Advanced Human-Computer Interaction:
Tangible Interaction

Céline Coutrix
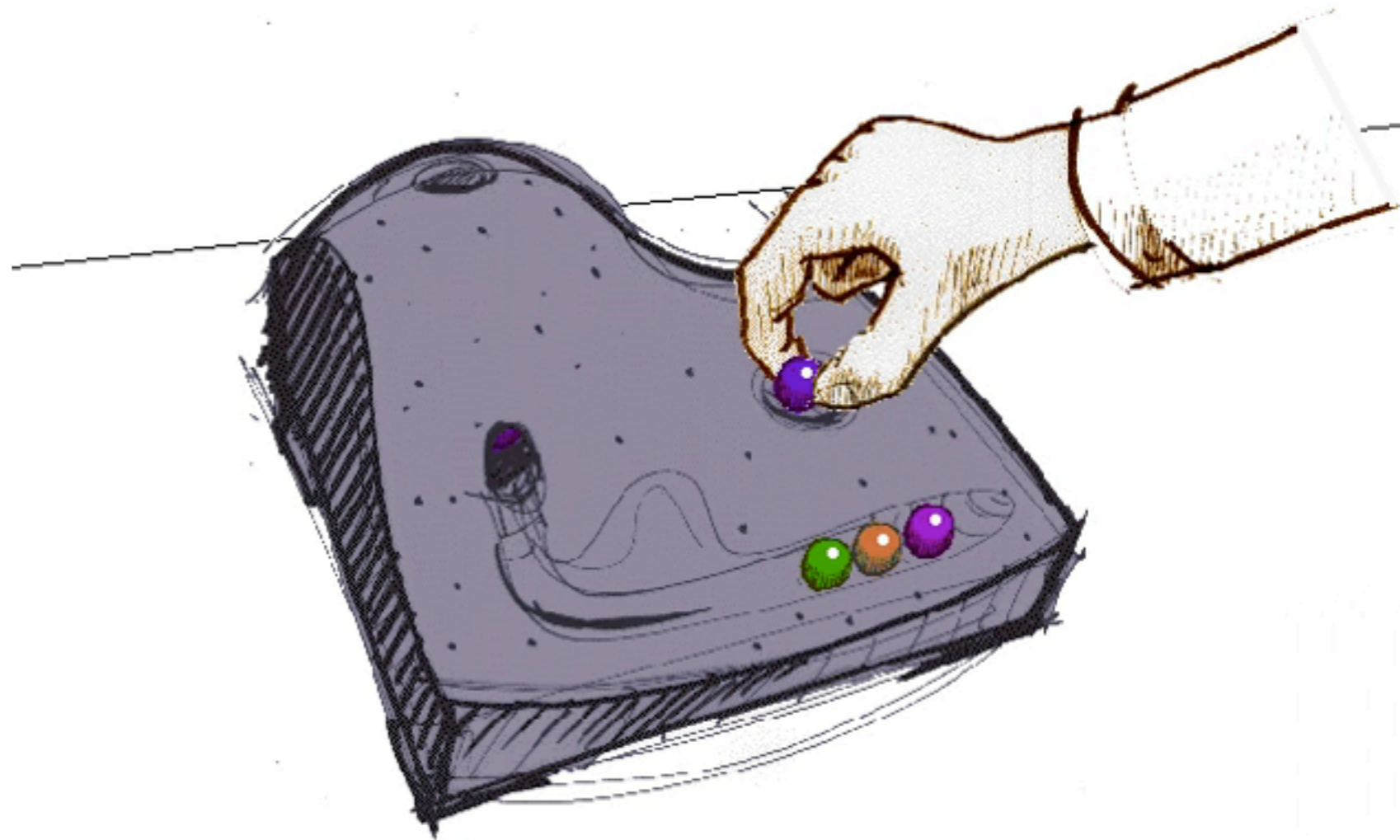http://iihm.imag.fr/coutrix/
Celine.Coutrix@imag.fr

Course objectives

- Answering basic questions, i.e.:

  - What are TUI?

  - What is their story?

  - What are they good for?

  - What are their limitations? + Research areas

- Building TUI

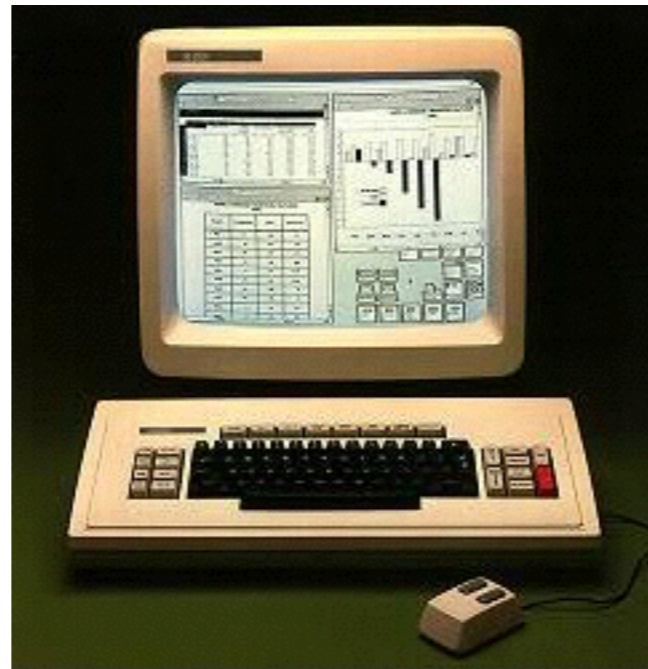# Tangible User Interfaces: What are they?

Tangible User Interfaces: What are they?

Interfaces involving physical objects
that can be grasped

Example:
Durell Bishop's
Answering Machine

Tangible User Interfaces: What are they?

Graphical User Interfaces
interfaces usually limited to std screen+keyboard+mouse

Tangible User Interfaces: What are they?

Virtual Reality Interfaces
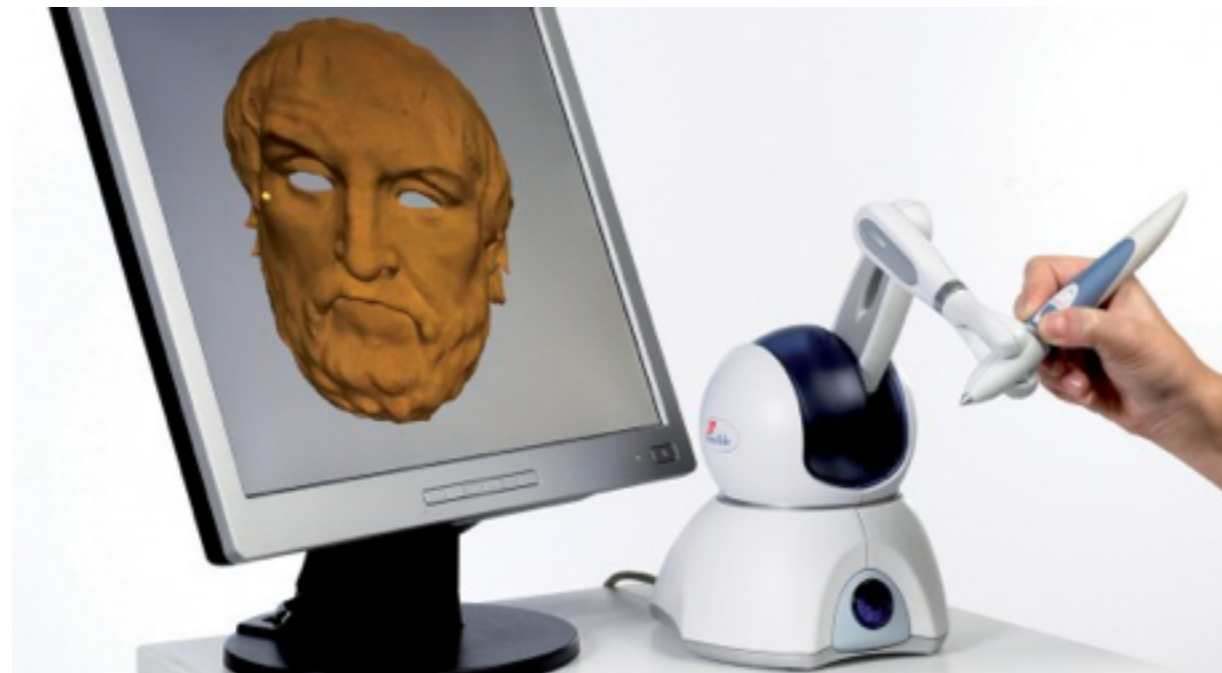interfaces to immerse the user in a digitally generated world

Tangible User Interfaces: What are they?

Augmented Reality (AR) and Augmented Virtuality (AV)
Tangible Interfaces belong to AR+AV

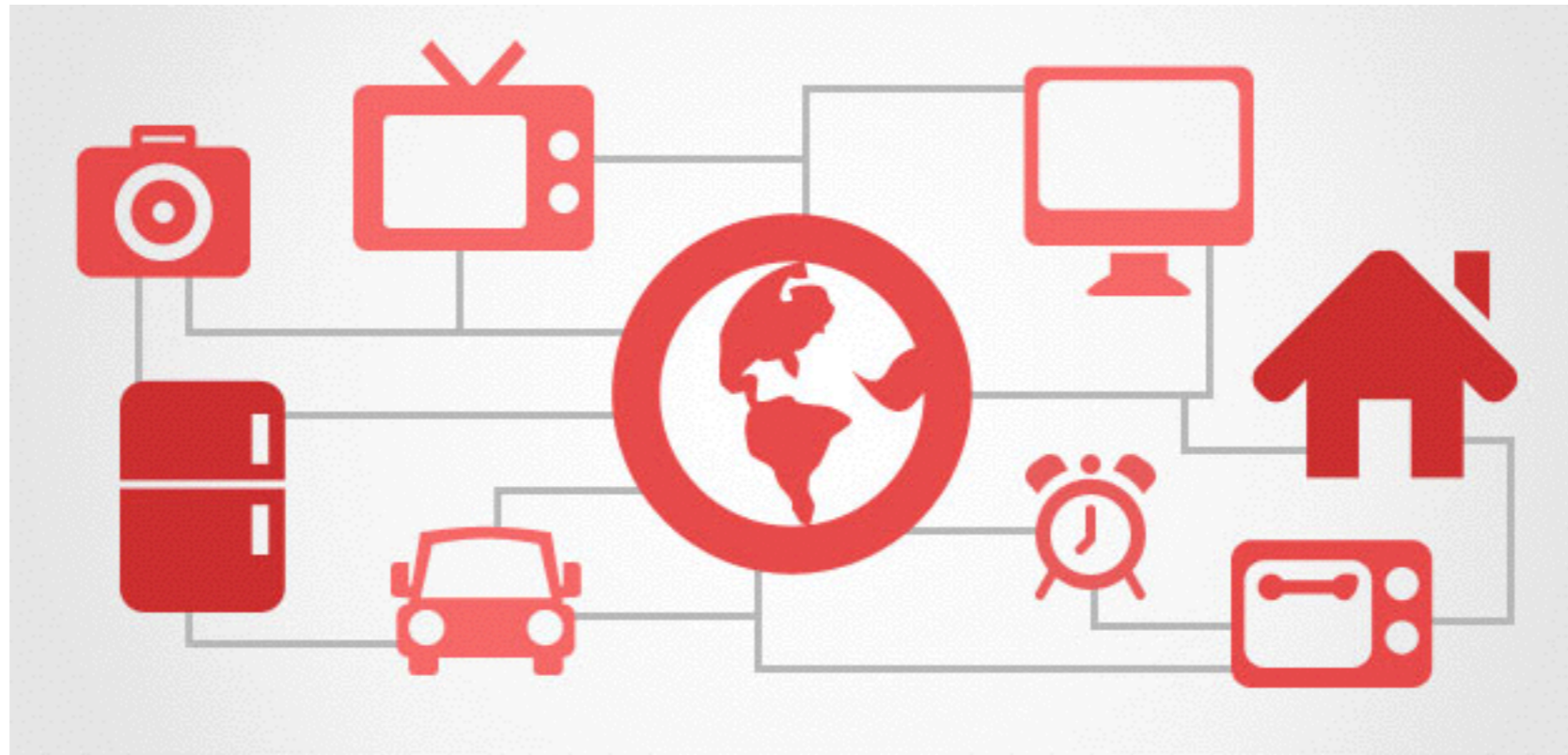# Tangible User Interfaces: What are they?

Haptic Interaction
Tangible Interfaces belong to Haptic:
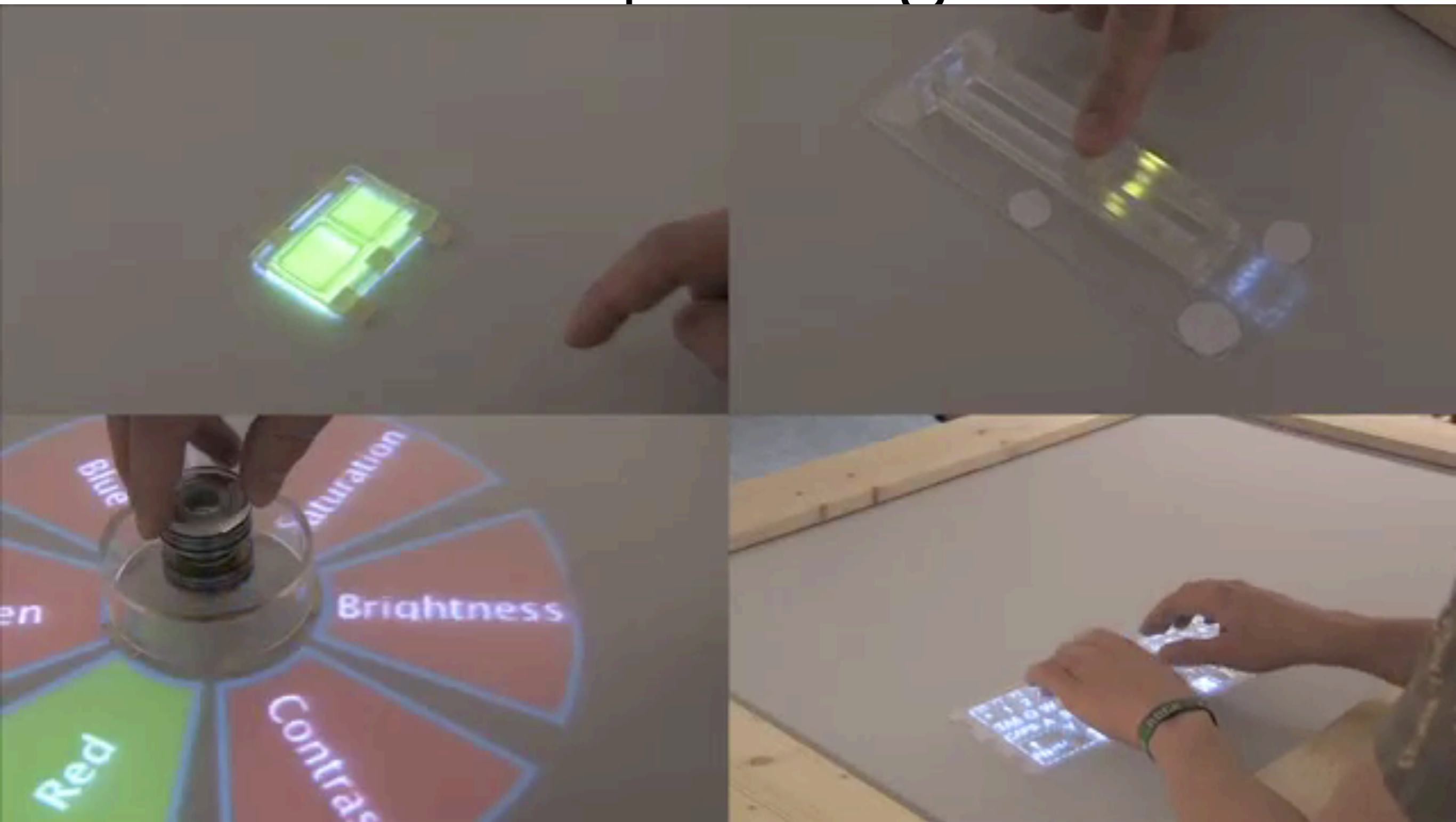Both involve touch and manipulation,
but haptic usually not passive

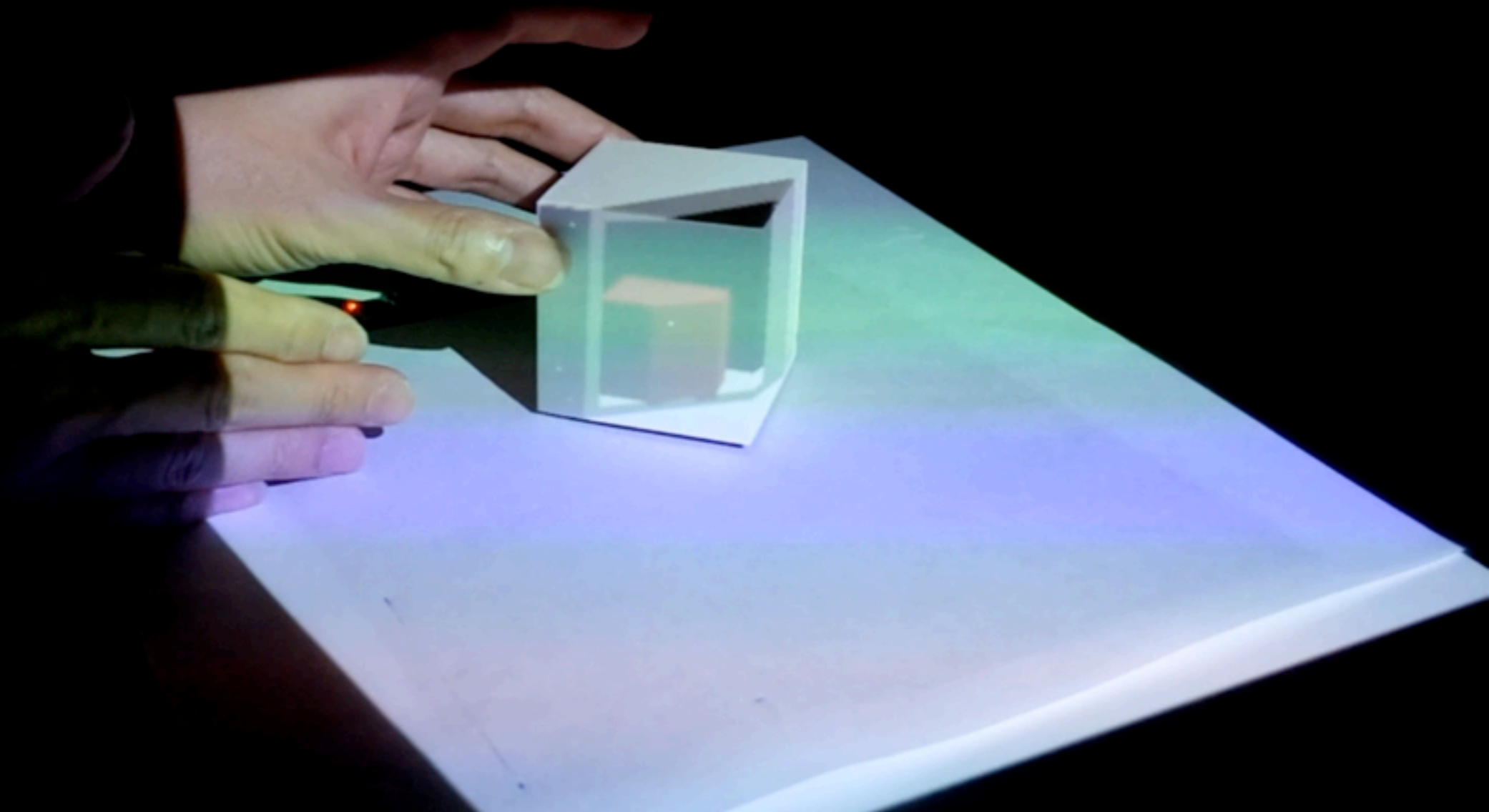# Tangible User Interfaces: What are they?

