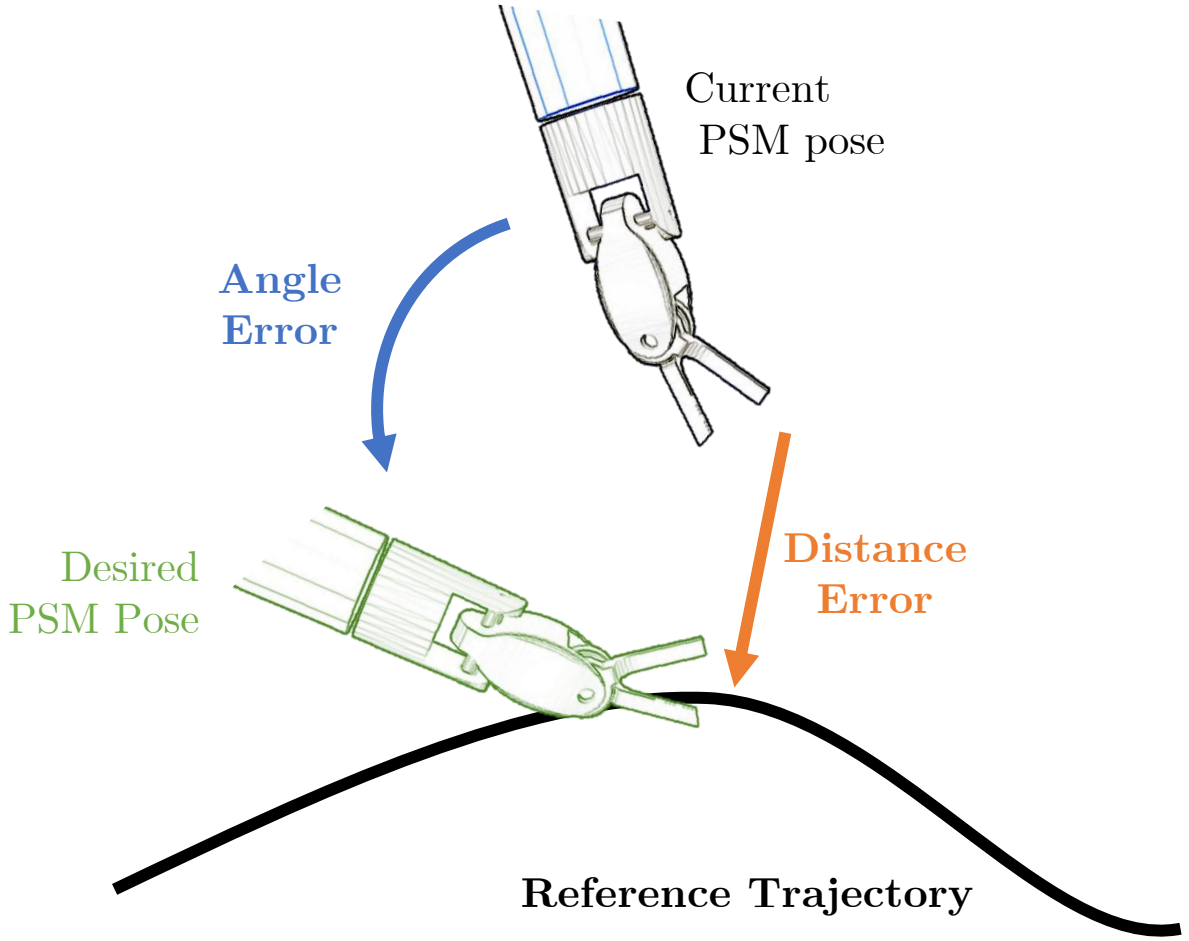


The Surgical Tasks

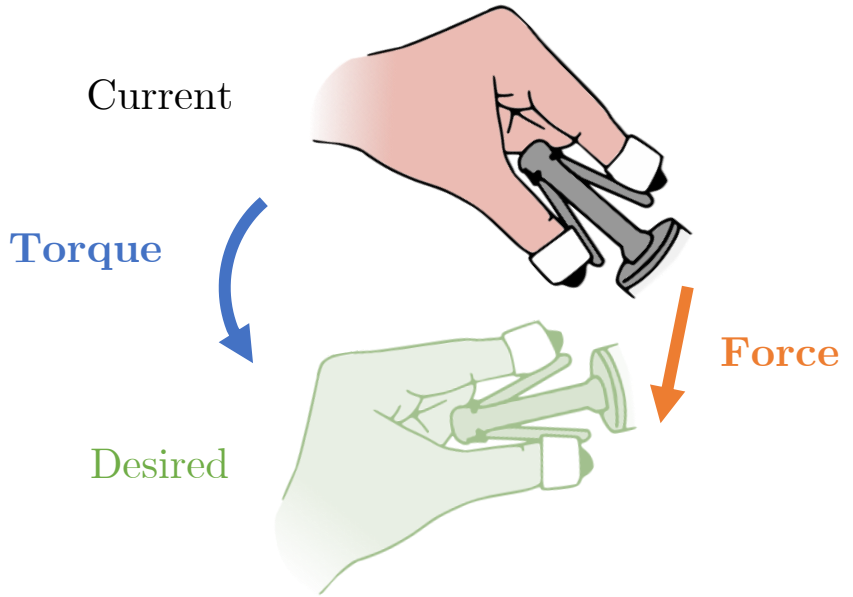


Bimanual control

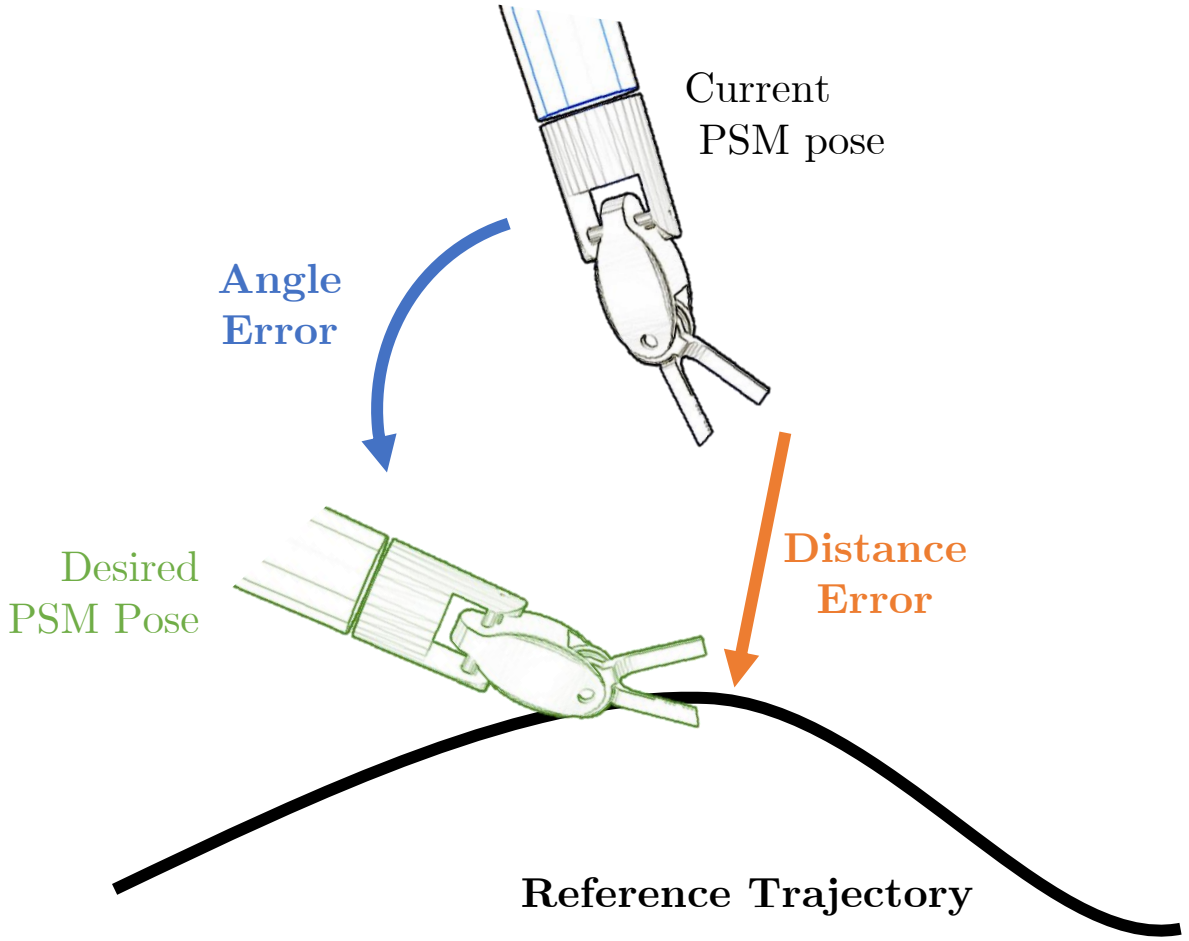
Haptic Assistance



Hand-Wrist Configurations



Haptic Assistance



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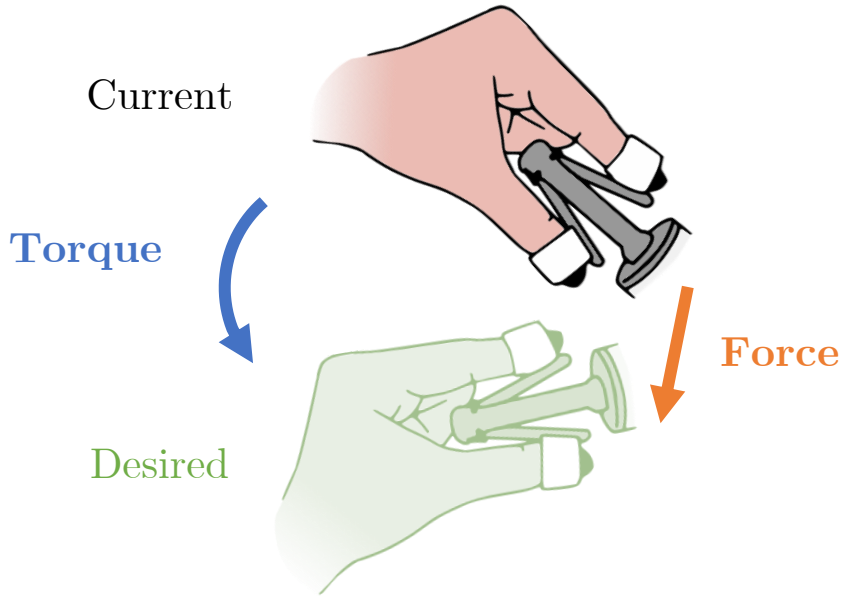
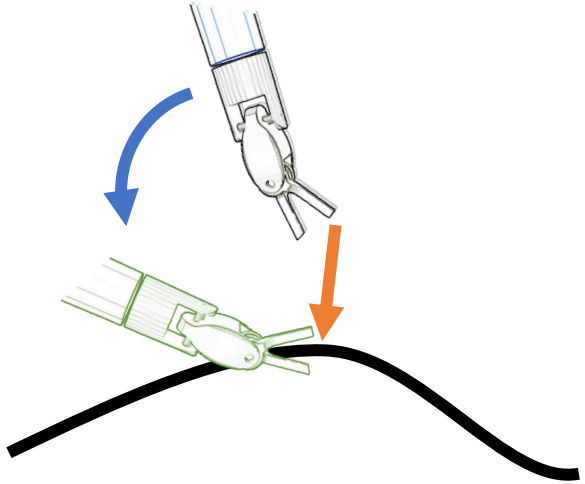
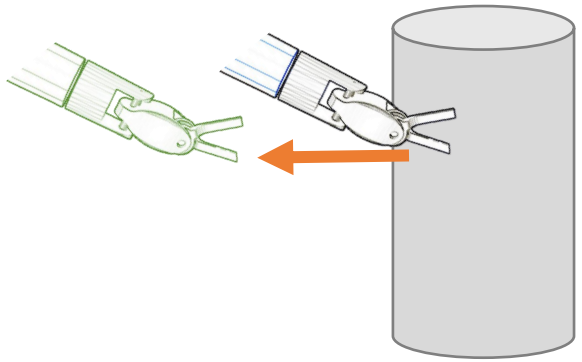