Internet of Things
TUI not necessarily connected to Internet
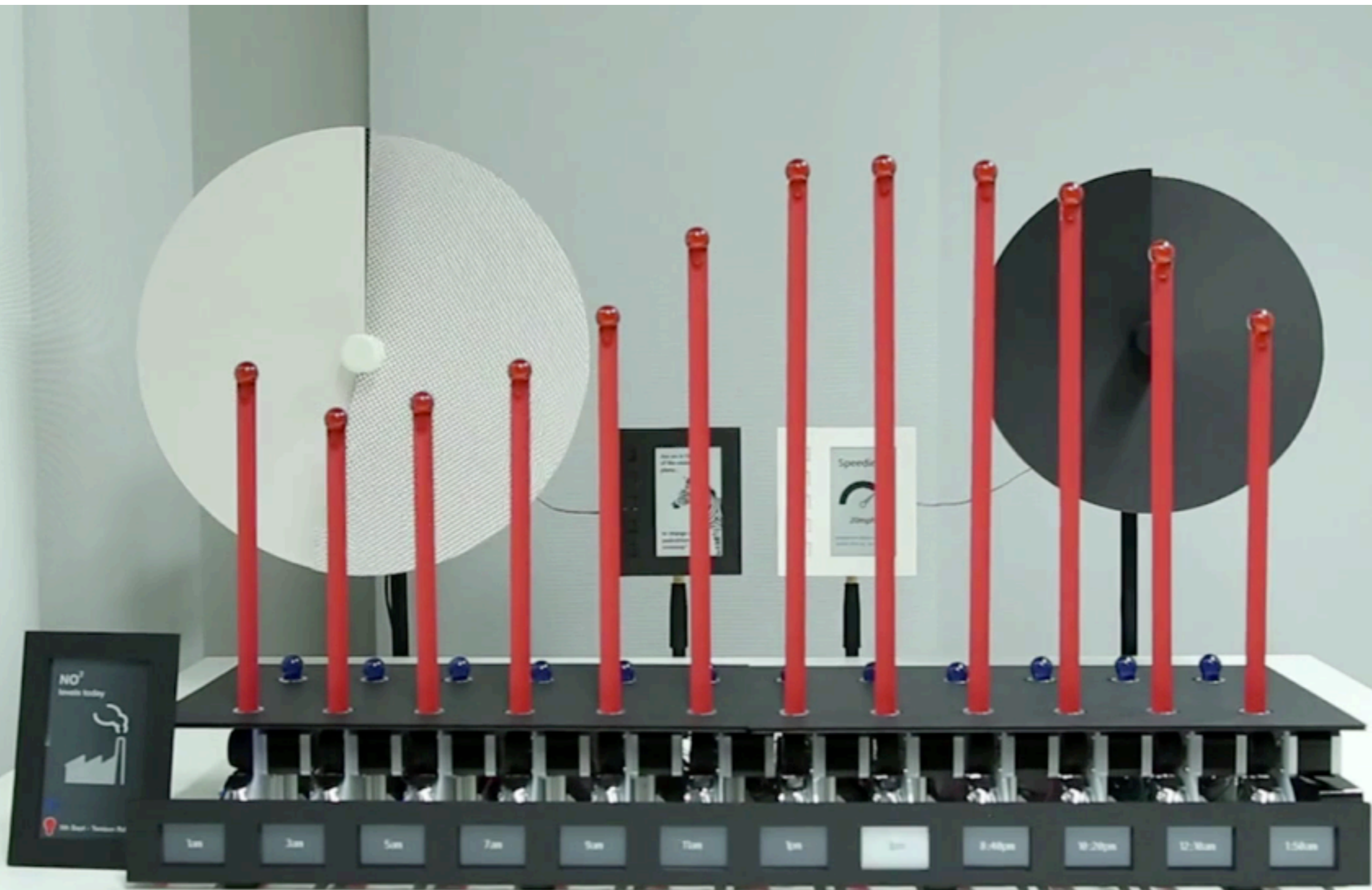If so, can be through a computer

Spread: GUI paradigm

Spread:
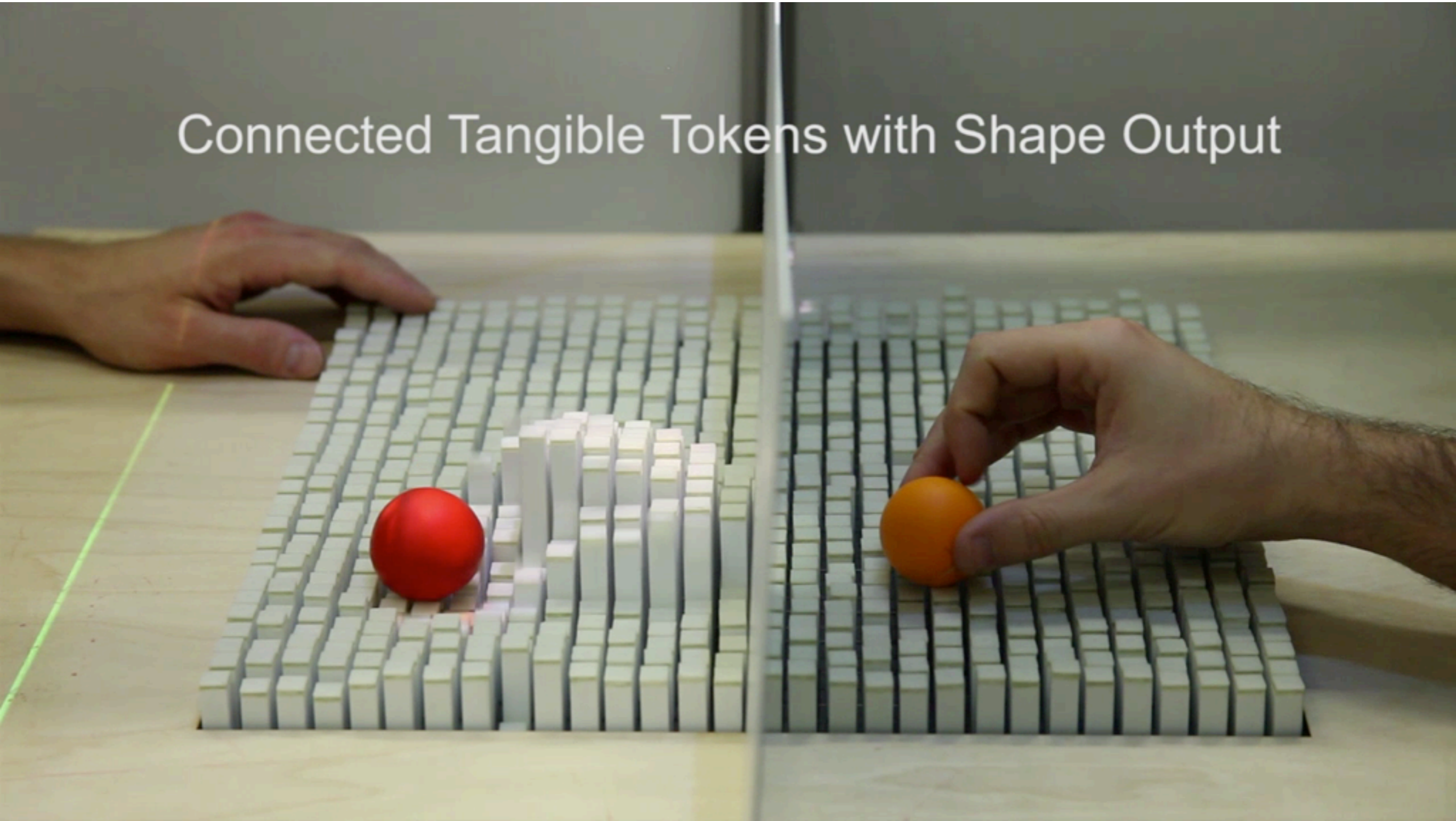# Augmented Reality paradigm
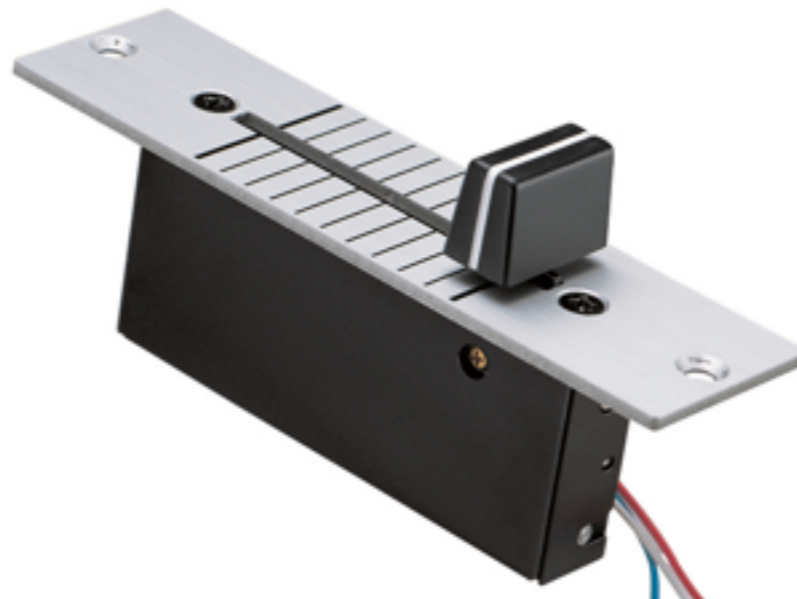

Section Cut to See Inside
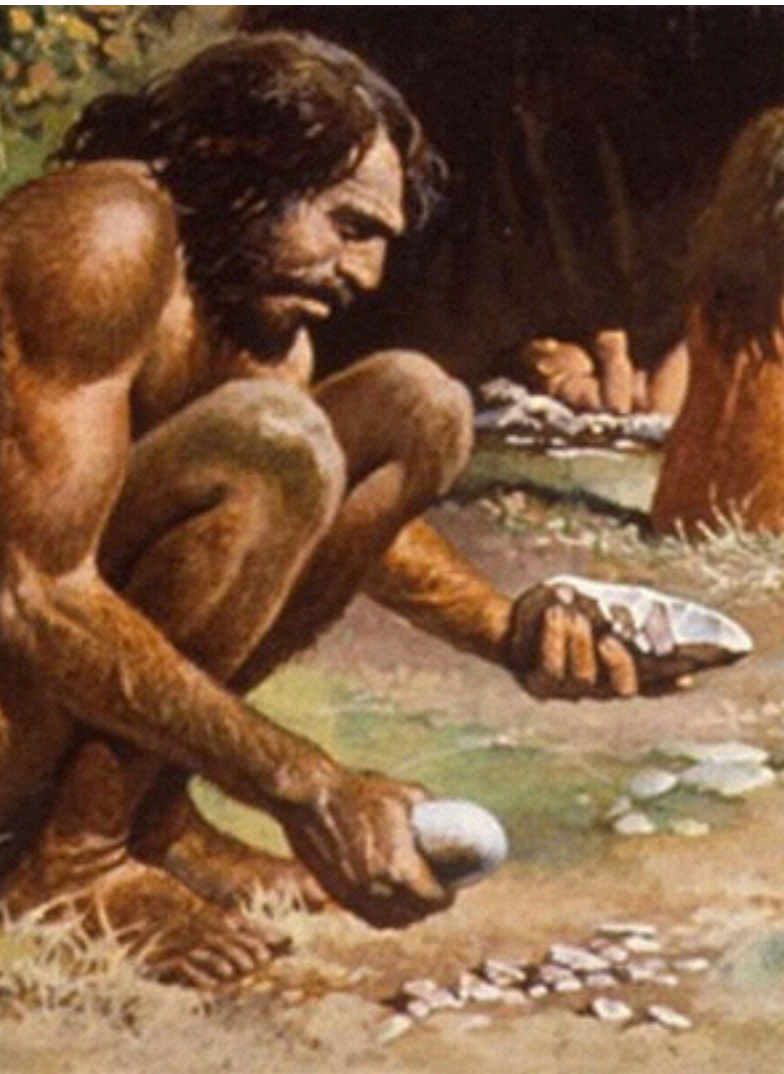
Spread: visualisation tasks

Spread:
Remote collaboration tasks

Connected Tangible Tokens with Shape Output

What is their story?

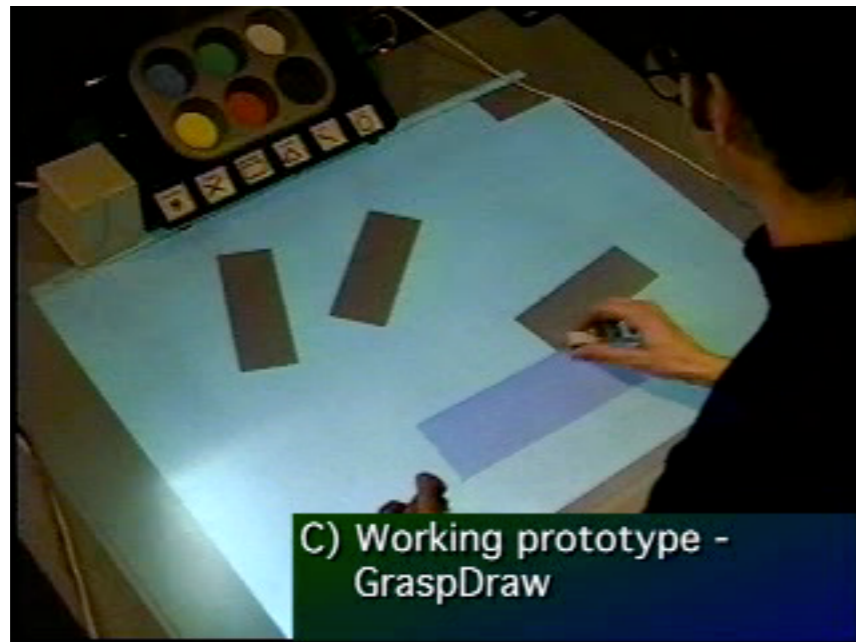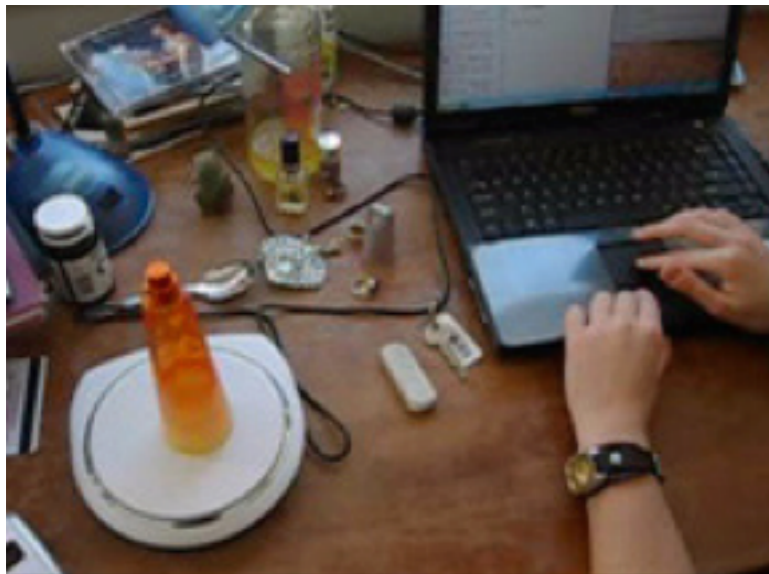# Manipulation of tangible tools has always been here...

... and is still here

Seminal papers

C) Working prototype - GraspDraw

Envisionment

Early works on Tangible User Interfaces

- DataTiles: Tangible overlay mixing Tangible and Graphical Interaction

  - https://www.youtube.com/watch?v=cmD8EKWxD4M

- Containers: mediaBlocks

  - http://vimeo.com/48827402

- metaDesk:

  - http://vimeo.com/44545109

- 3D animation with tangible sliders (1996):

  - https://www.youtube.com/watch?v=SnDHjY5aD5c
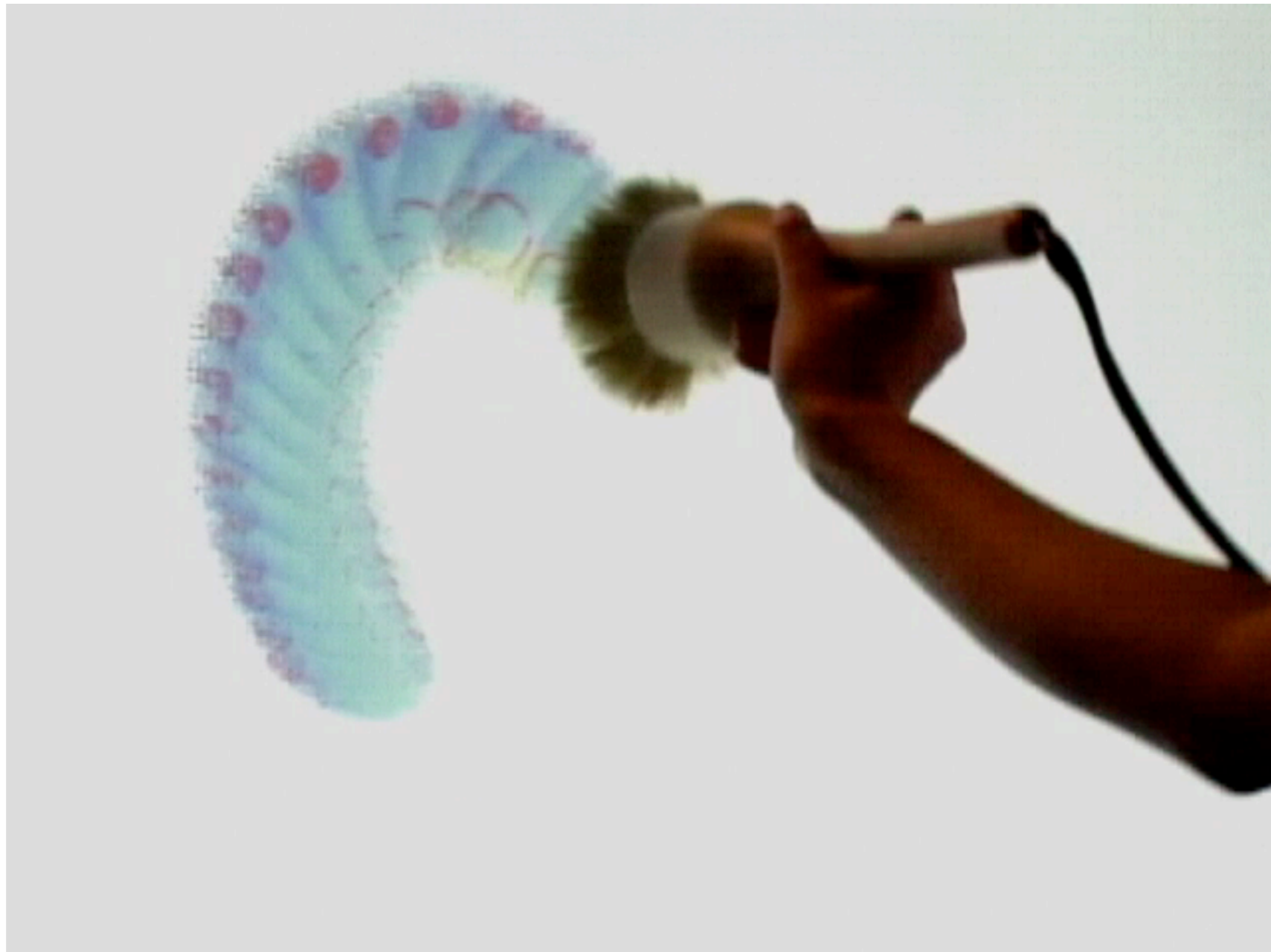
Example of
Tangible User Interfaces

Example of
Tangible User Interfaces

Example of
Tangible User Interfaces

I/O Brush

Tangible User Interfaces
What are they good for?

Tangible User Interfaces
What are they good for?

- **Interaction embodied
  in the physical world of the user**:
  Physical User & Physical Interface

- **Performance**:
  passive haptic feedback
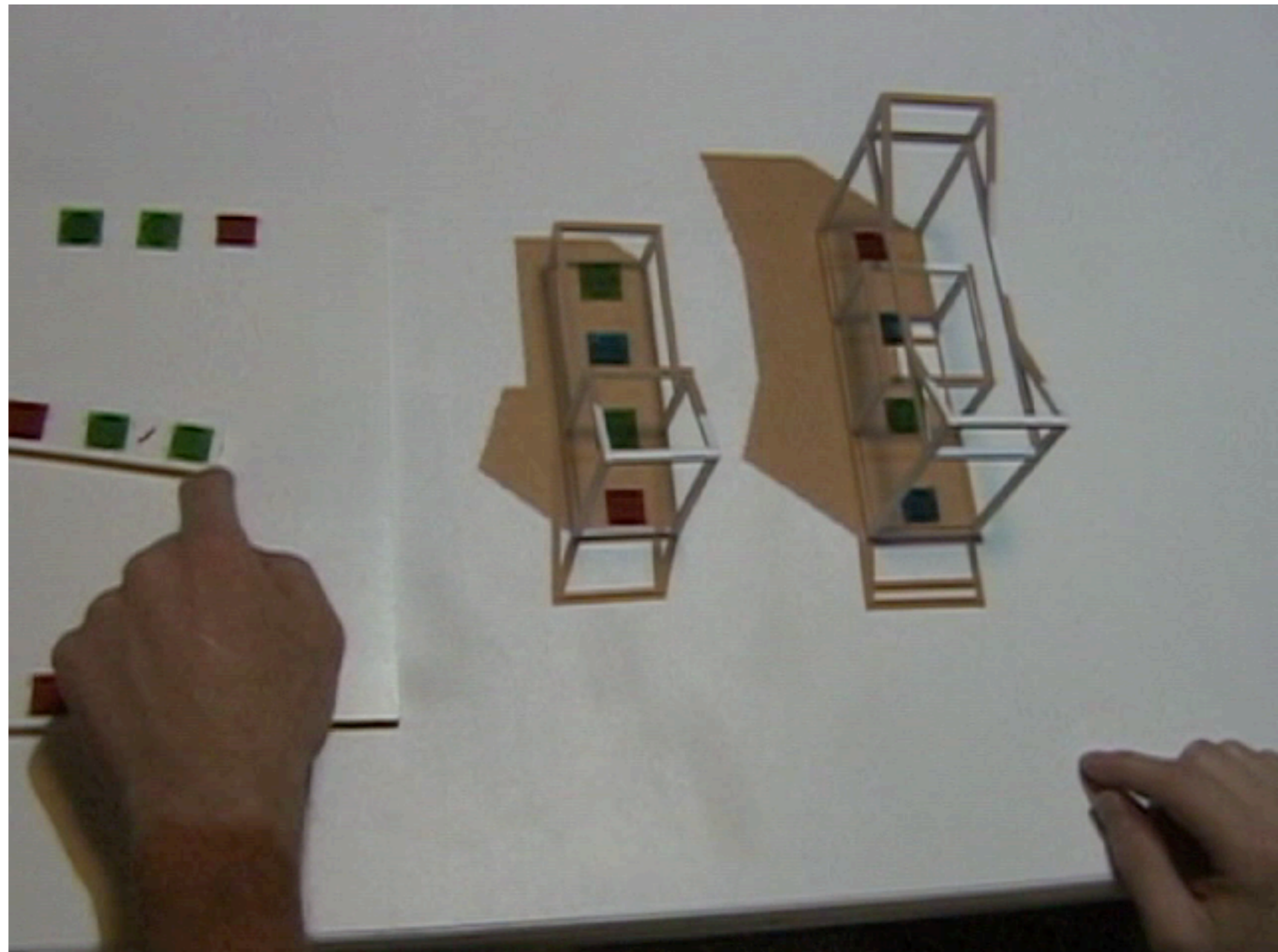
Embodied interaction

Object (prop) to interact at a distance with GUI
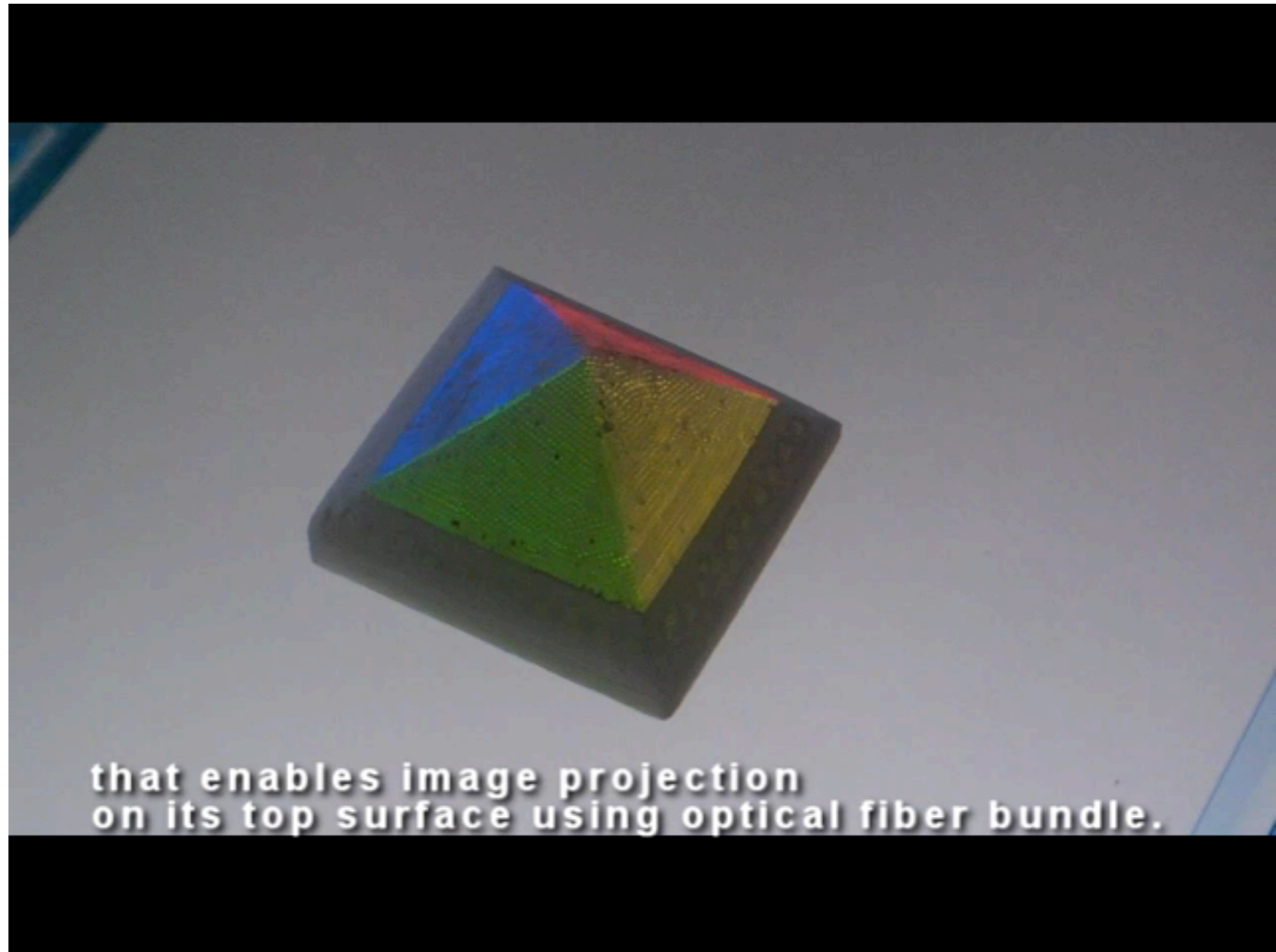
Embodied interaction

Tangible and overlaid projection

Example: URP

Embodied interaction
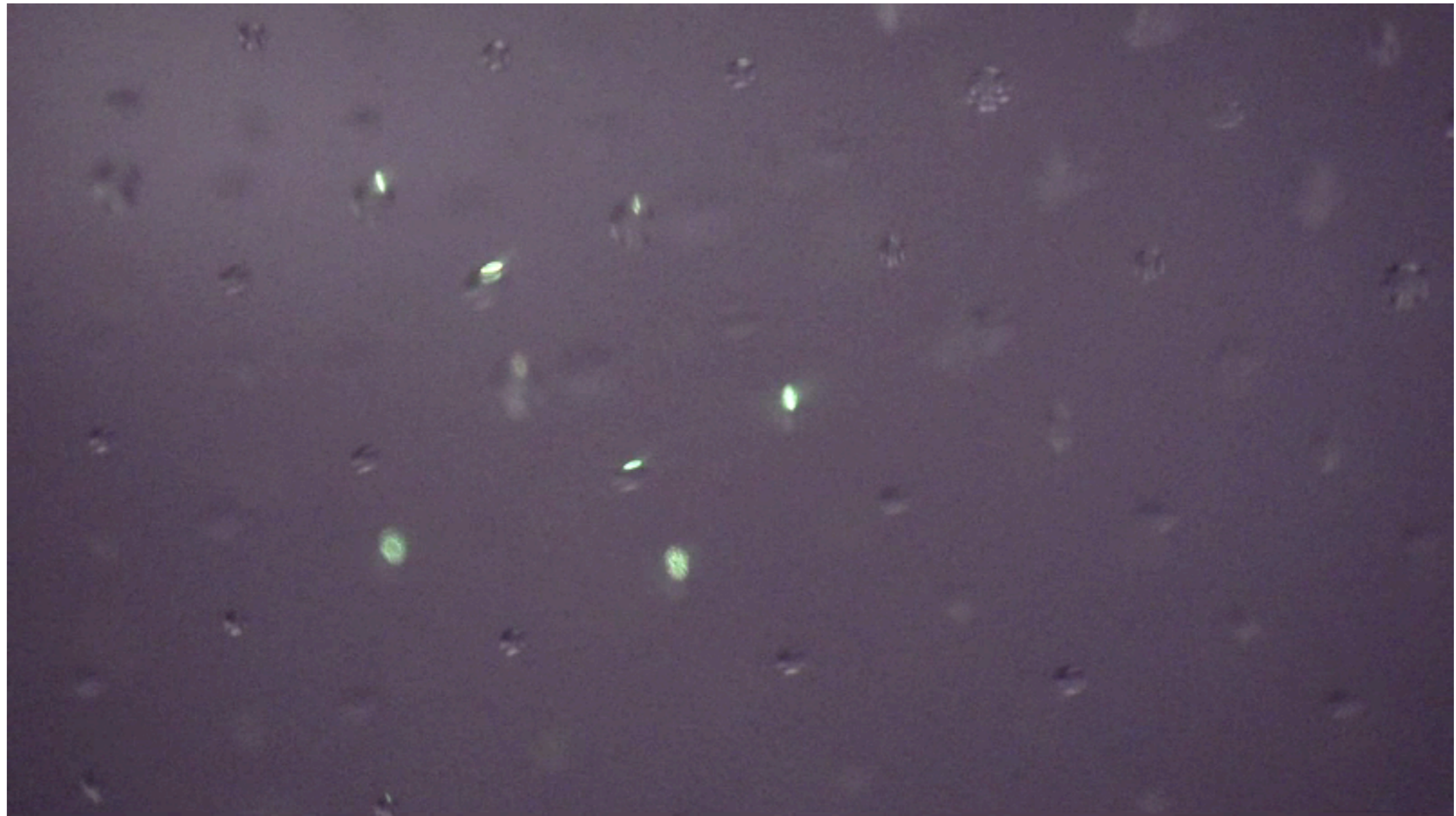
Rear-projection and optical fibers

that enables image projection
on its top surface using optical fiber bundle.

Example: Ficon

Embodied interaction

Printed Optics

Fishkin's metaphors

Analogy between the system effect of a user action to the real-world effect of similar actions

- **None** = No analogy between action and result

  - E.g., command-line UI, clock in URP

Fishkin's metaphors

Analogy between the system effect of a user action to the real-world effect of similar actions

- **Noun** = shape-related: "an <X> in the system is like an <X> in the real world"

  - E.g., dictionary (http://dl.acm.org/citation.cfm?doid=302979.303111)

Fishkin's metaphors

Analogy between the system effect of a user action to the real-world effect of similar actions

- **Verb** = motion-related: "<X>-ing in our system is like <X>-ing in the real world"

- E.g., NAVRNA

Fishkin's metaphors

Analogy between the system effect of a user action to the real-world effect of similar actions

- **Noun & Verb** = "<X>-ing an <A> in our system is like <X>-ing something <A>-ish in the real world"

  - E.g., eraser in Digital Desk, building in URP

Fishkin's metaphors

Analogy between the system effect of a user action to the real-world effect of similar actions

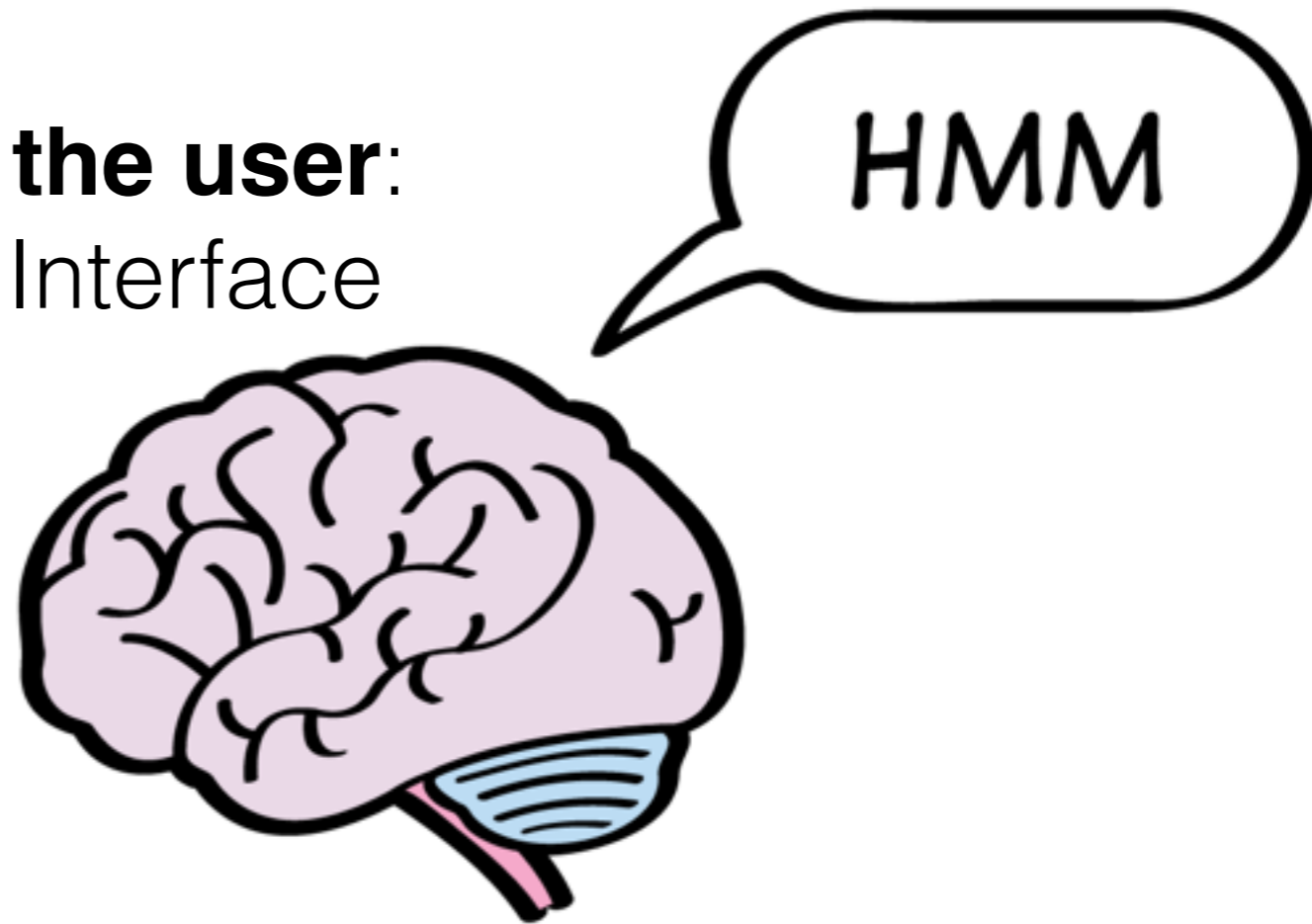- **Full** = In user's mind, there is no system

  - E.g., Illuminating Clay
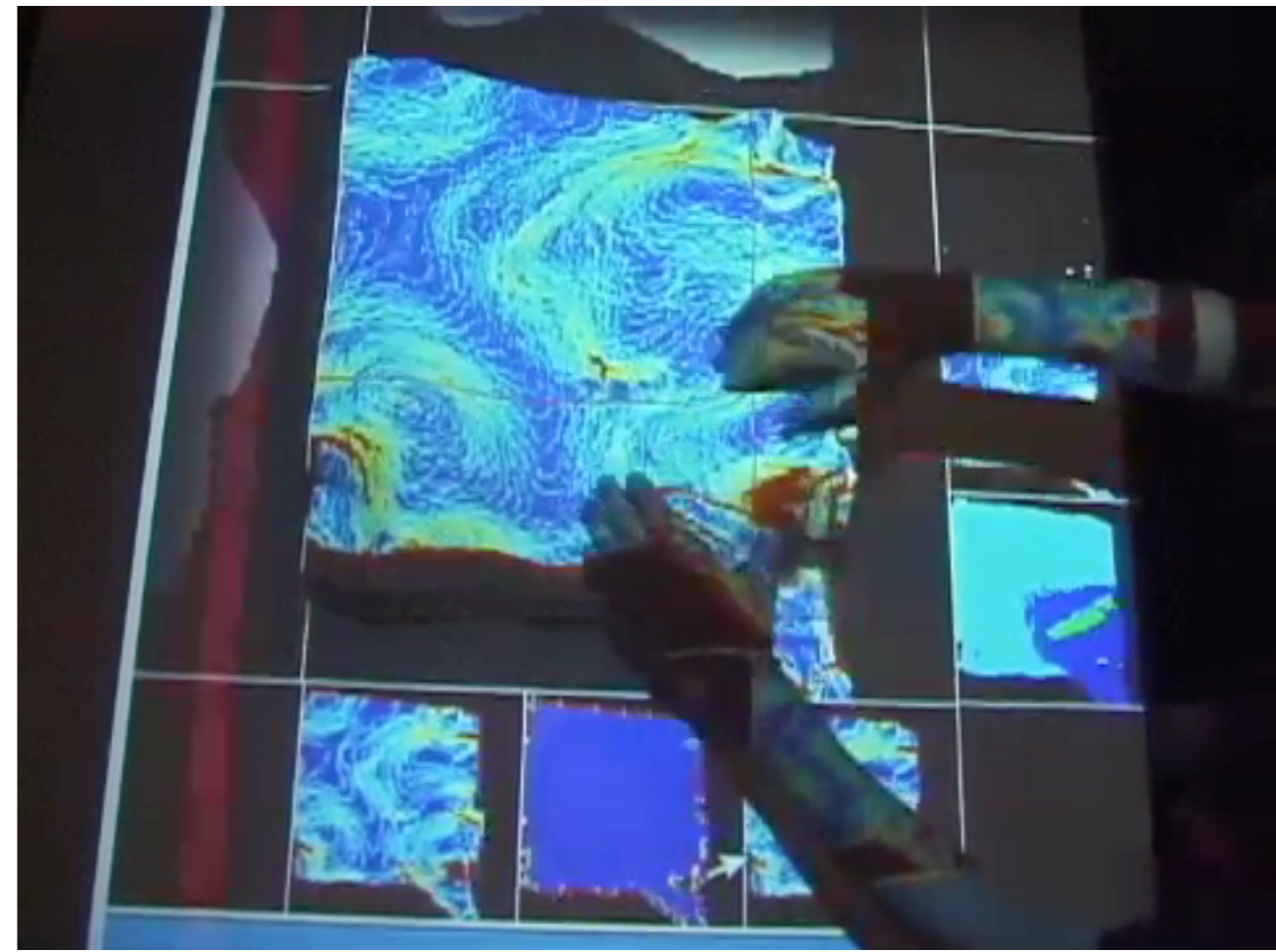
Tangible User Interfaces
What are they good for?