Haptic Assistance

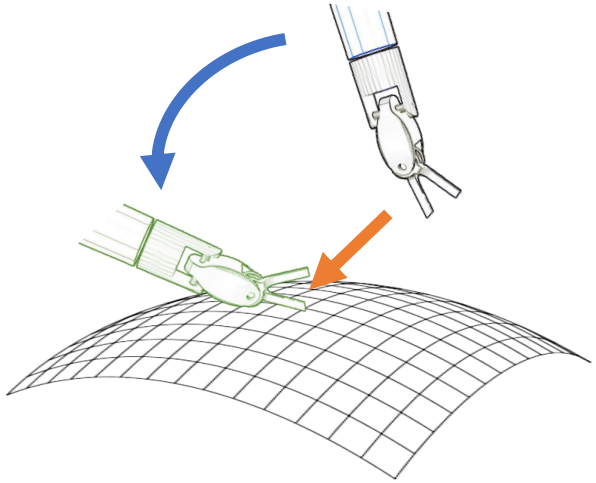
Trajectory **Guidance**



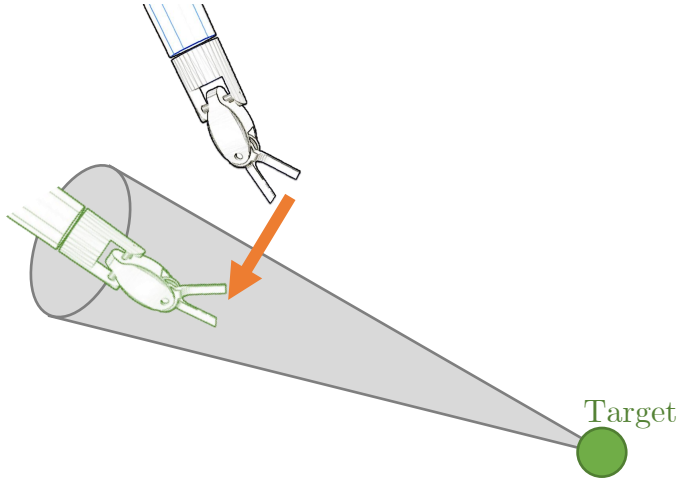
Obstacle **Avoidance**



Surface **Guidance**



Insertion **Guidance**



Clinical and Experimental Validation

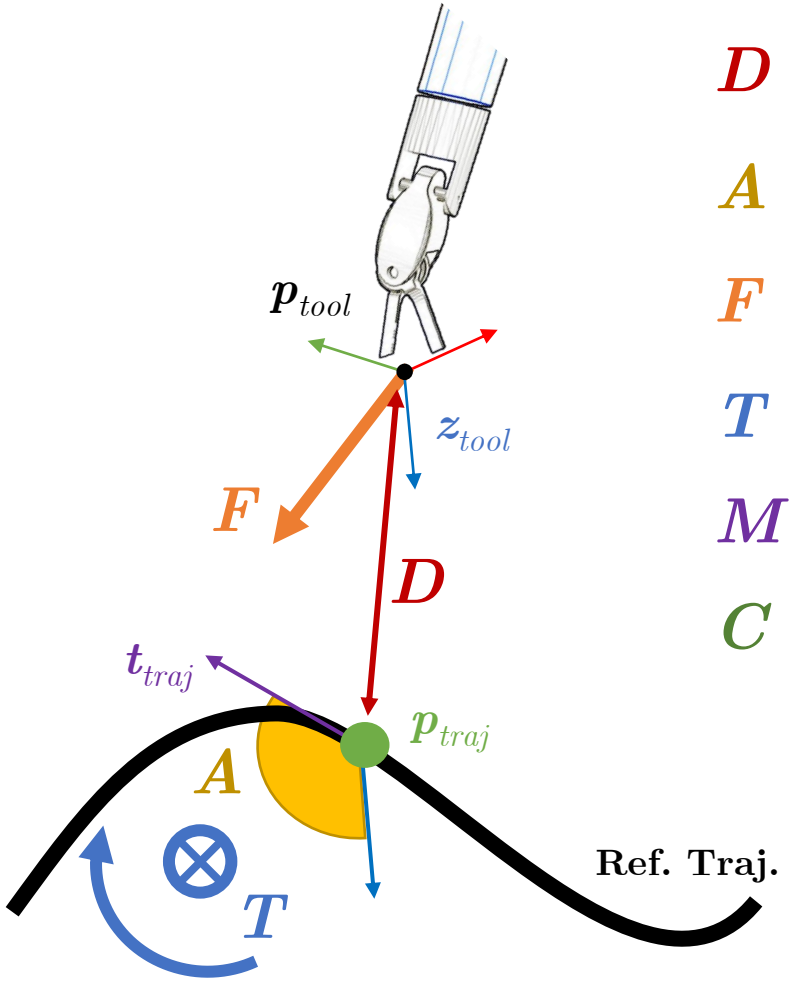
IEO Istituto Europeo di Oncologia

	Day 1	Day 2 to Day 4	Day 5 and 6	Day 7
Control Group	Playground & **Training**	**Training**	Break	**Evaluation**
Assisted Group	Playground & **Training**	**Training**	Break	**Evaluation**

= With assistance = Without assistance

Skill Retention **Skill Transfer**

Performance Metrics



$D = |p_{tool} - p_{traj}|$ Distance Error $[mm]$

$A = \text{acos}(z_{tool} \cdot t_{traj})$ Angular Error $[rad]$

$F = f(D, v, K, \eta)$ Force Feedback magnitude $[N]$

$T = f(A, \omega, K, \eta)$ Torque Feedback magnitude $[Nm]$

M Number of drops when exchanging an instrument $[adim]$

C Fraction of time spent repositioning $[adim]$

Quantitative indices of **performance** P

Performance

Absolute Metrics: $X \in \{D,\ A,\ F,\ T,\ M,\ C\}$ ➡ Non comparable

Relative metrics: $\hat{X} = \dfrac{X_{subject}}{X_{expert}}$ $[adim.]$ ➡ **Comparable**

The **quantitative performance score** $\boldsymbol{P}$ is the weighted average of the metrics

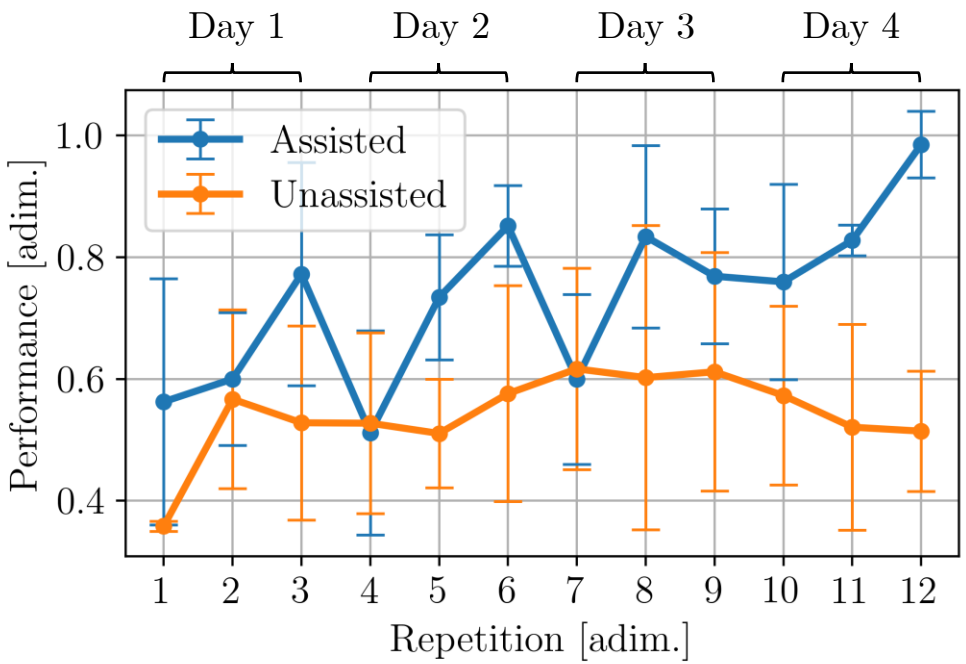
Weights: $w \in \{w_D,\ w_A,\ w_F,\ w_T,\ w_M,\ w_C\}$

Task	w_D	w_A	w_F	w_T	w_M	w_C
Thymectomy	**5**	0	4	0	0	1
Suturing	2	**3**	1	2	1	1

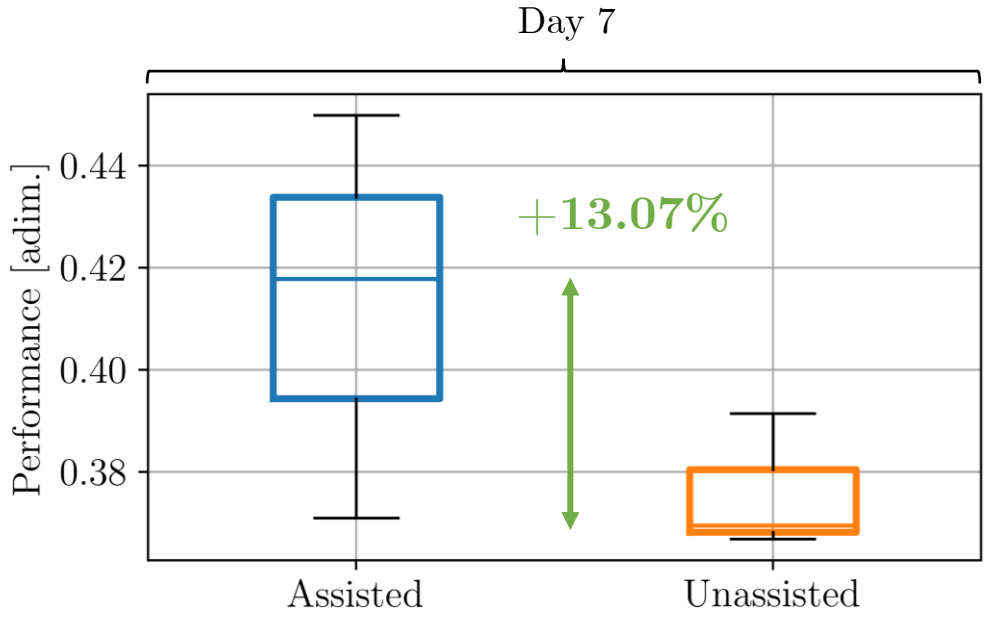
Performance $[adim.]$

$$\boldsymbol{P} = \frac{1}{10}\sum_{k=1}^{k=6} w_k \cdot \hat{X}_k$$

Results



Assisted subjects execute tasks with a **consistently better performance**



Assisted subjects experienced an **improved skill transfer** towards non-assisted executions

Conclusions

- Developed a **surgical training simulator** featuring **assistance strategies**
- Achieved **validation** in a clinical context

Assistance strategies for surgical training curricula yield:

- **Increase in performance**
- **Improvements in skill transfer**

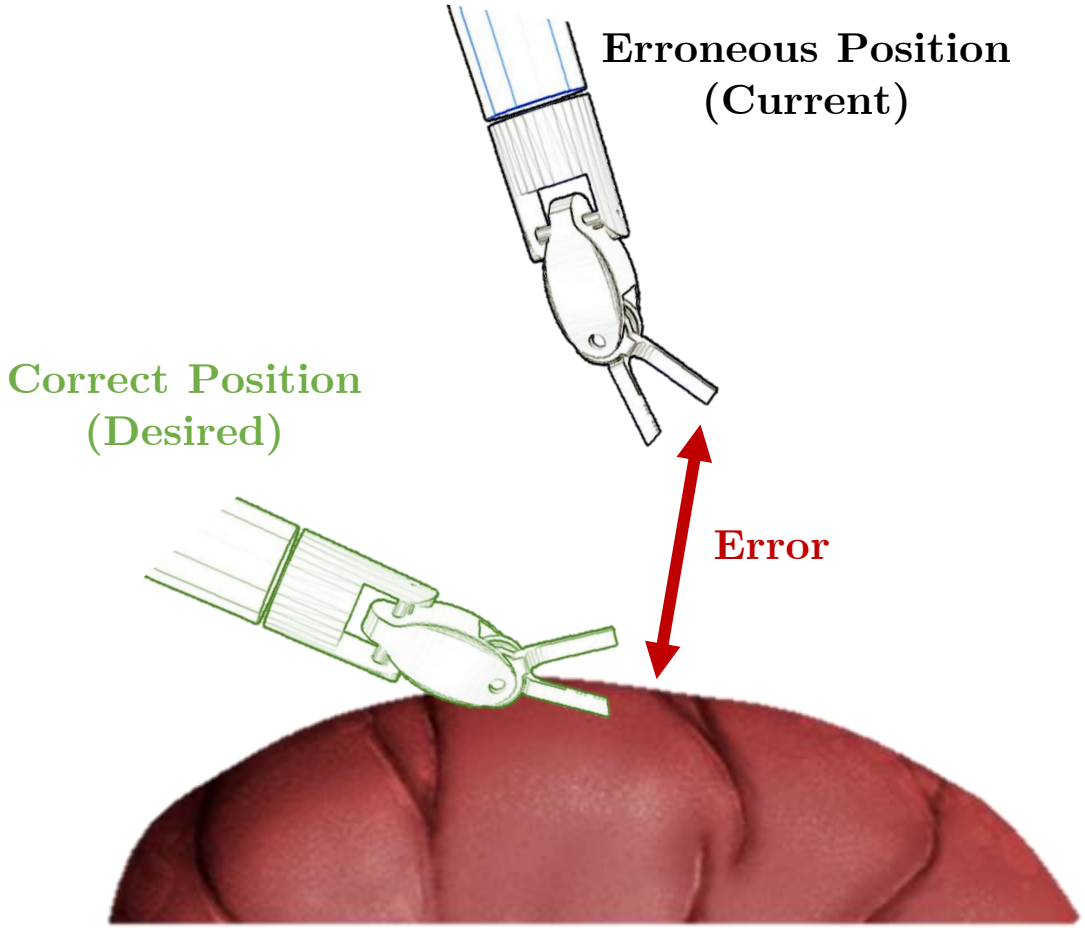
Future Developments:

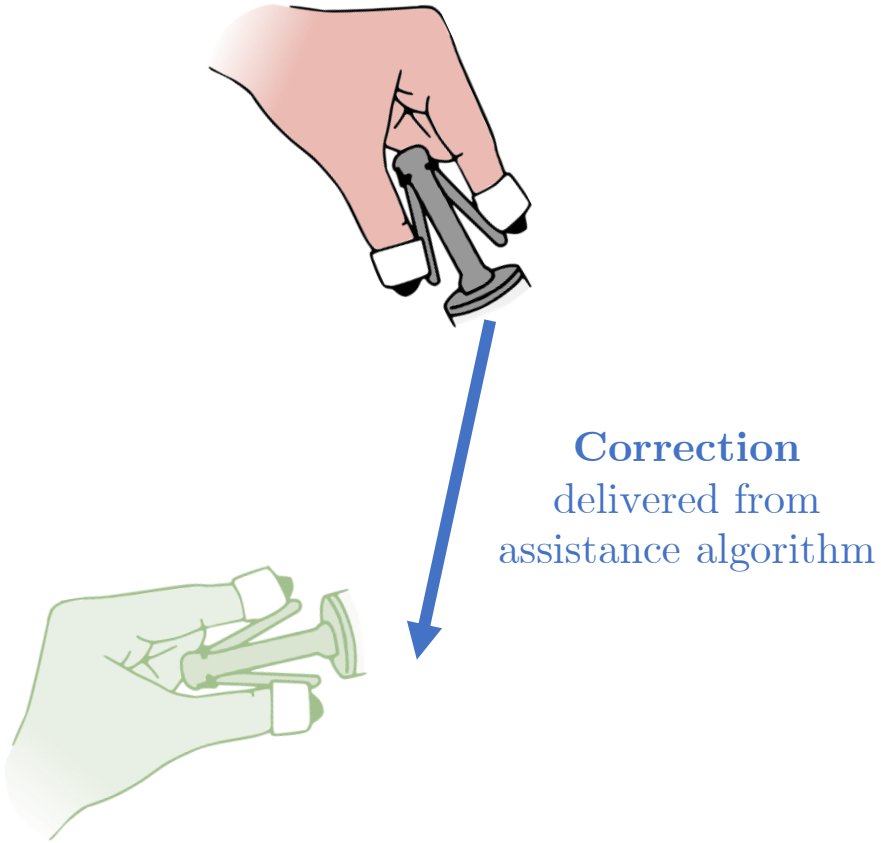
- **Adaptivity** of assistance level and task difficulty
- Extend and improve performance metrics

POLITECNICO
MILANO 1863

Thank you

Haptic Assistance





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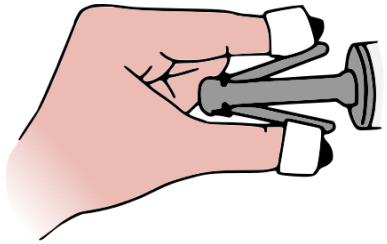

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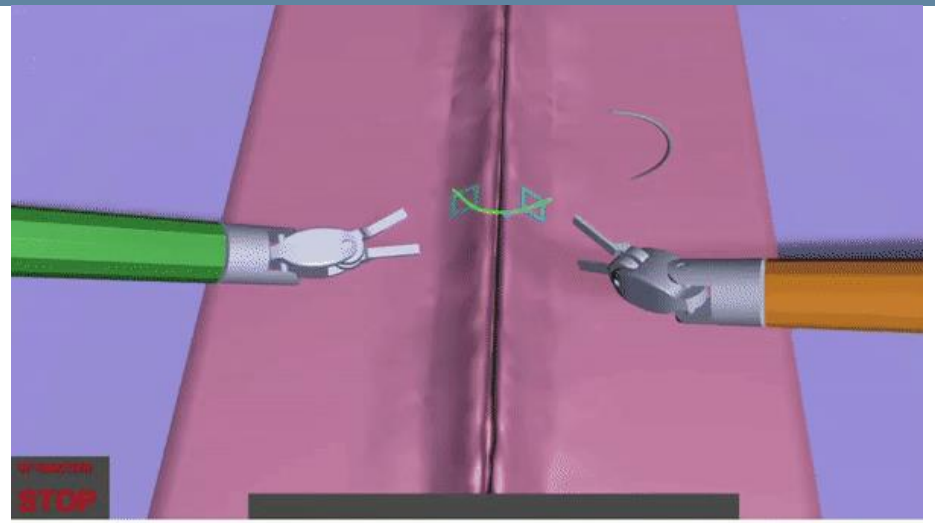

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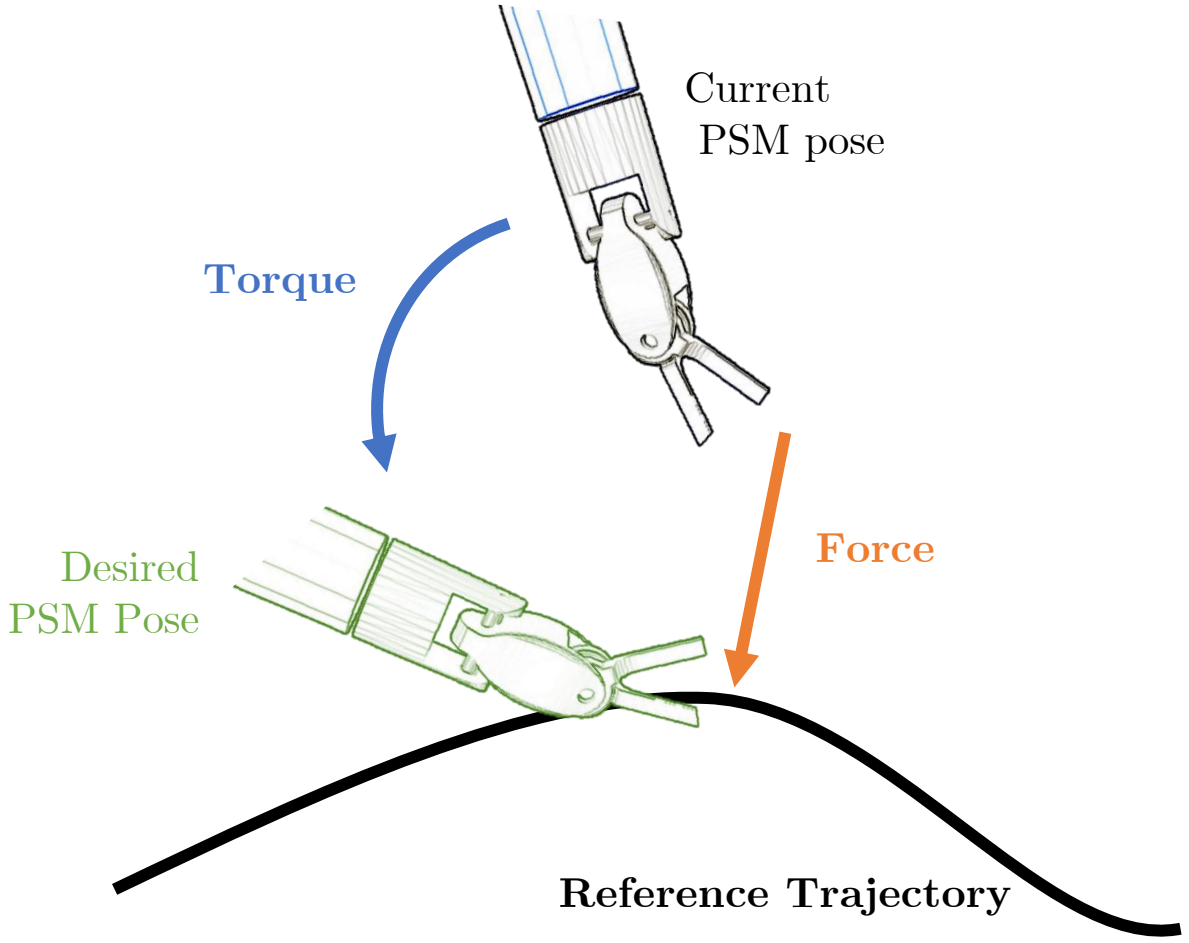

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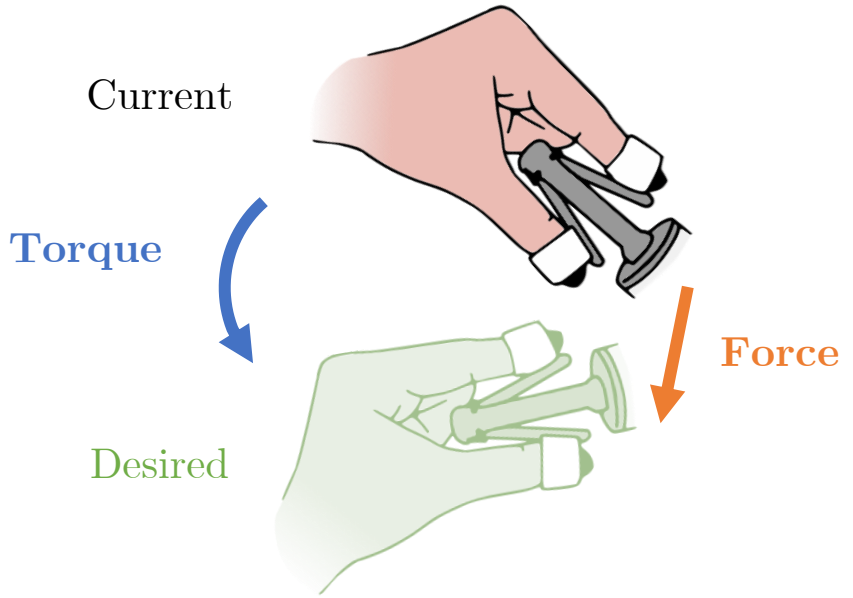
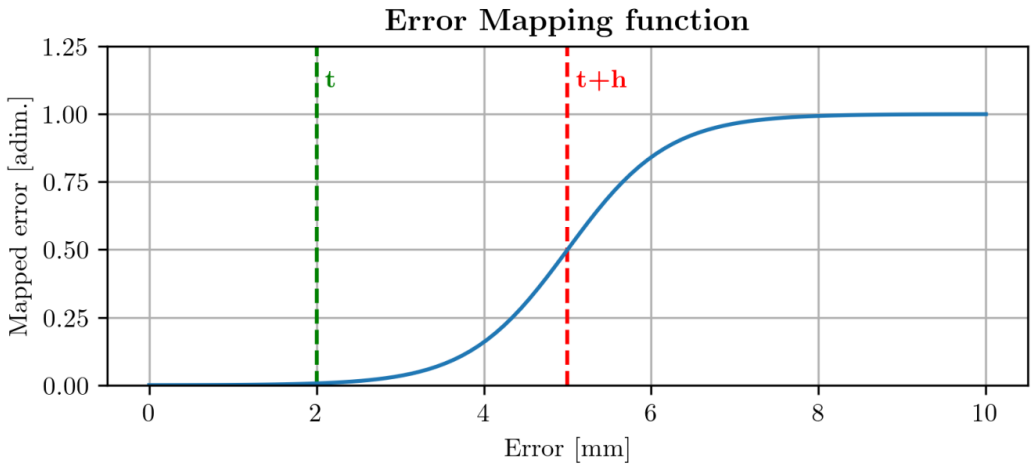


Error Mapping

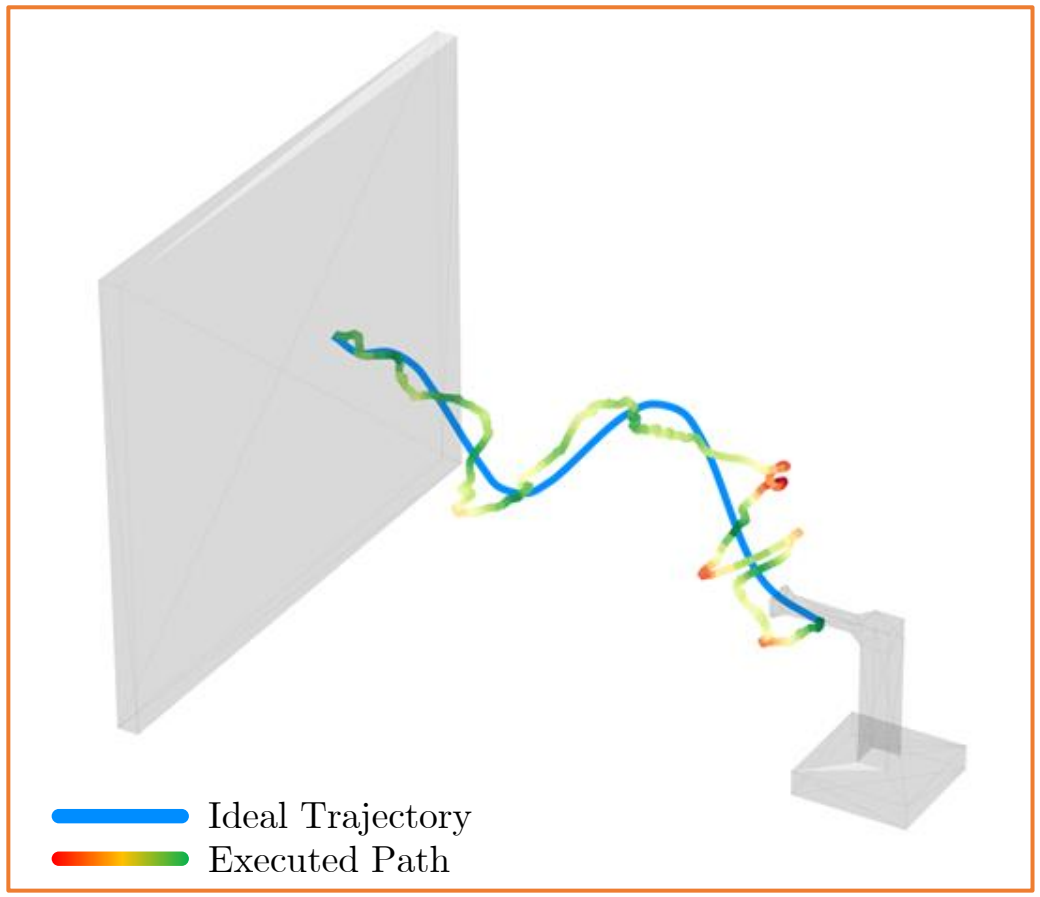
$$f_{map}(x) = \frac{1}{1 + e^{5\delta w(x-t-h)}}$$