- **Interaction embodied in the physical world of the user**: Physical User & Physical Interface

- **Performance**: passive haptic feedback

HMM

Tangible User Interfaces: What are they good for?

Several experiments demonstrated their benefits

Tangible User Interfaces: Benefit over GUI

- Time-multiplexed vs. Space-multiplexed input: inter-device transaction phases

- Specialized vs. Generic form-factor

Tangible User Interfaces: Benefit over GUI

- Time-multiplexed vs. Space-multiplexed input: inter-device transaction phases

GUI	TUI
Acquire physical device	Acquire physical device
|	|
Acquire logical device	|
|	|
Manipulate logical device	Manipulate logical device

Tangible User Interfaces: Benefit over GUI

Task: continuously track four targets moving randomly on the screen (compound tasks)

- Rotor: position and rotation

- Brick: position and rotation

- Strechable square: position, rotation and scale

- Ruler: position, rotation and scale
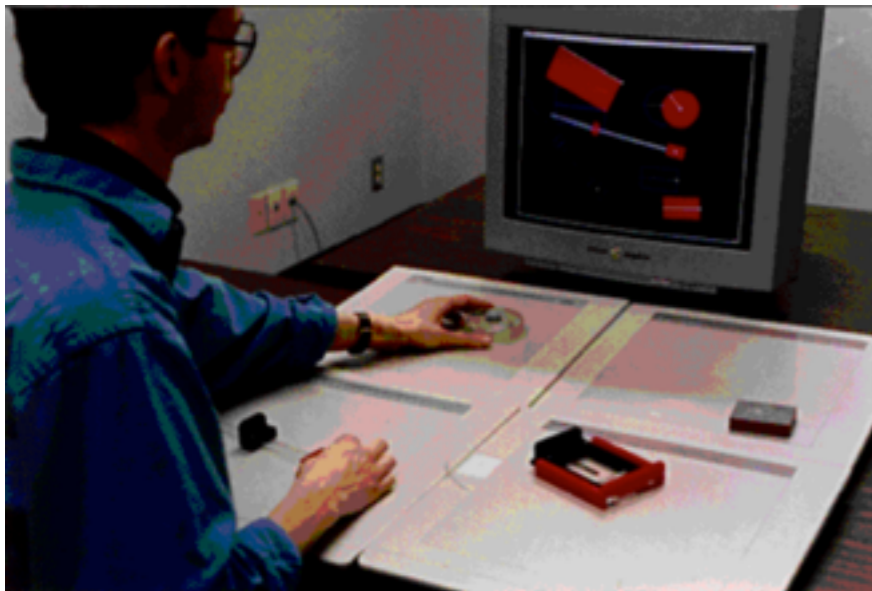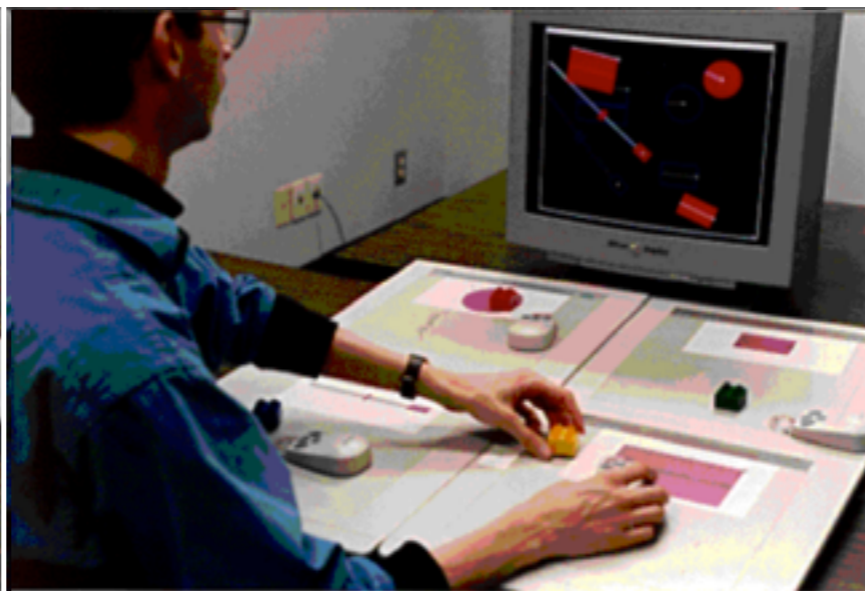

Space-multiplexed
Specialized
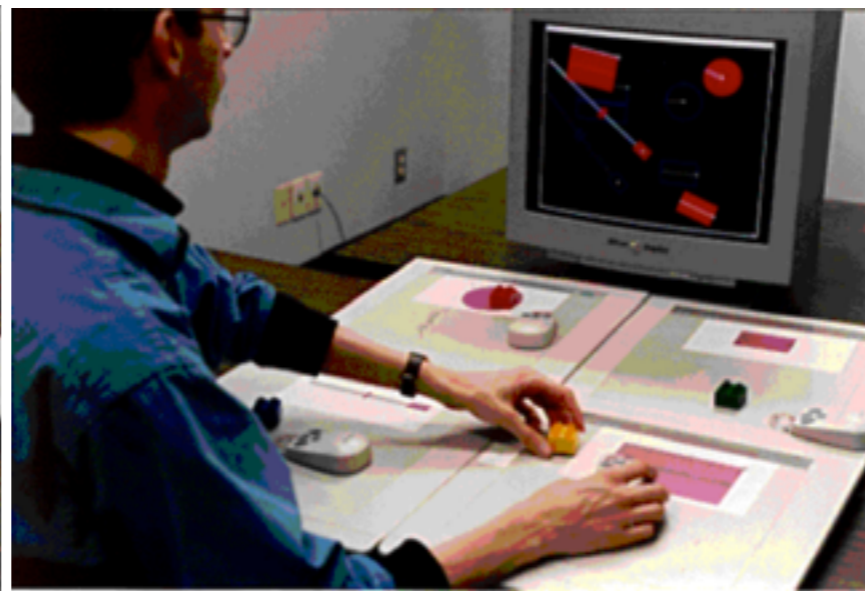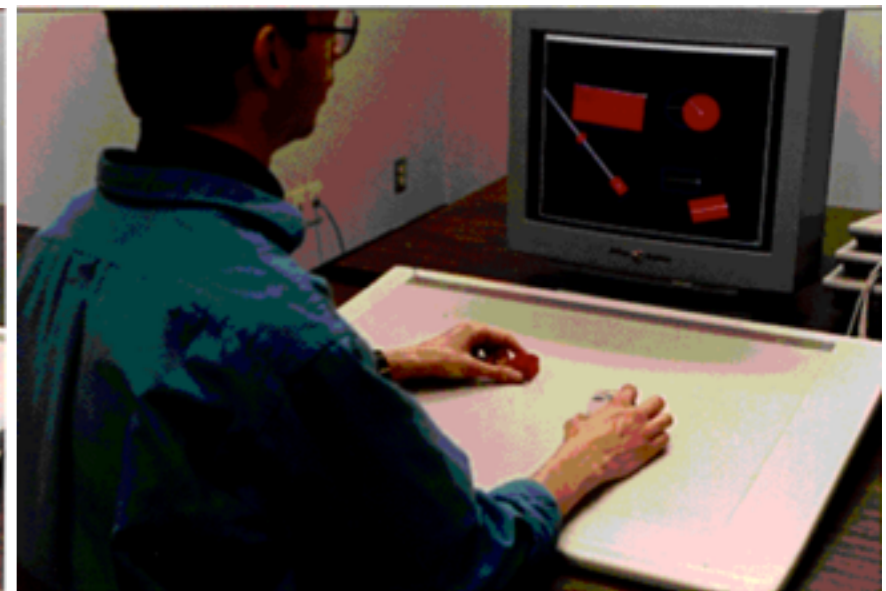
Space-multiplexed
Generic

Time-multiplexed
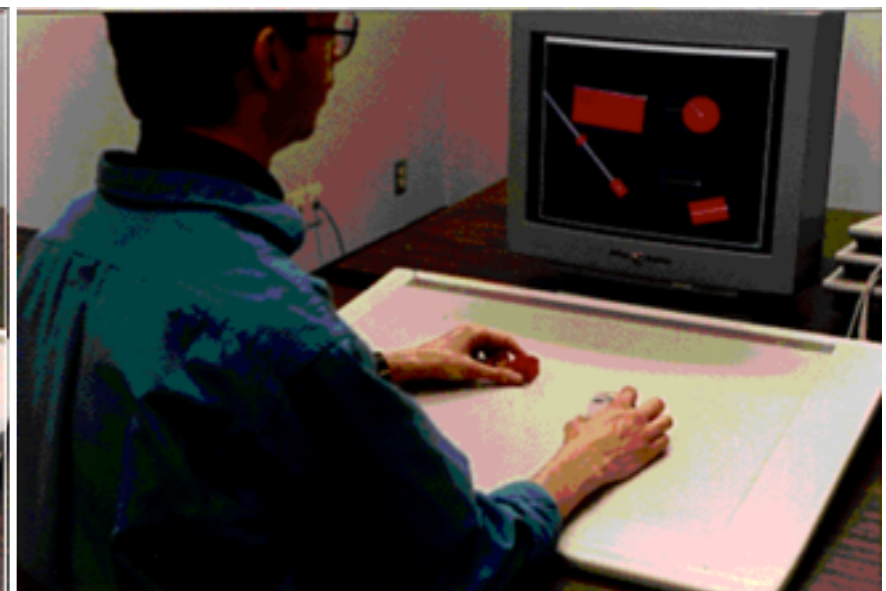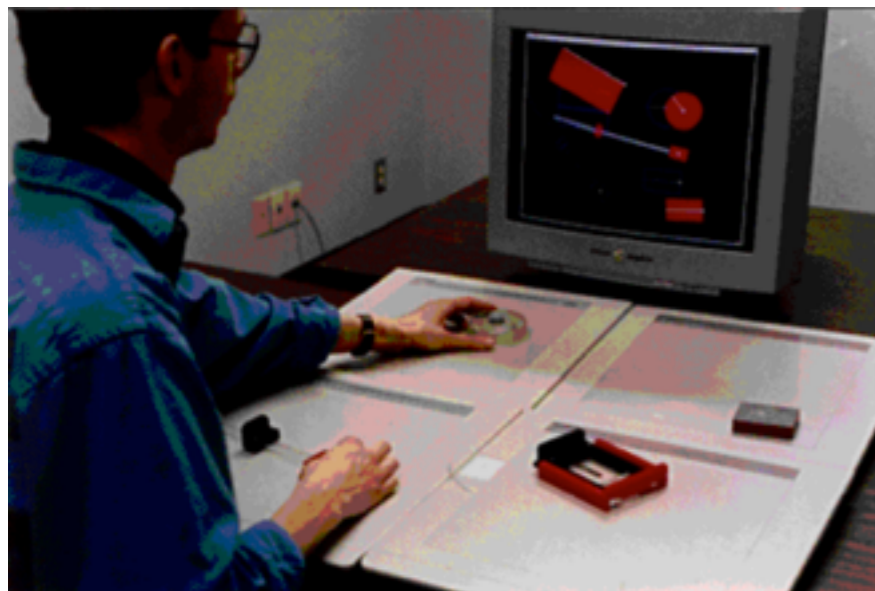
Tangible User Interfaces: Benefit over GUI

Does the **physical switching** cost more than the **logical switching** between tools?
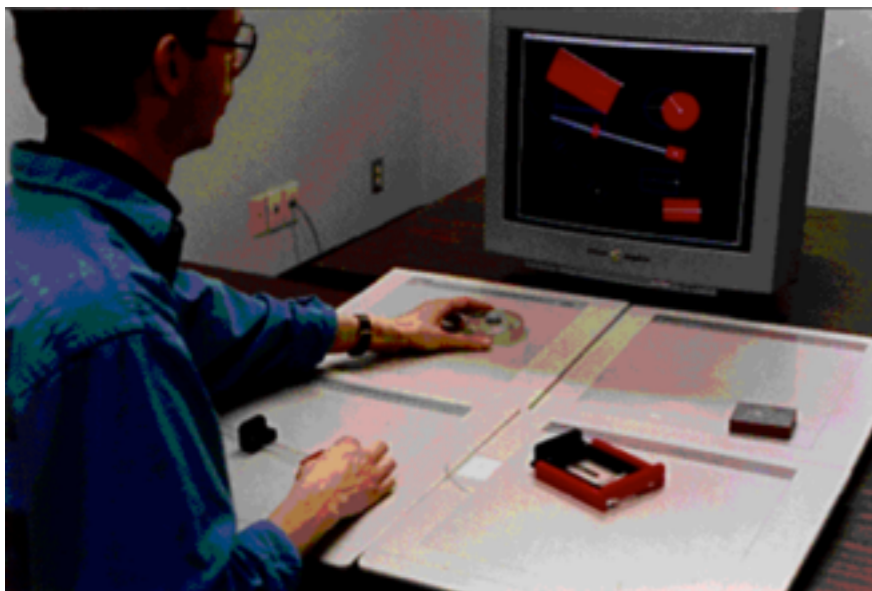
Space-multiplexed Specialized
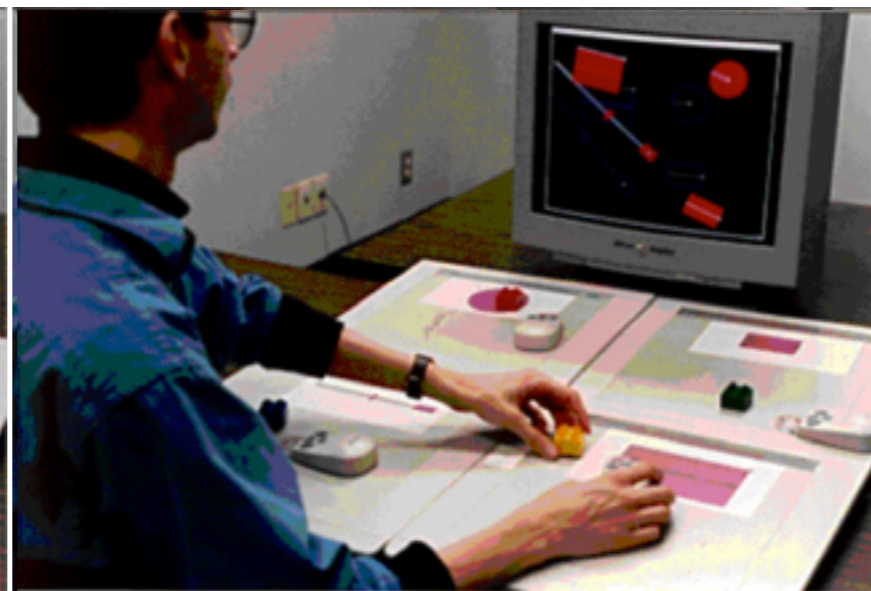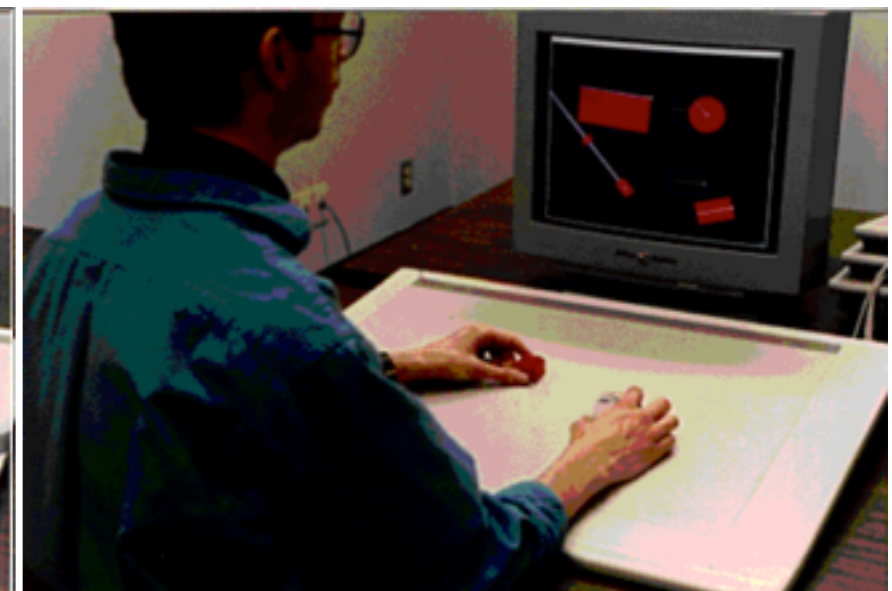
Space-multiplexed Generic

Time-multiplexed

Tangible User Interfaces: Benefit over GUI

Does the **physical switching** cost more than the **logical switching** between tools?