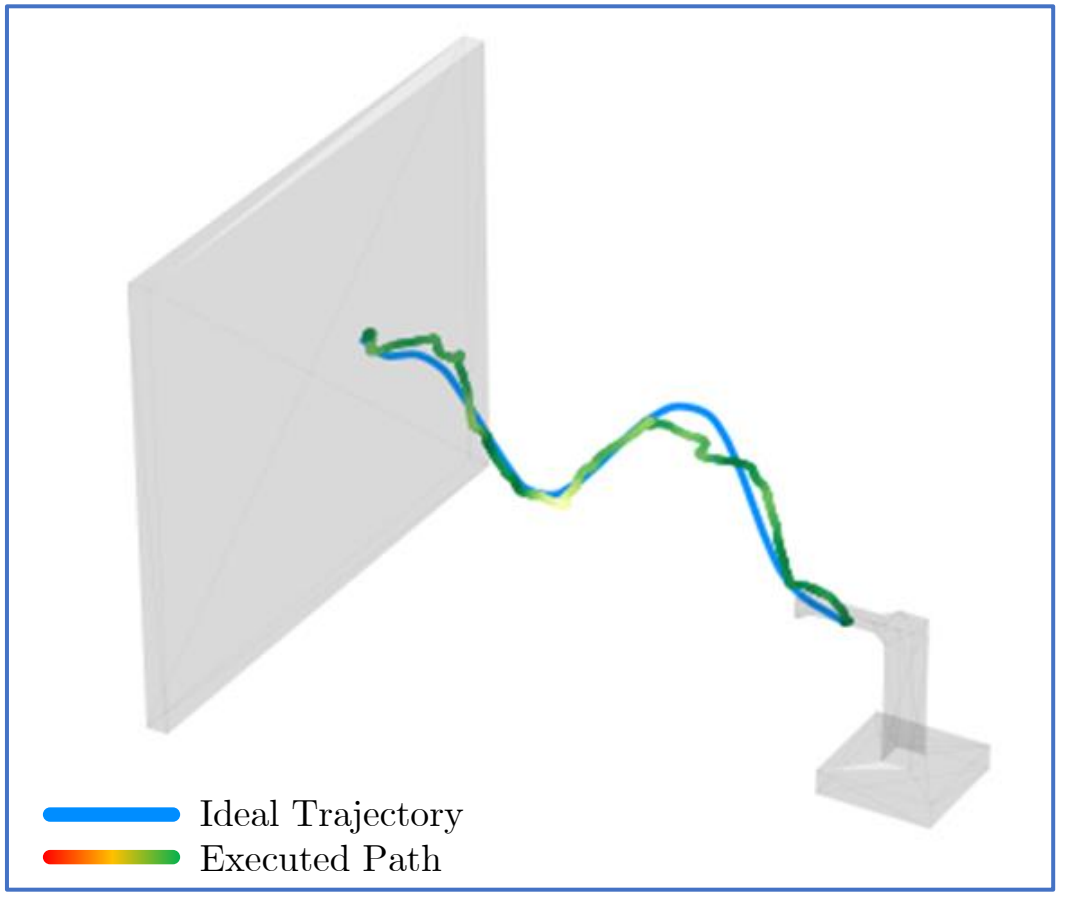
Task	t	h	w
Path	2 mm	2 mm	500
Rings	2 mm	2 mm	500
Pillars	0.5 mm	1 mm	1000
Exchange (distance)	3 mm	2 mm	500
Exchange (angular)	5°	5°	2
Thymectomy	0.5 mm	1 mm	1000
Nephrectomy	2 mm	2 mm	500
Liver Resection (distance)	2 mm	5 mm	200
Liver Resection (angular)	5°	15°	1
Suturing (distance)	1 mm	3 mm	300
Suturing (angular)	5°	5°	2

Results

Unassisted Performance



Assisted Performance



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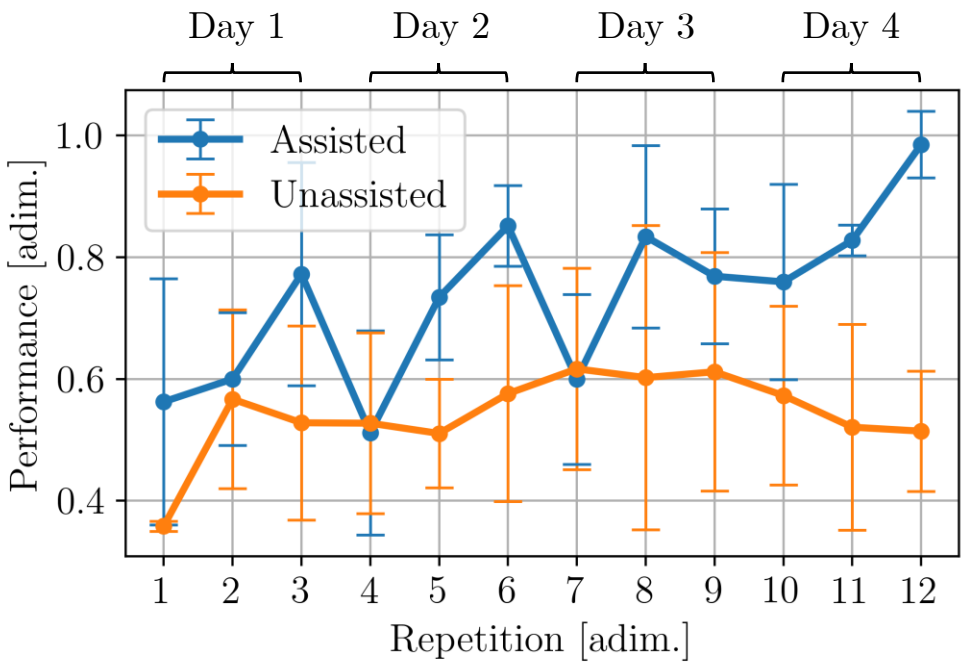