Is the **specialized** input useful?
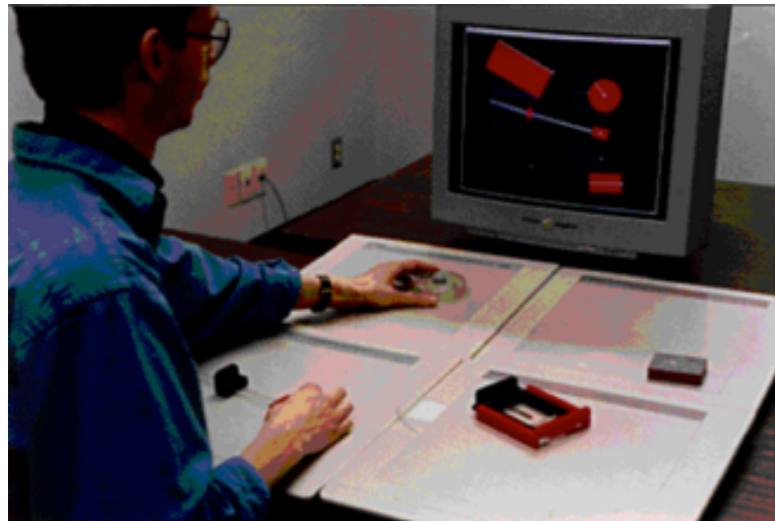

Space-multiplexed
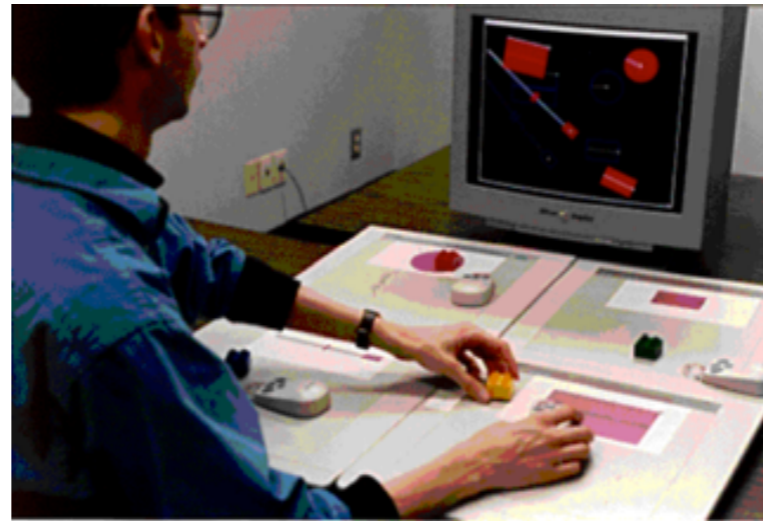Specialized

Space-multiplexed
Generic

Time-multiplexed

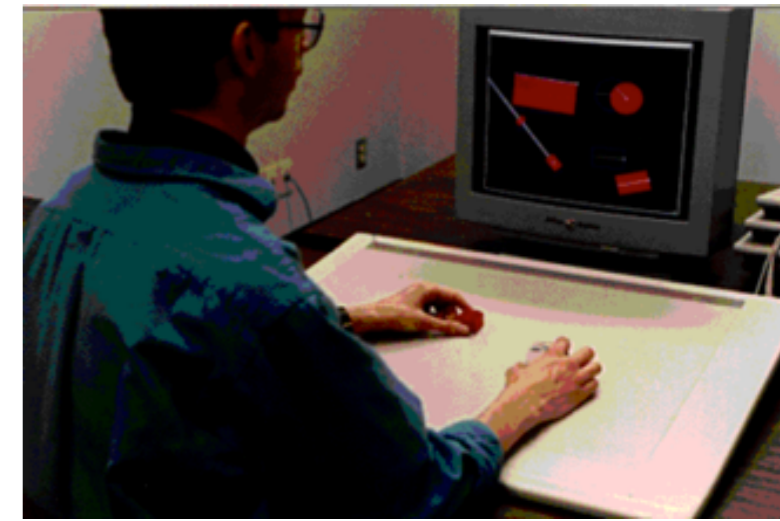# Tangible User Interfaces: Benefit over GUI

Space-multiplexed
Specialized
performs best

\>

Space-multiplexed
Generic
**performs better than Time-multiplexed
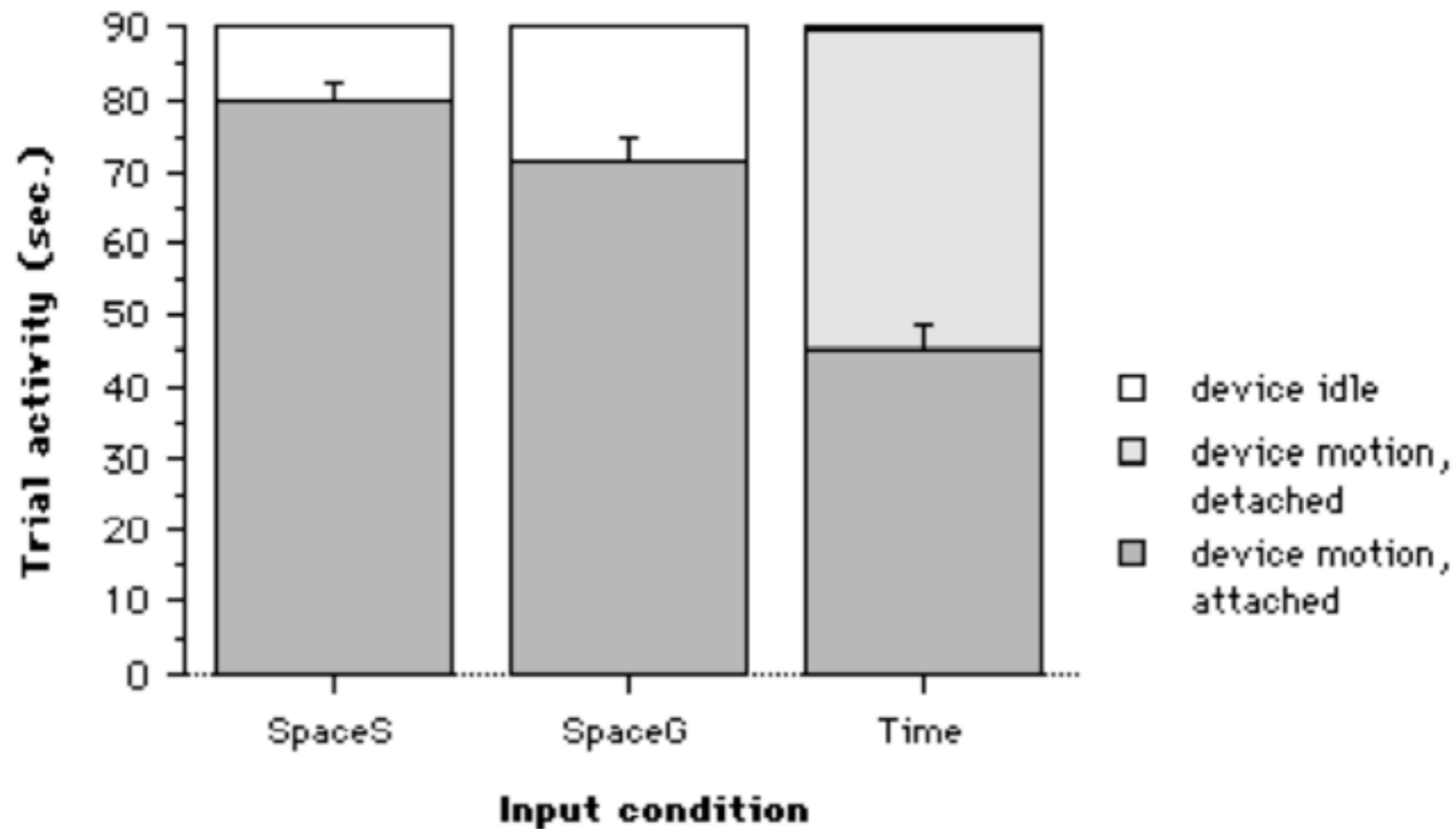but worst than Specialized**

\>

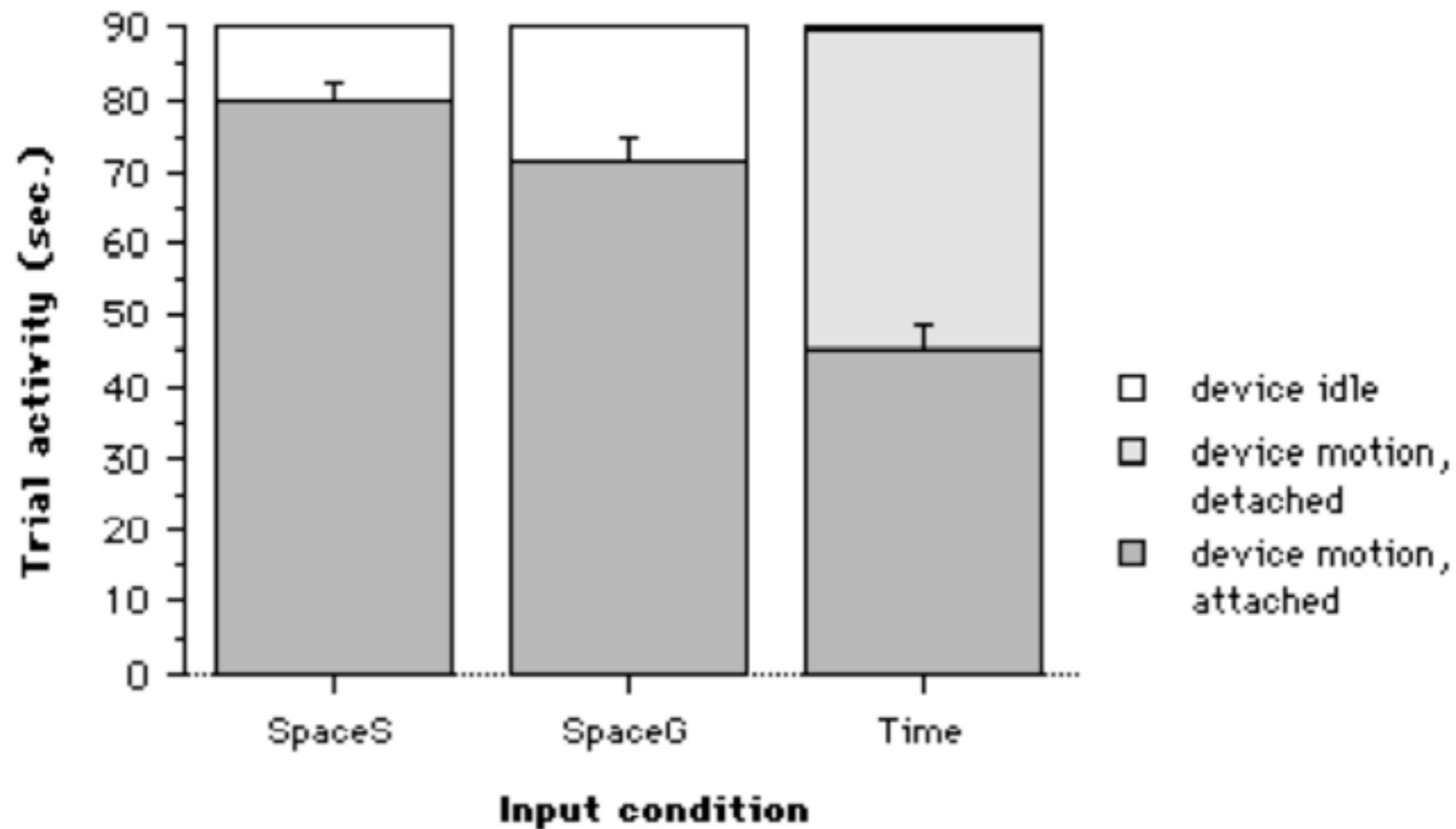Time-multiplexed

performs worst

- Consistent across the 4 devices

- (Score based on root mean square errors of all dimensions (position, orientation and scale if applicable) of all devices)

Tangible User Interfaces: Benefit over GUI

Tangible User Interfaces: Benefit over GUI

Users spend more time switching between tools with time-multiplexed UI rather than with space-multiplexed UI

Tangible User Interfaces: Benefit over GUI

1. Space-multiplexed > Time-multiplexed input:

    • Persistance of attachement between physical and logical (software, graphical) controllers

    • Parallel 2-handed vs.
      Sequential 1-handed interaction

2. Specialized vs. Generic form-factor

    • Visual and tactile reminder

Tangible User Interfaces: What are they good for?

Several experiments demonstrated their benefits

Tangible User Interfaces: Benefit over multitouch

What about multitouch input?

Tangible User Interfaces: Benefit over multitouch

What about multitouch input?

also space-multiplexed

Tangible User Interfaces: Benefit over multitouch

Two experiments

Acquisition

Manipulation

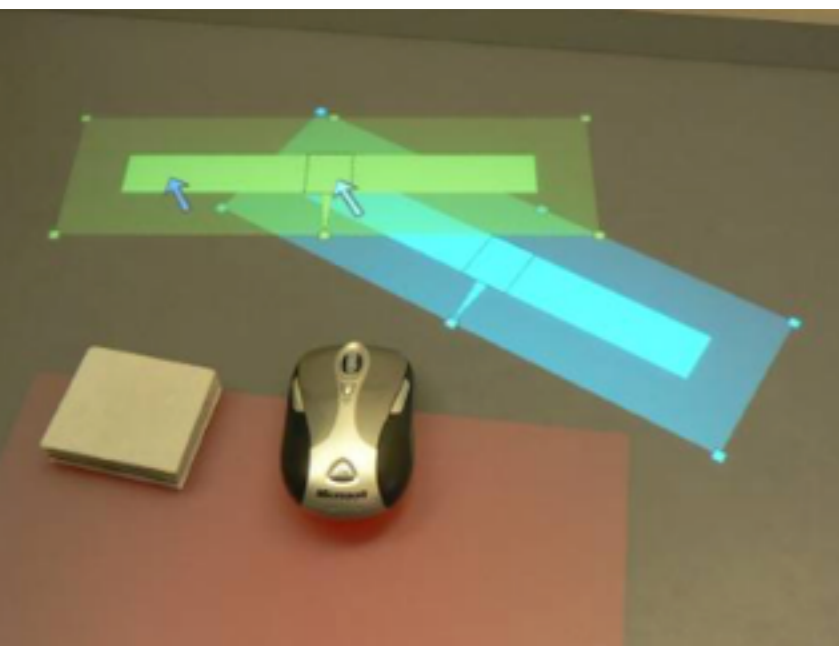# Tangible User Interfaces: Benefit over multitouch

Manipulation

Assumes users already acquired
the control widget

Tangible User Interfaces: Benefit over multitouch

Task: match position+orientation+cursor of blue object
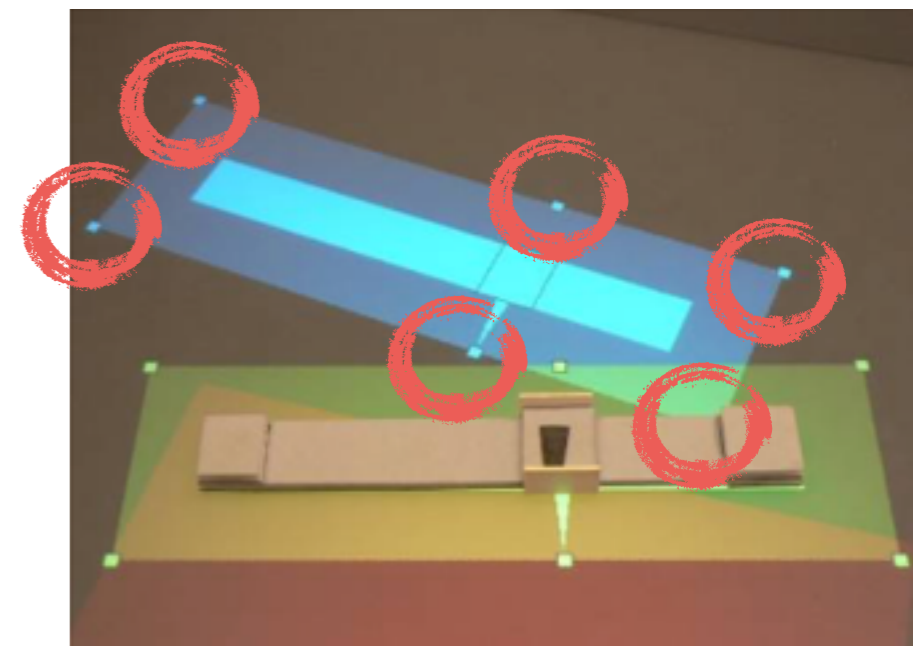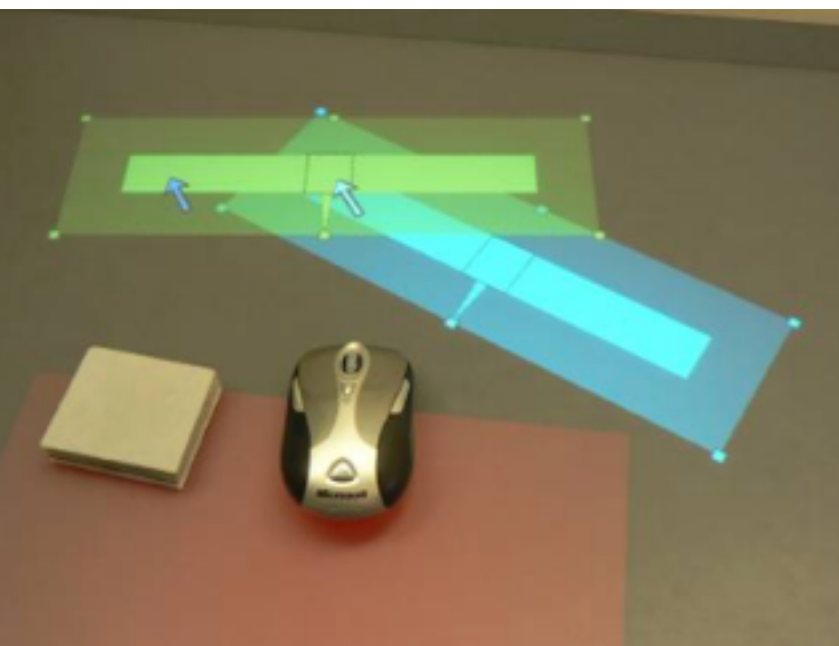manipulating yellow object
as quickly as possible

Mouse+Puck   Multitouch   Tangible
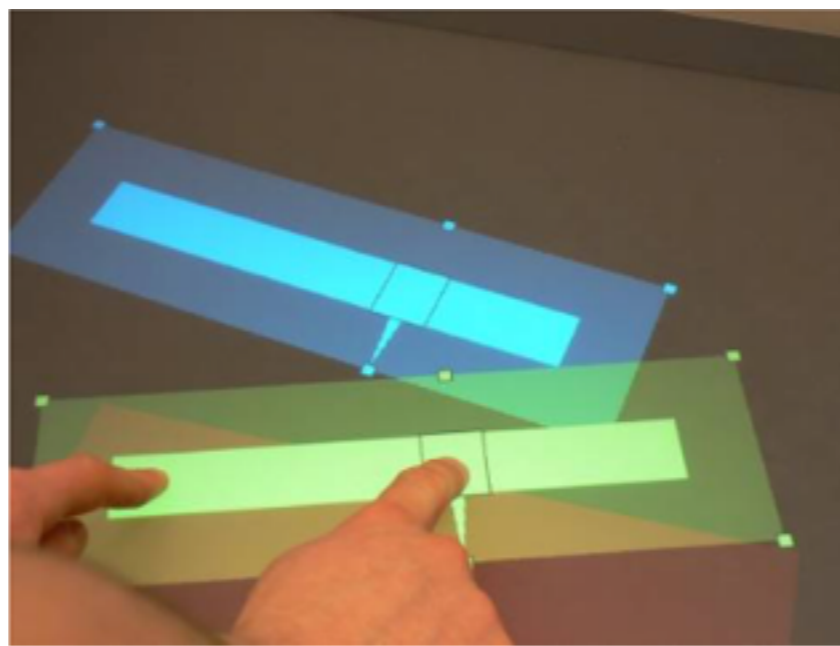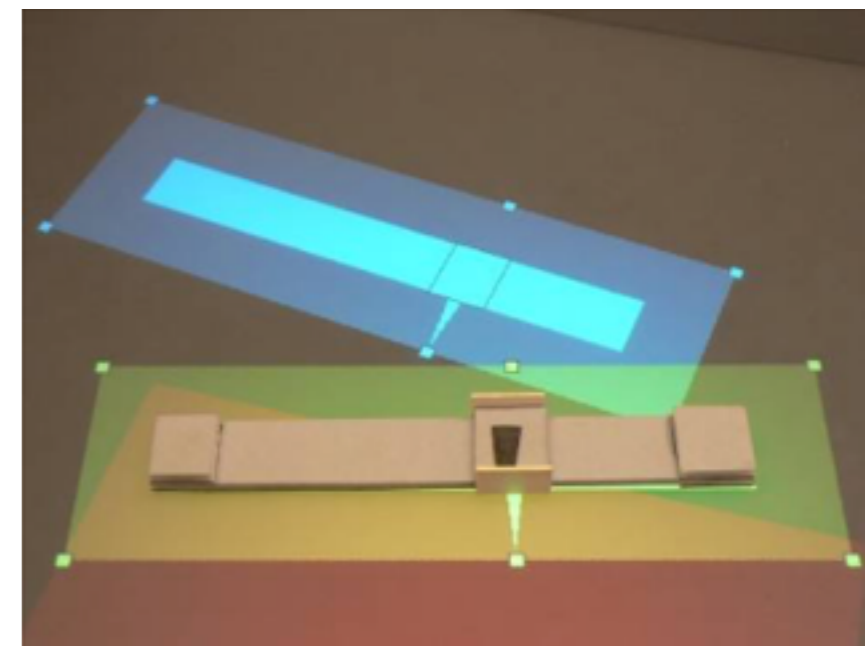
(all conditions sensed through multitouch table)