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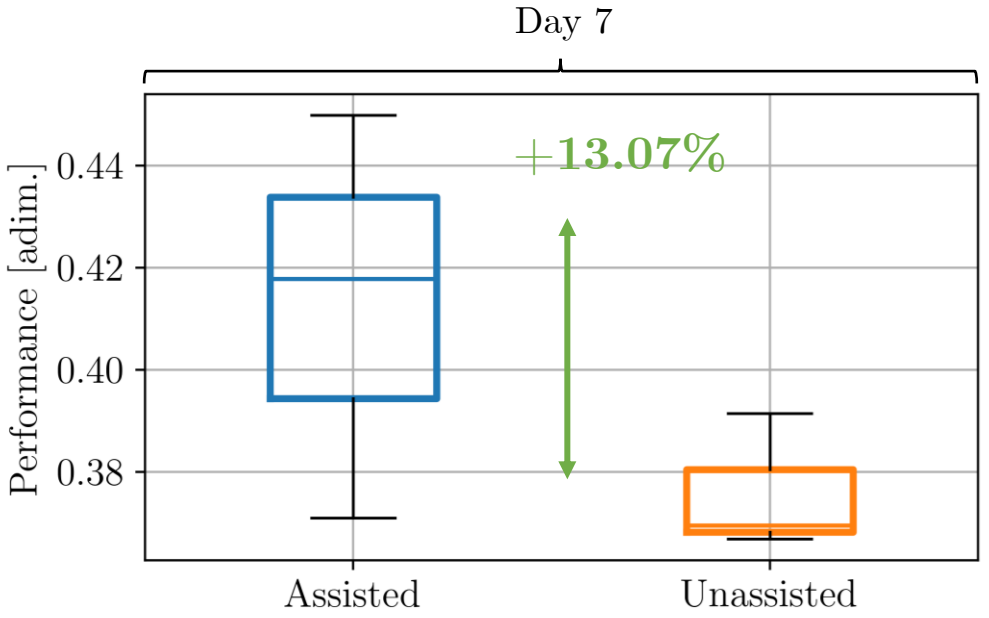
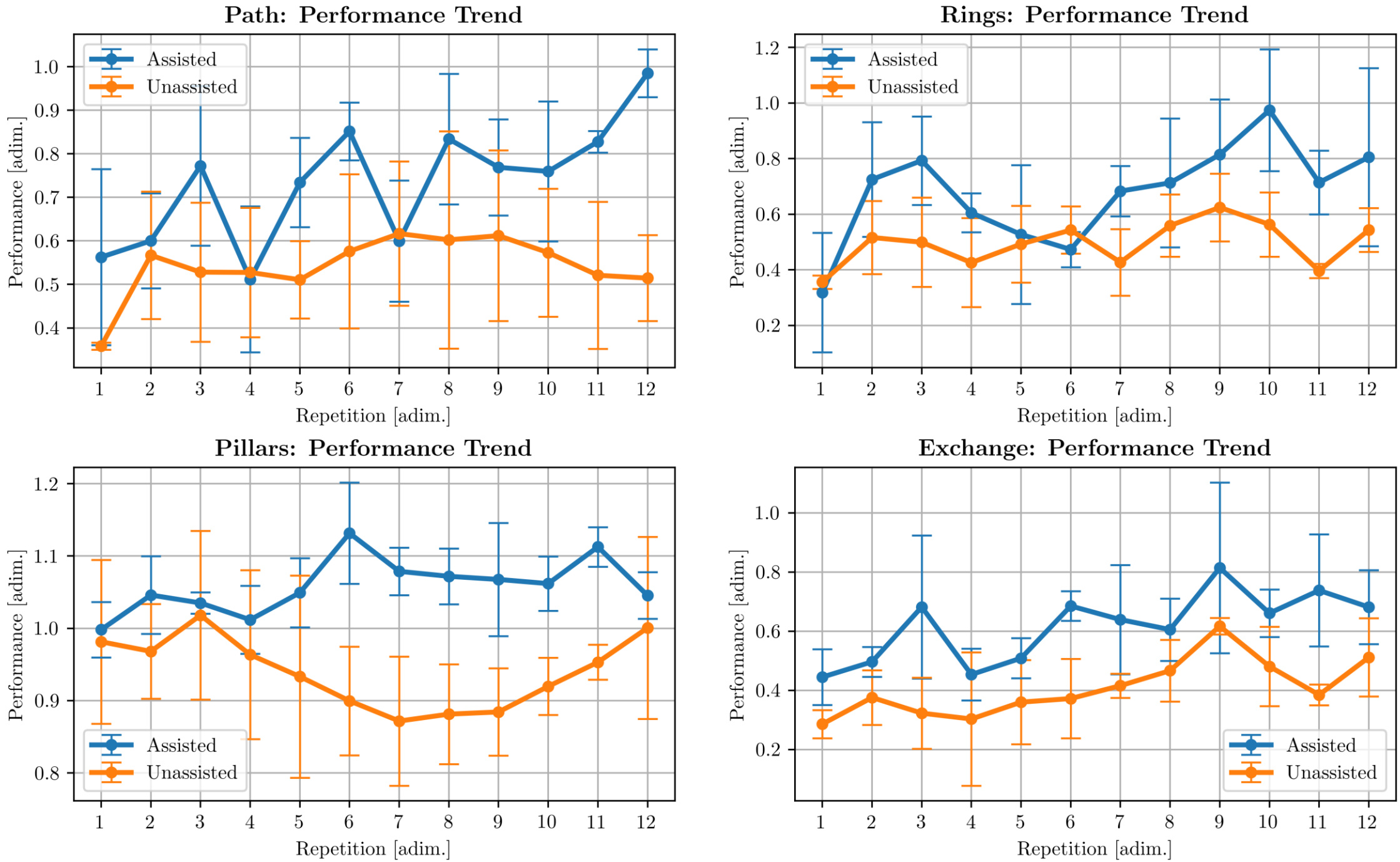