Tangible User Interfaces: Benefit over multitouch

Task: match position+orientation+cursor of blue object
manipulating yellow object
as quickly as possible
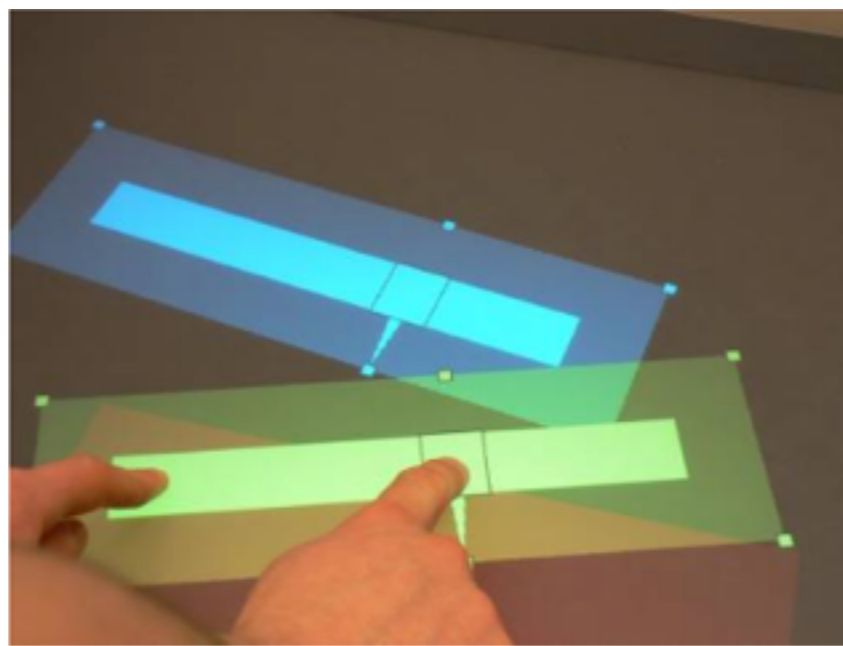
±5px
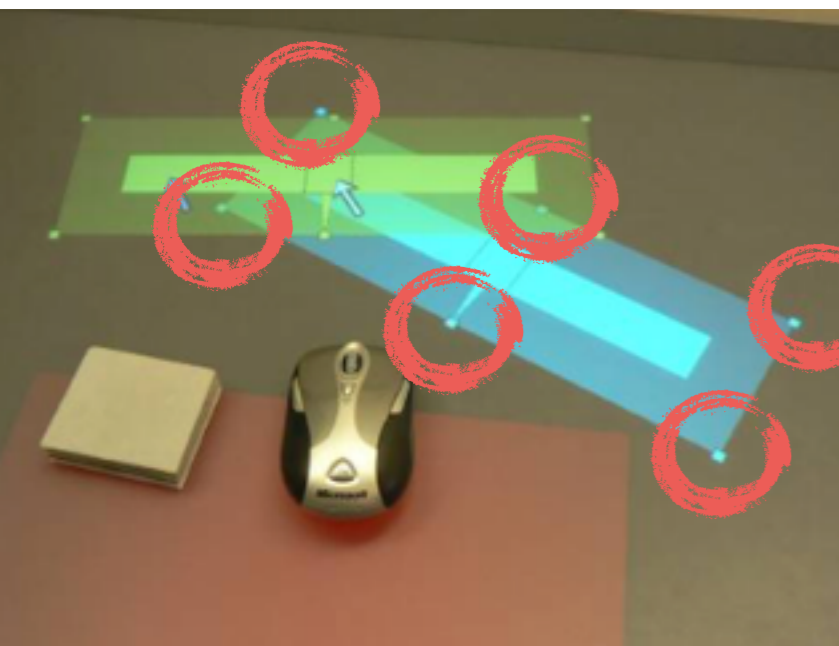
Mouse+Puck
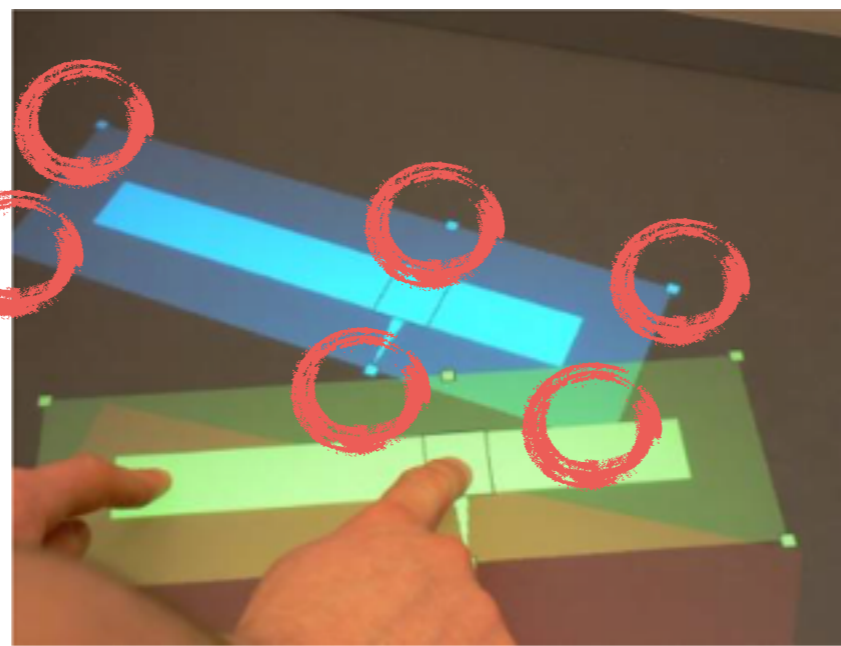
Multitouch

Tangible

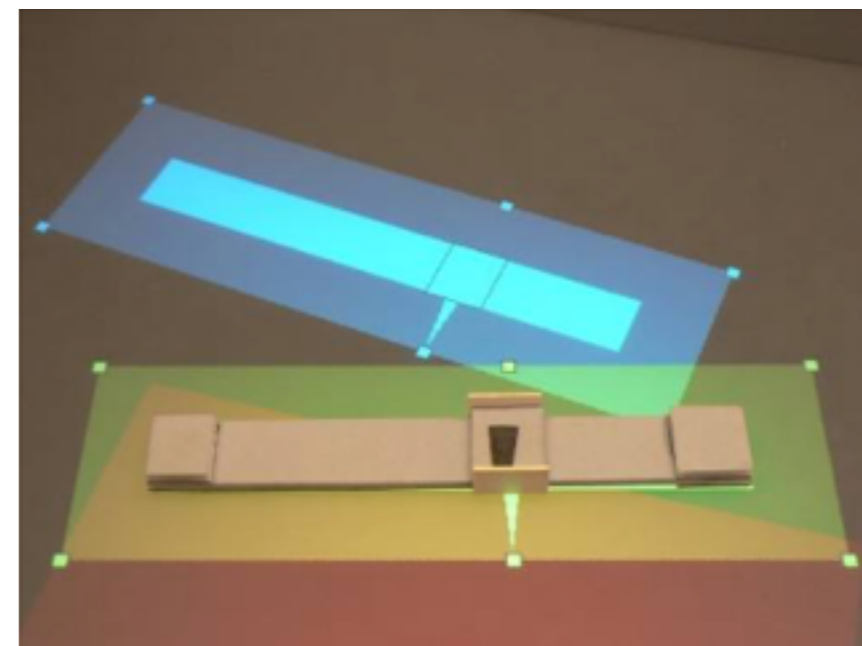# Tangible User Interfaces: Benefit over multitouch

Measures: Time to complete matching task
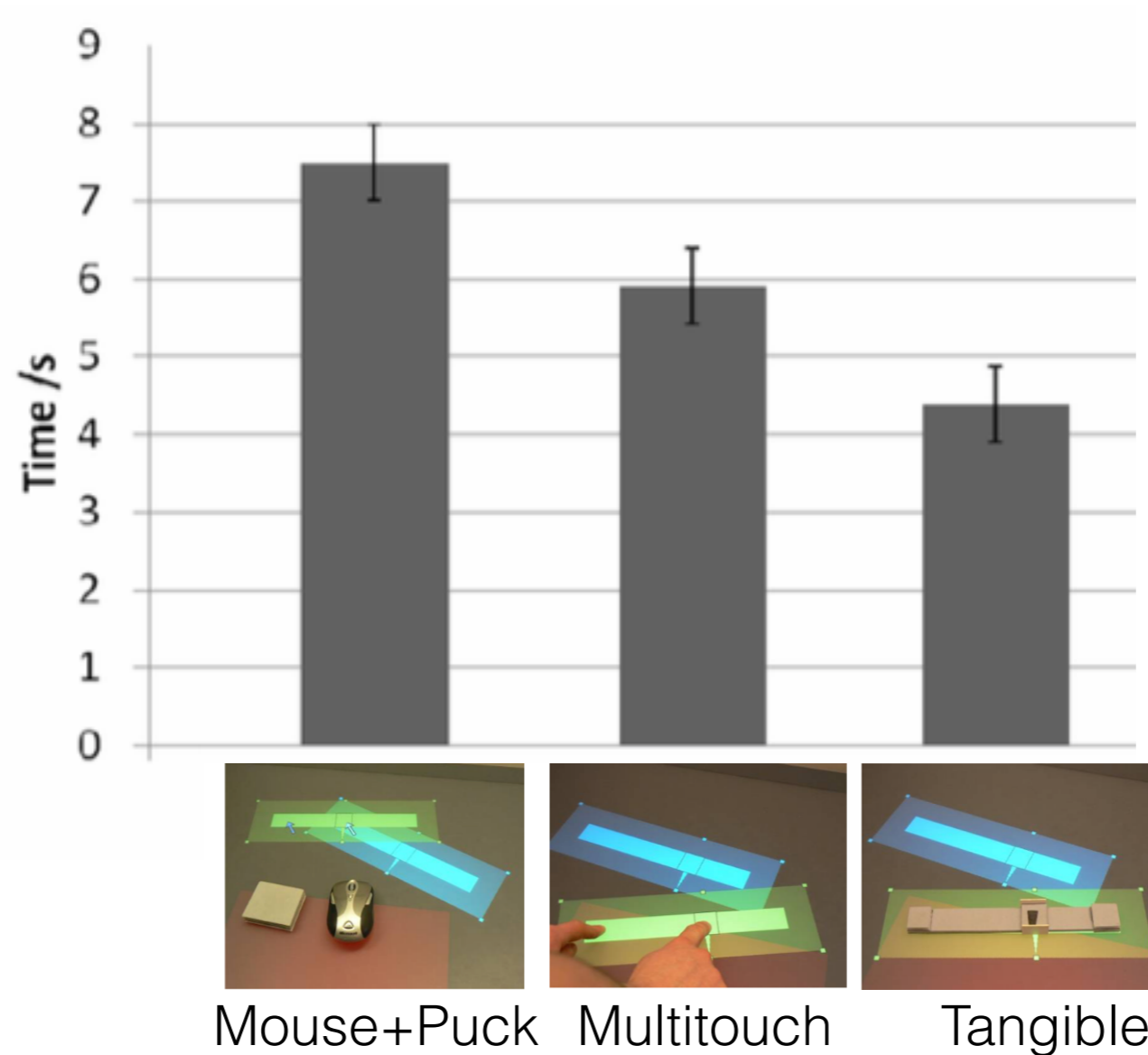Subjective comfort
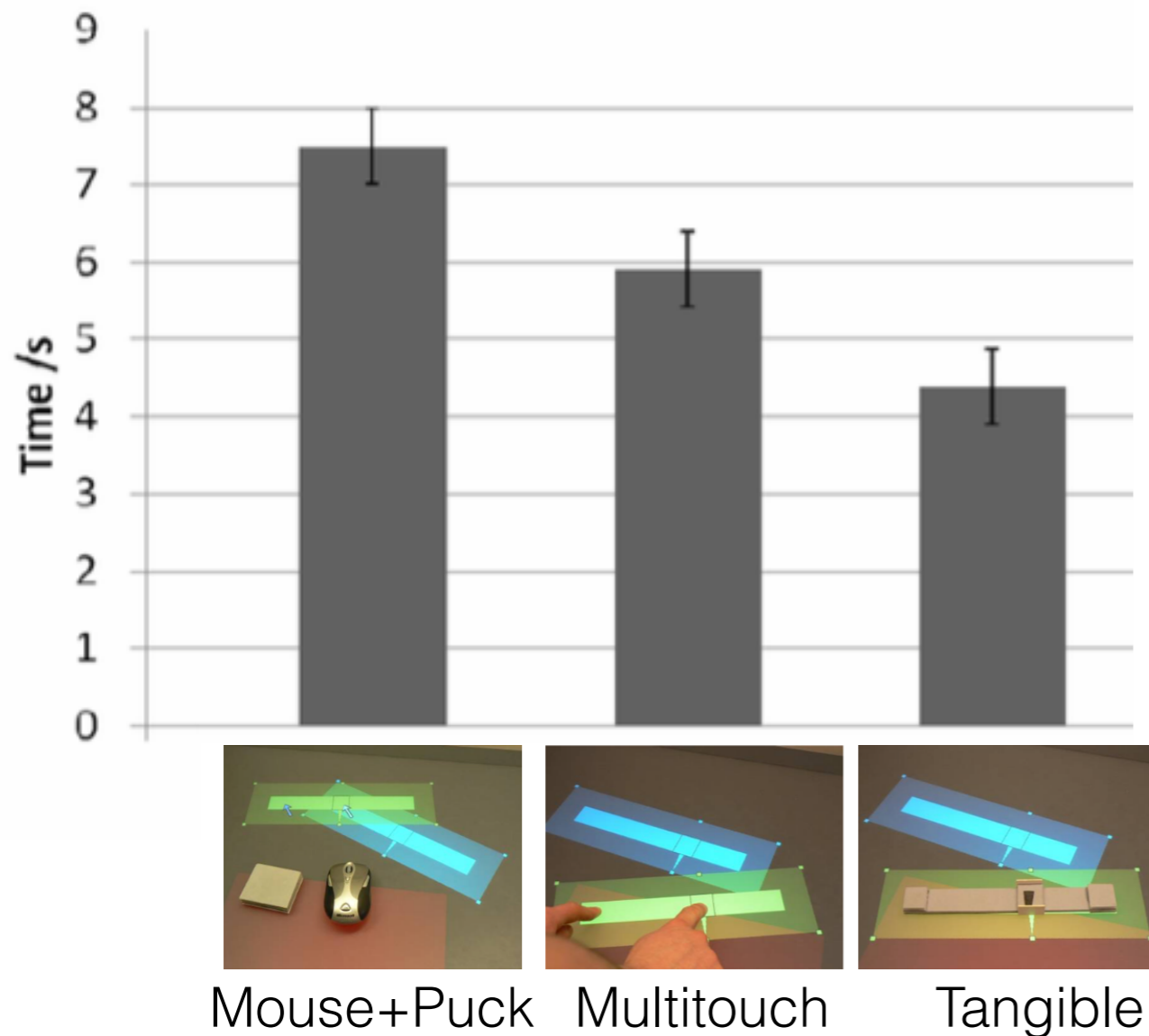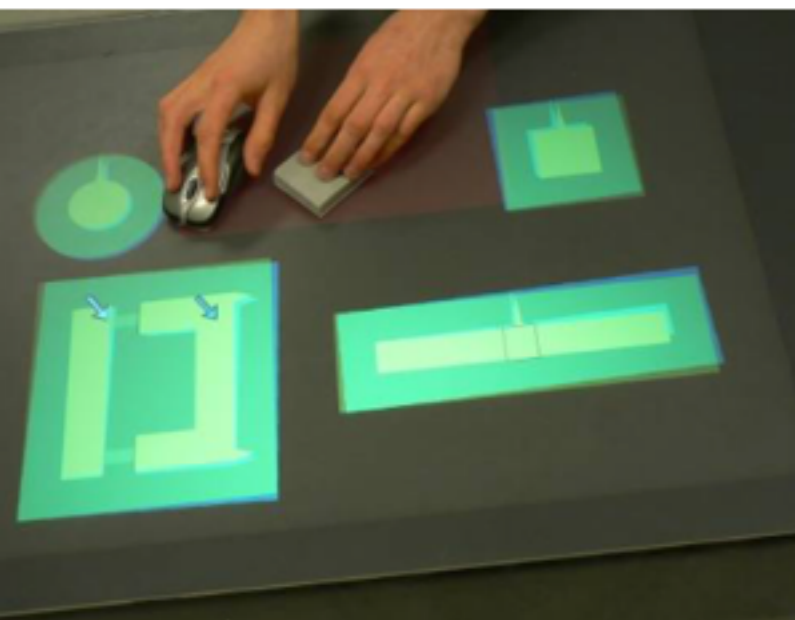Subjective ease of use

Mouse+Puck

Multitouch

Tangible

Tangible User Interfaces: Benefit over multitouch

Mouse+Puck   Multitouch   Tangible

Tangible User Interfaces: Benefit over multitouch

Mouse+Puck   Multitouch   Tangible

+ Little difference in comfort and ease of use

A participant:
« better degree of control with tangibles, especially when rotating »

Tangible User Interfaces: Benefit over multitouch

Manipulation

Tangible User Interfaces: Benefit over multitouch

Two experiments

Acquisition

Manipulation

Tangible User Interfaces: Benefit over multitouch
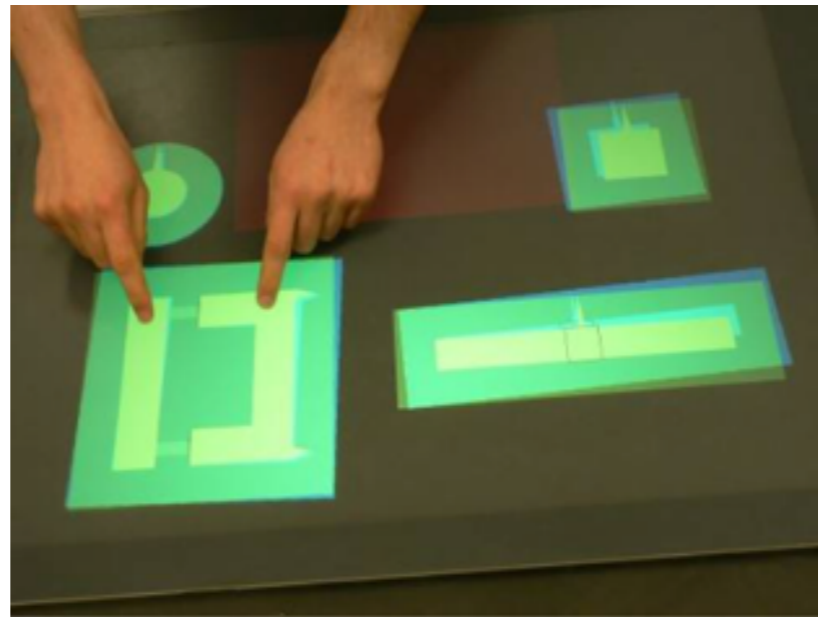
Acquisition