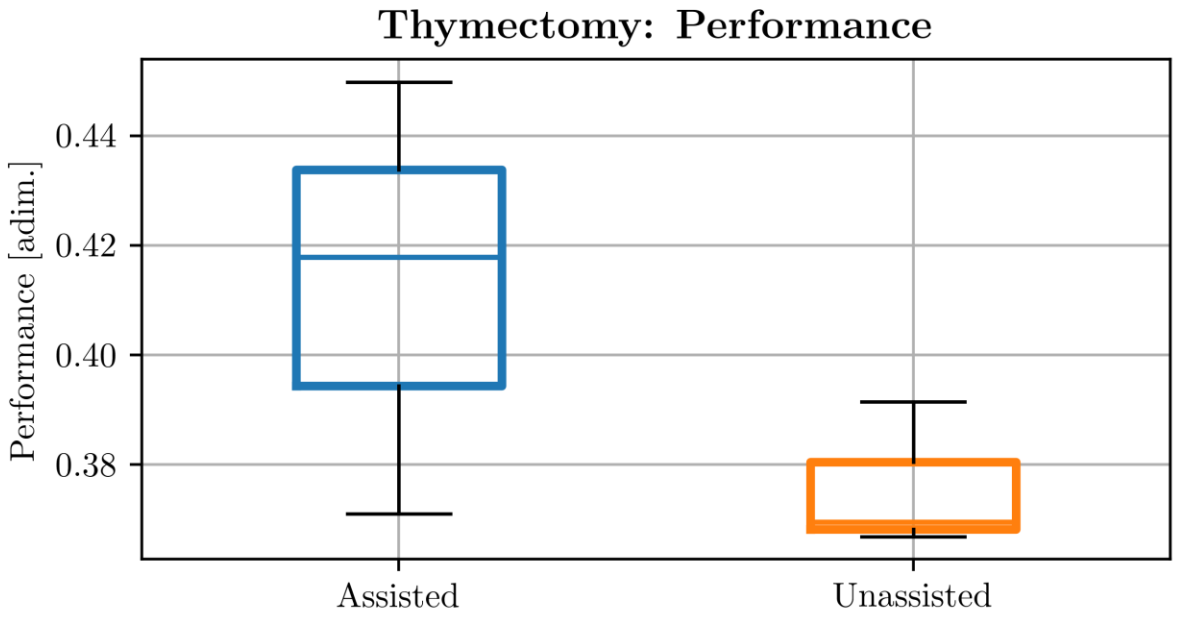
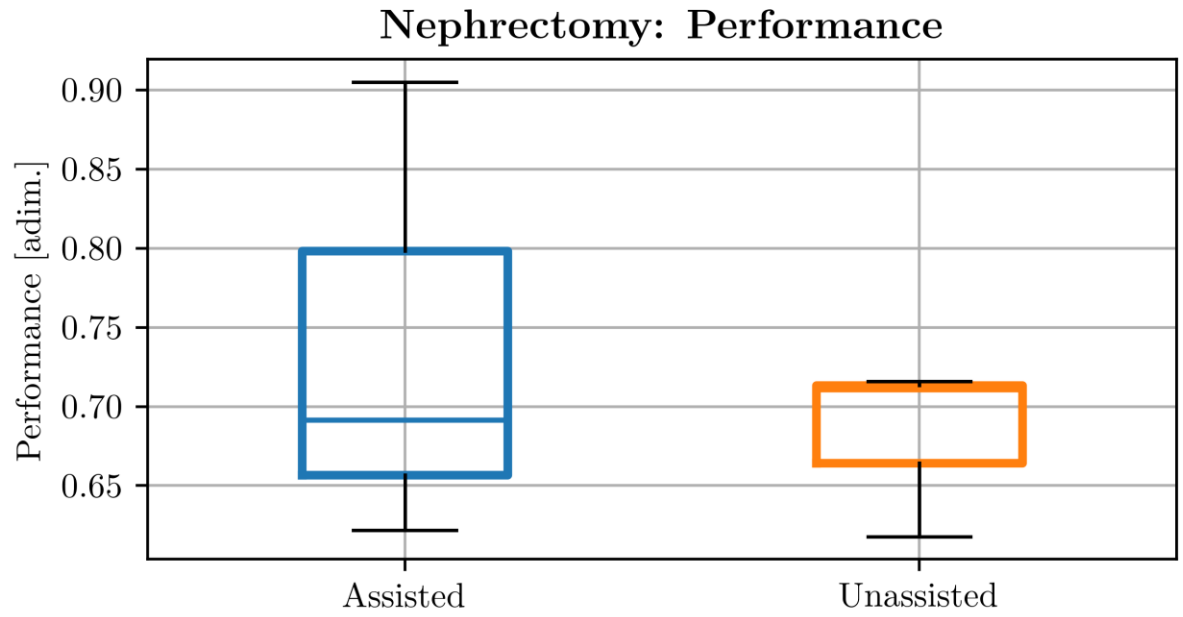
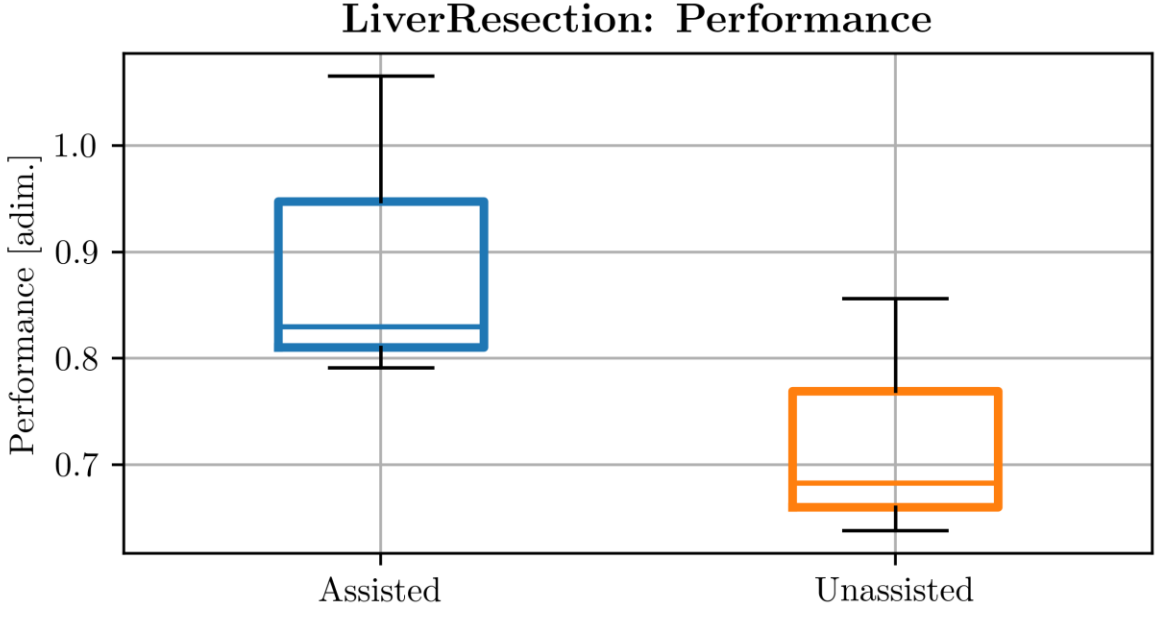


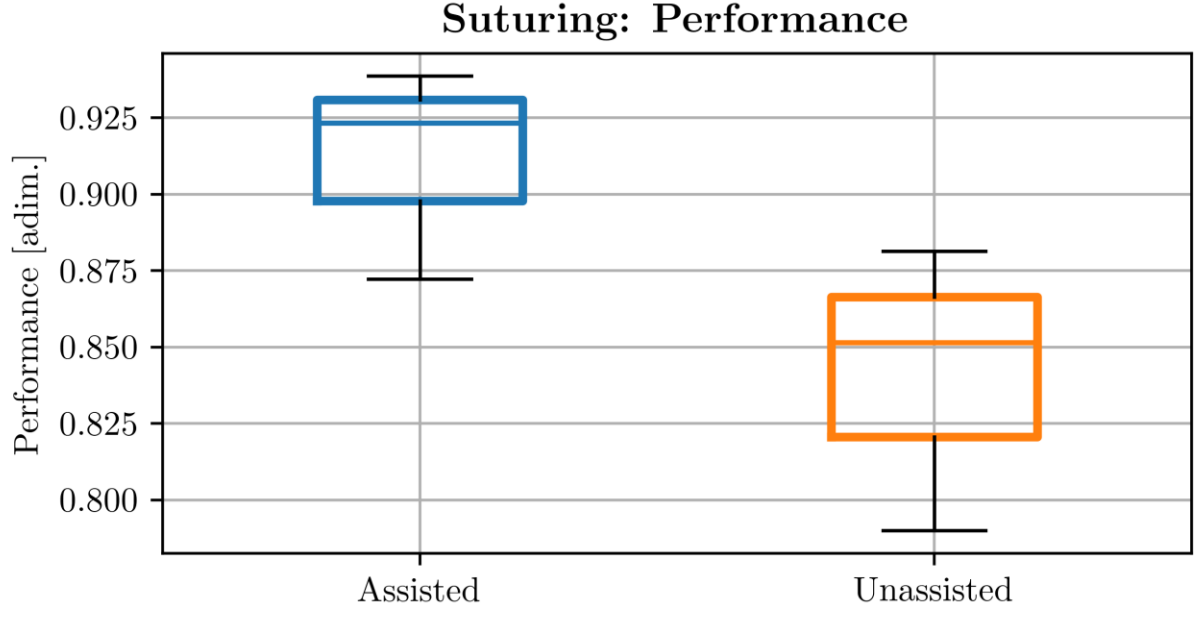
Assisted subjects experienced an **improved skill transfer** towards non-assisted executions


Path: Performance Trend
Rings: Performance Trend
Pillars: Performance Trend
Exchange: Performance Trend
Assisted
Unassisted
Performance [adim.]
Repetition [adim.]


Thymectomy: Performance
Performance [adim.]
0.44
0.42
0.40
0.38
Assisted
Unassisted


Nephrectomy: Performance
Performance [adim.]
0.90
0.85
0.80
0.75
0.70
0.65
Assisted
Unassisted


LiverResection: Performance
Performance [adim.]
1.0
0.9
0.8
0.7
Assisted
Unassisted


Suturing: Performance
Performance [adim.]
0.925
0.900
0.875
0.850
0.825
0.800
Assisted
Unassisted

Task	$w_{\hat{D}}$	$w_{\hat{A}}$	$w_{\hat{F}}$	$w_{\hat{T}}$	$w_{\hat{M}}$	$w_{\hat{C}}$
Path	3	2	3	1	0	1
Rings	5	0	4	0	0	1
Pillars	5	0	4	0	0	1
Exchange	2	2	2	1	2	1
Thymectomy	5	0	4	0	0	1
Nephrectomy	5	0	4	0	0	1
Liver Resection	3	2	3	1	0	1
Suturing	2	3	1	2	1	1

Path	*Trajectory Guidance*
Rings	*Insertion Guidance*
Pillars	*Obstacle Avoidance*
Exchange	*Trajectory Guidance*
Thymectomy	*Obstacle Avoidance*
Nephrectomy	*Insertion Guidance*
Liver Resection	*Surface Guidance*
Suturing	*Trajectory Guidance*