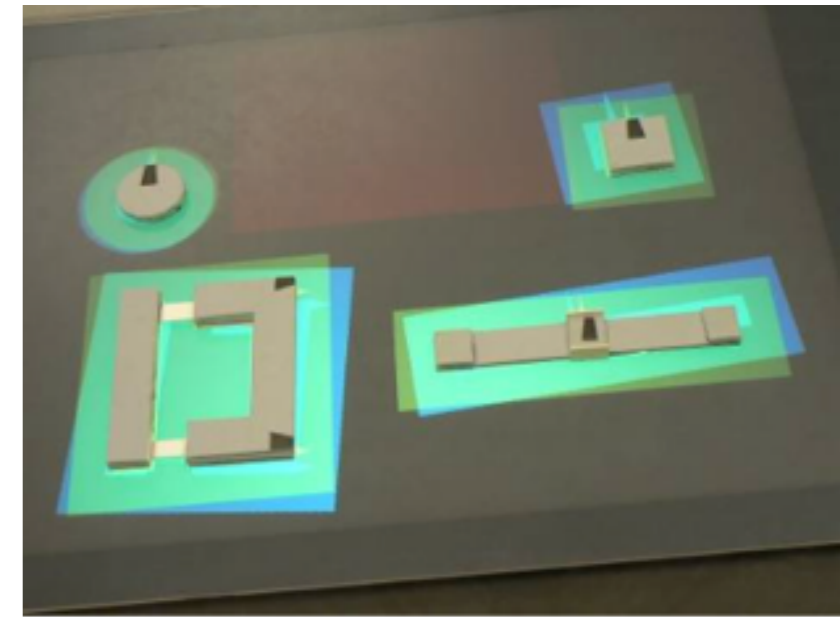# Tangible User Interfaces: Benefit over multitouch

Task: match position+orientation+cursor of blue objects
manipulating yellow objects
at all times

Mouse+Puck

Multitouch

Tangible

(all conditions sensed through multitouch table)
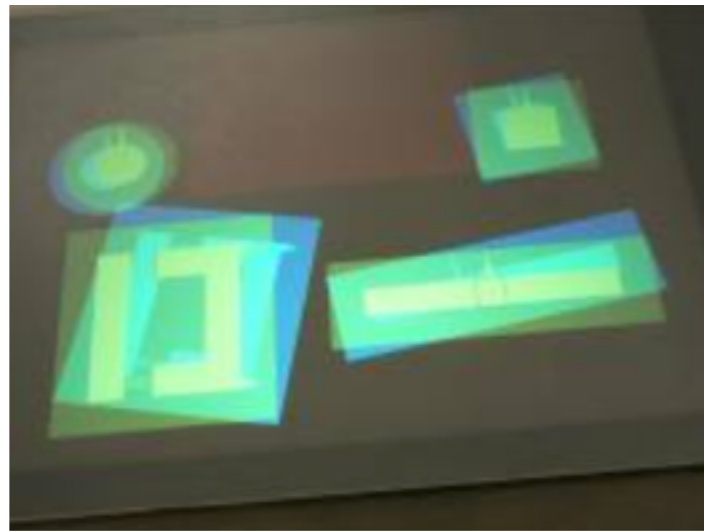
Tangible User Interfaces: Benefit over multitouch

time

Task: match position+orientation+cursor of blue objects
manipulating yellow objects
at all times

⇒ move between widgets ⇒ many (re)acquisitions
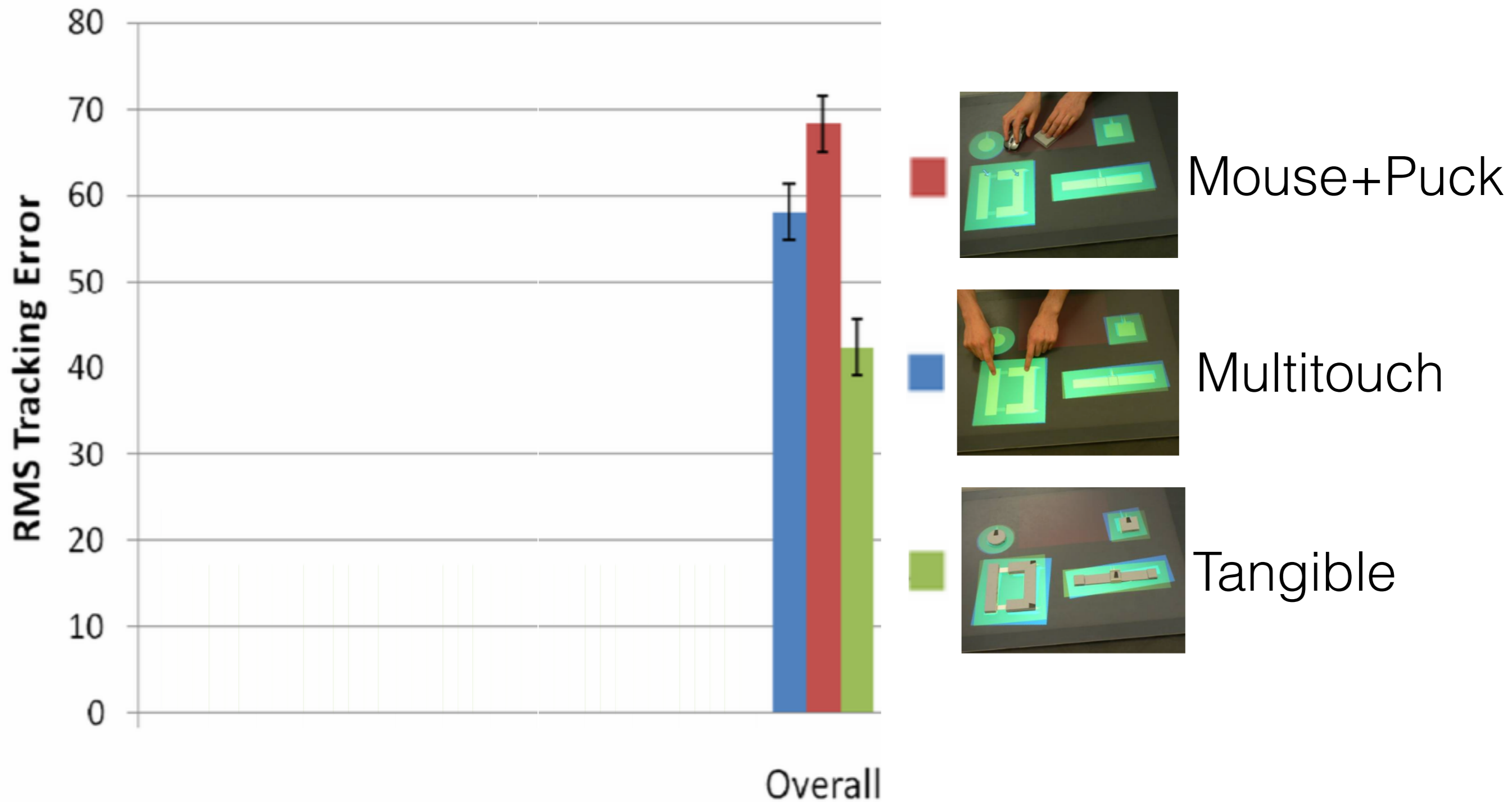
Tangible User Interfaces: Benefit over multitouch

Measures: root-mean-square errors
of all dimensions
(position, orientation and scale or cursor position if applicable)
of all devices

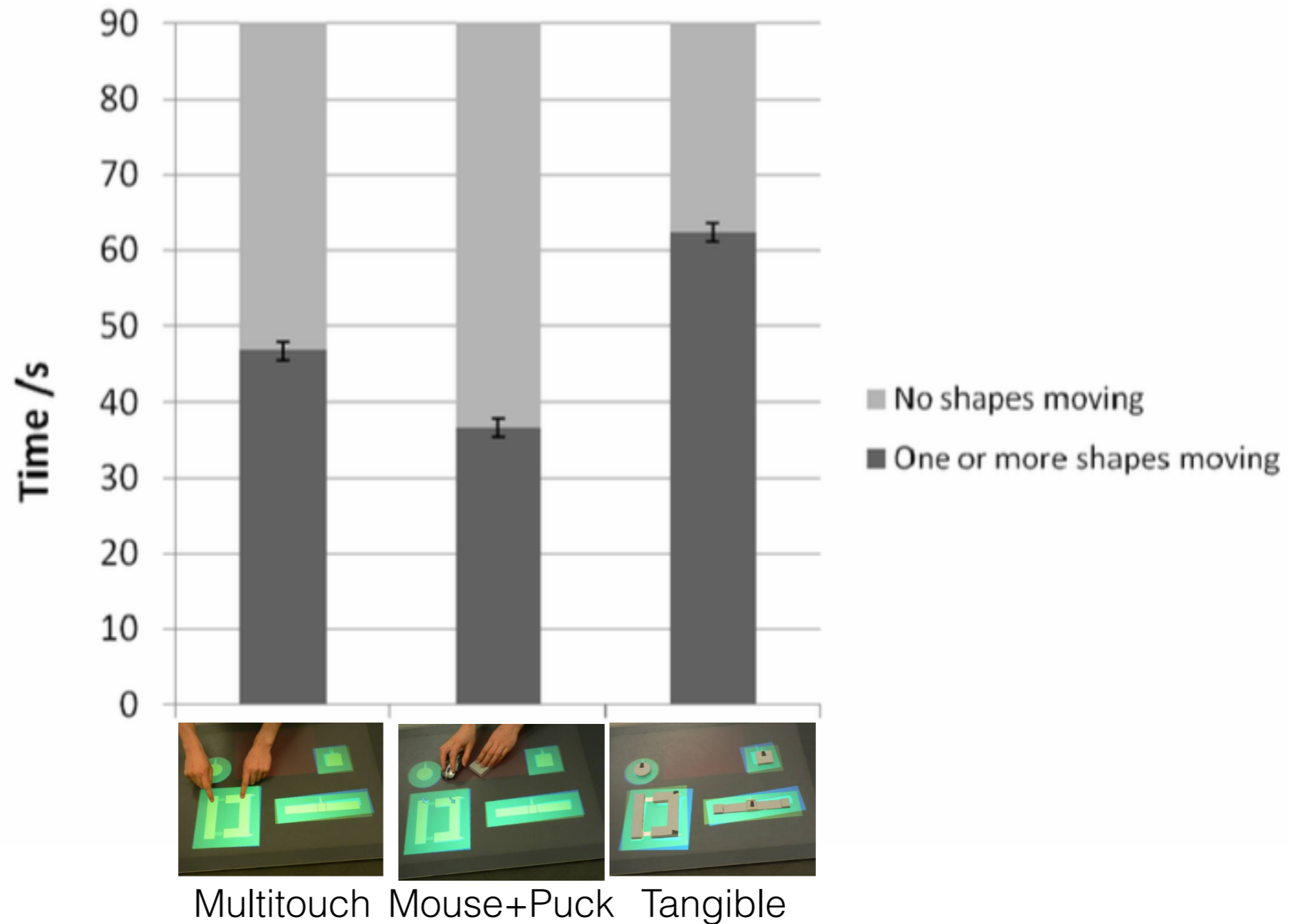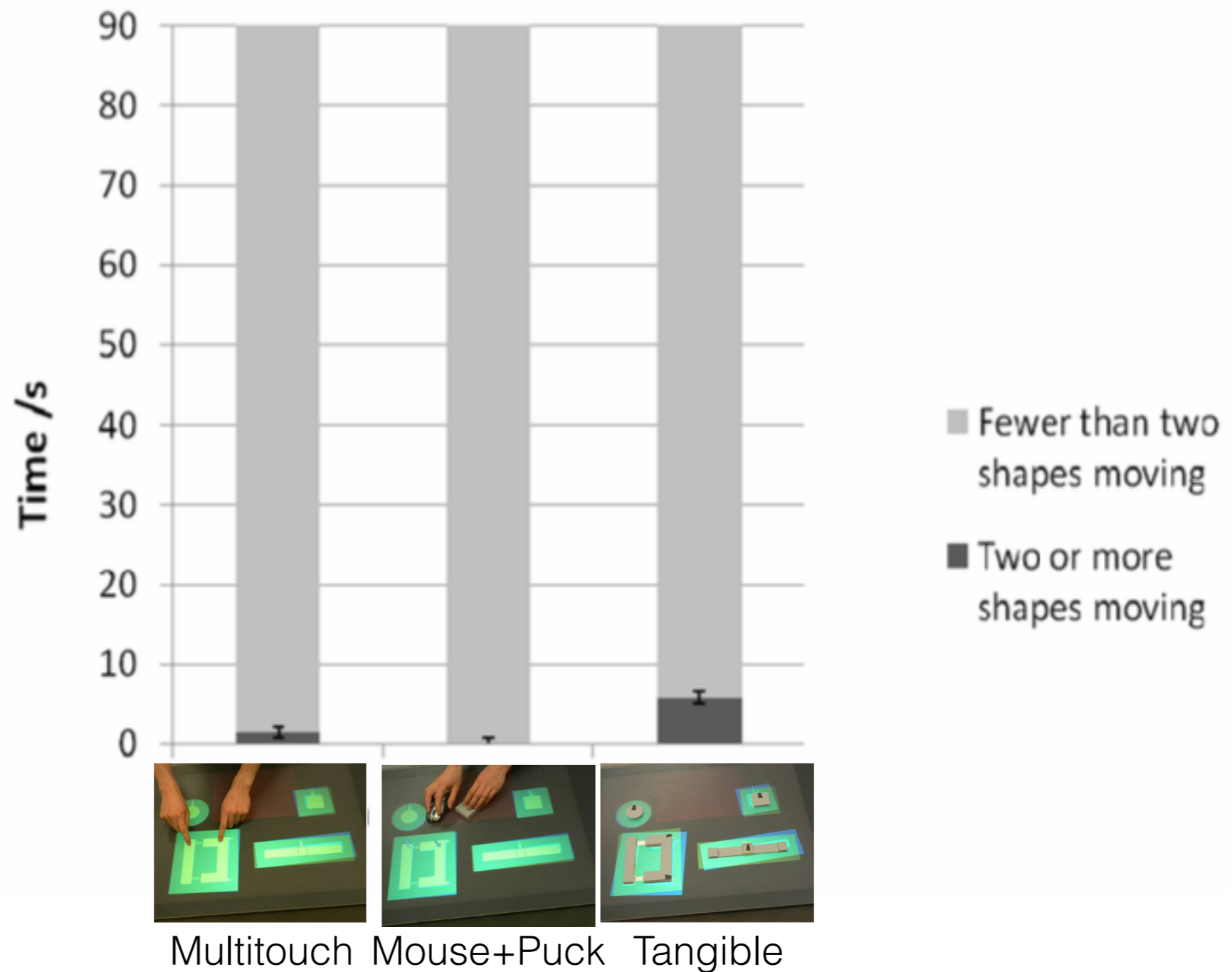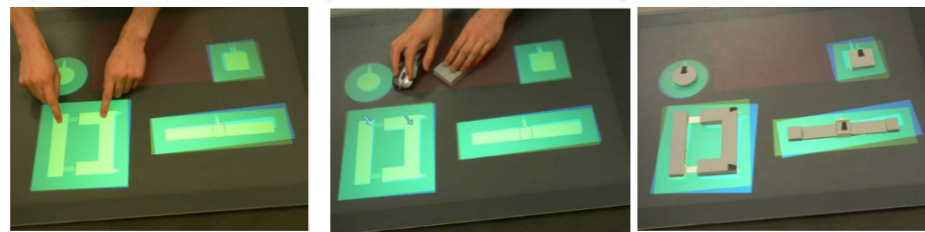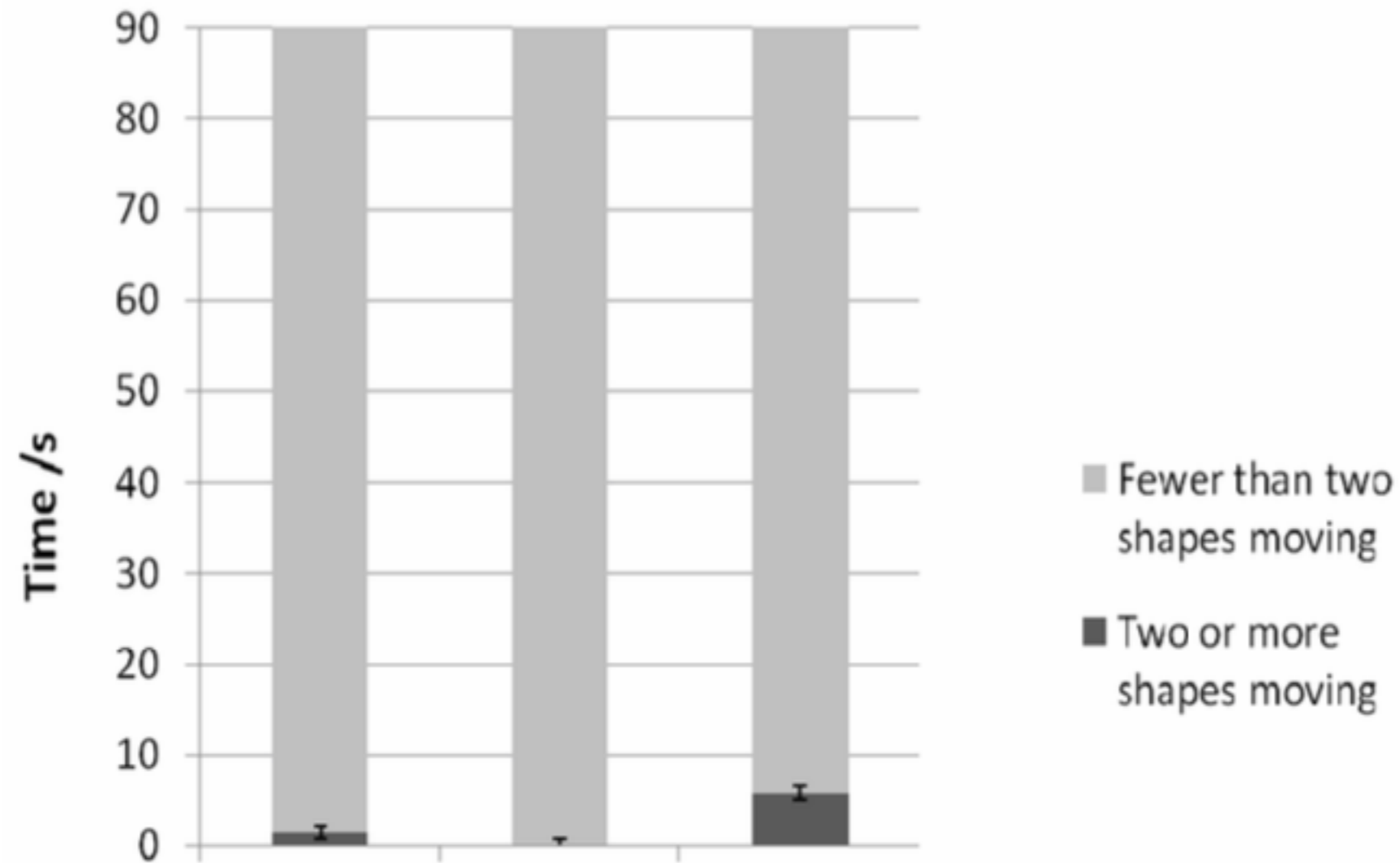+ subjective preference, confort and ease of use

Tangible User Interfaces: Benefit over multitouch

Tangible User Interfaces: Benefit over multitouch

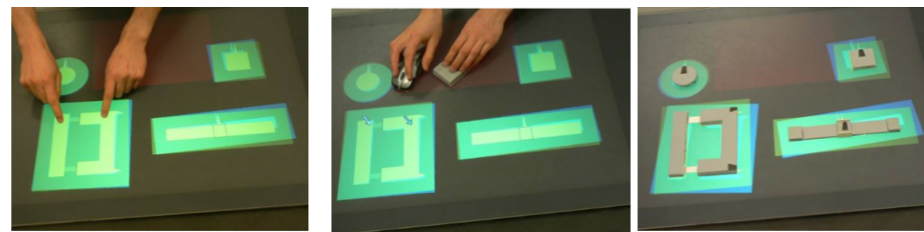# Tangible User Interfaces: Benefit over multitouch

Multitouch Mouse+Puck Tangible

Tangible User Interfaces: Benefit over multitouch

Multitouch   Mouse+Puck   Tangible

Tangible User Interfaces: Benefit over multitouch

Time /s

Fewer than two shapes moving

Two or more shapes moving
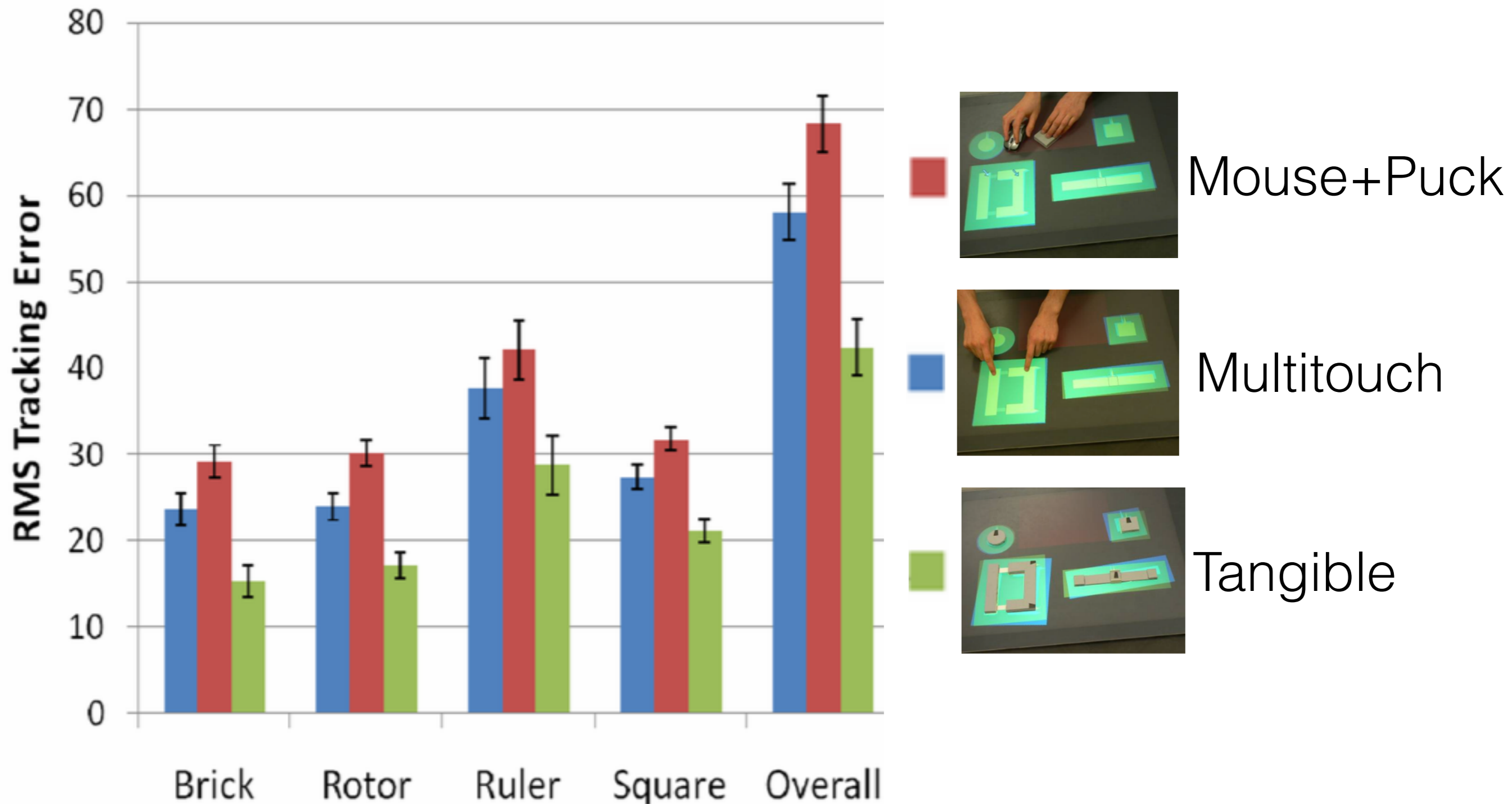
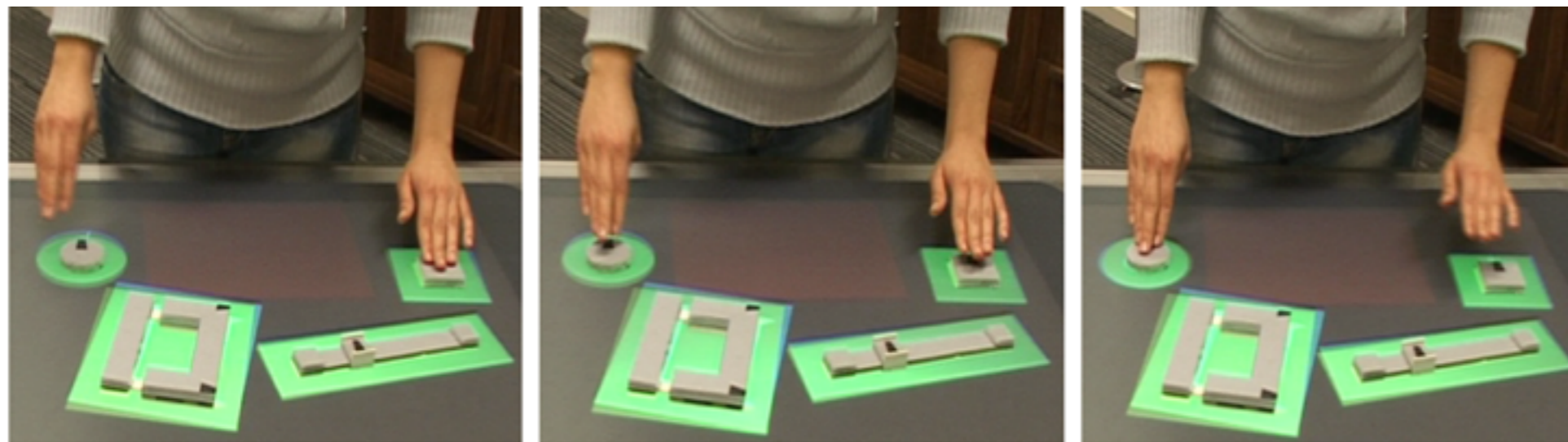Multitouch Mouse+Puck Tangible

→ (little) bimanualism

Tangible User Interfaces: Benefit over multitouch

+ Little difference in preference,
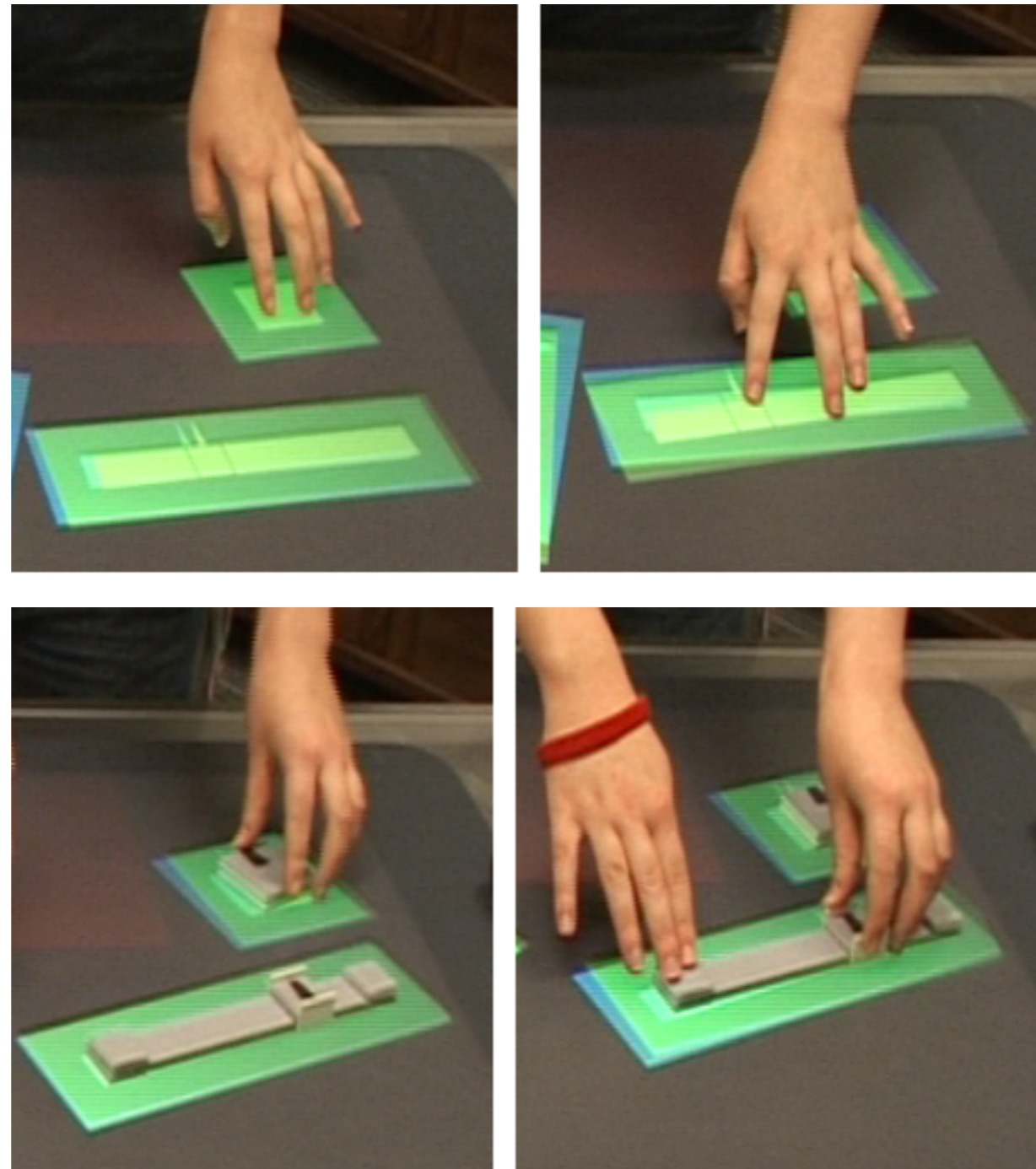comfort
and ease of use

Multitouch Mouse+Puck Tangible
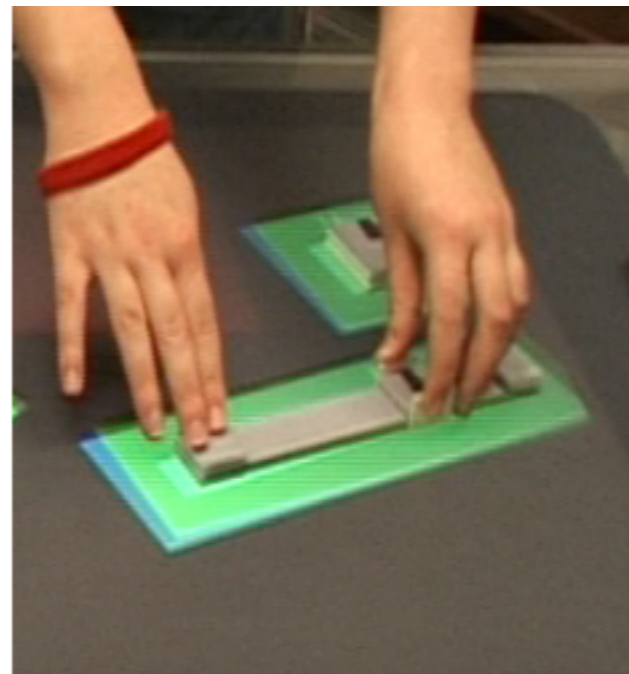
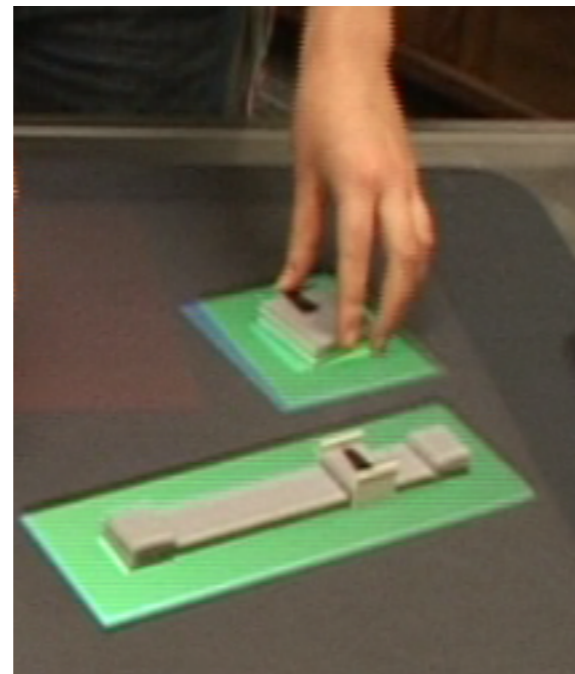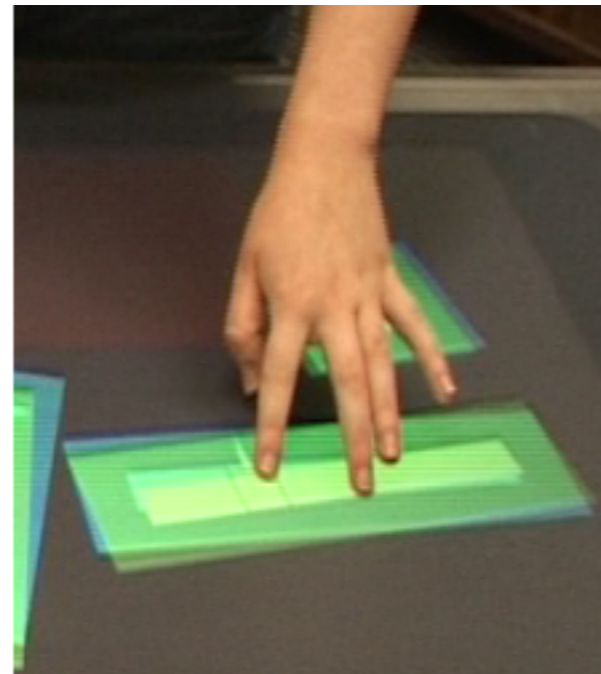# Tangible User Interfaces: Benefit over multitouch
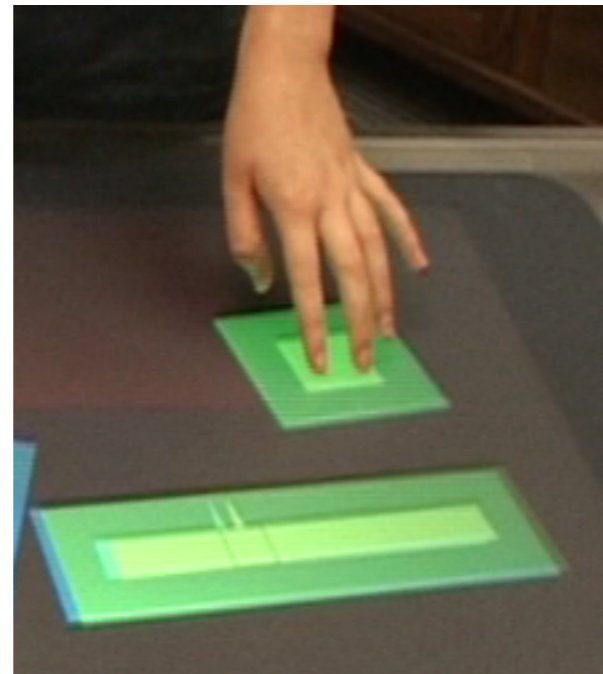

Same pattern for multitouch and tangible

Tangible User Interfaces: Benefit over multitouch
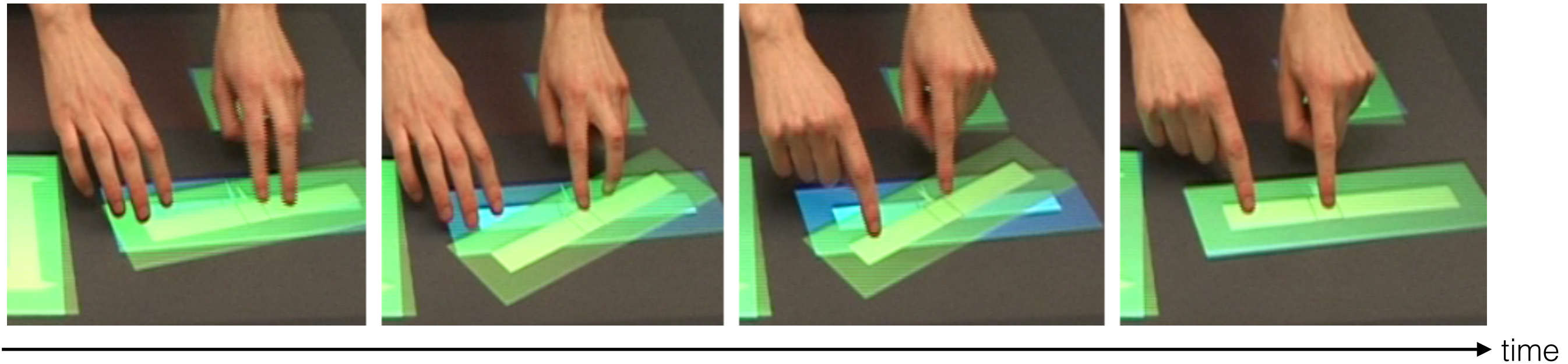

multitouch
≠
tangible

Tangible User Interfaces: Benefit over multitouch
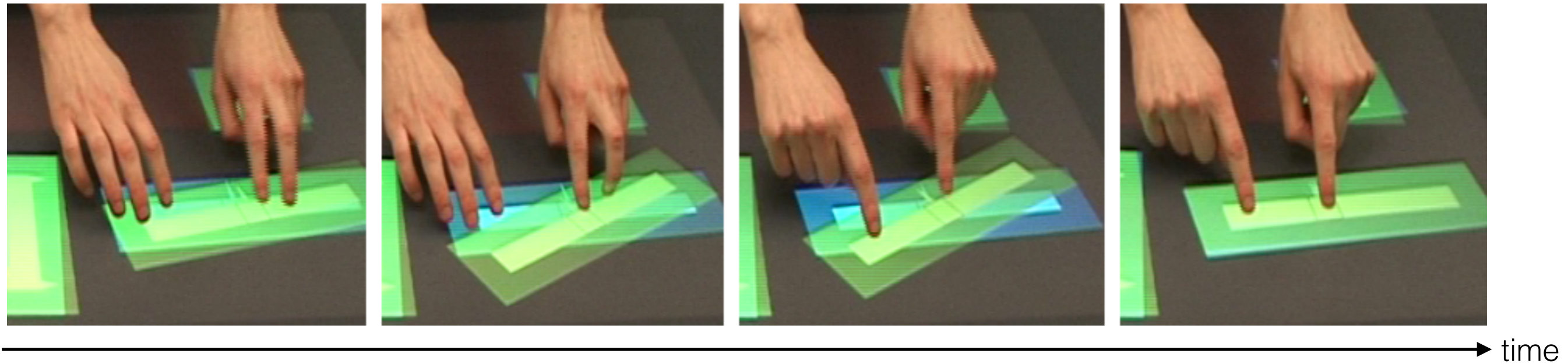

number of contact points

multitouch ≠ tangible

Tangible User Interfaces: Benefit over multitouch

time

multitouch:
number of contact points

Tangible User Interfaces: Benefit over multitouch

time →

multitouch:
number of contact points decrease ⇒ more accurate

tangible:
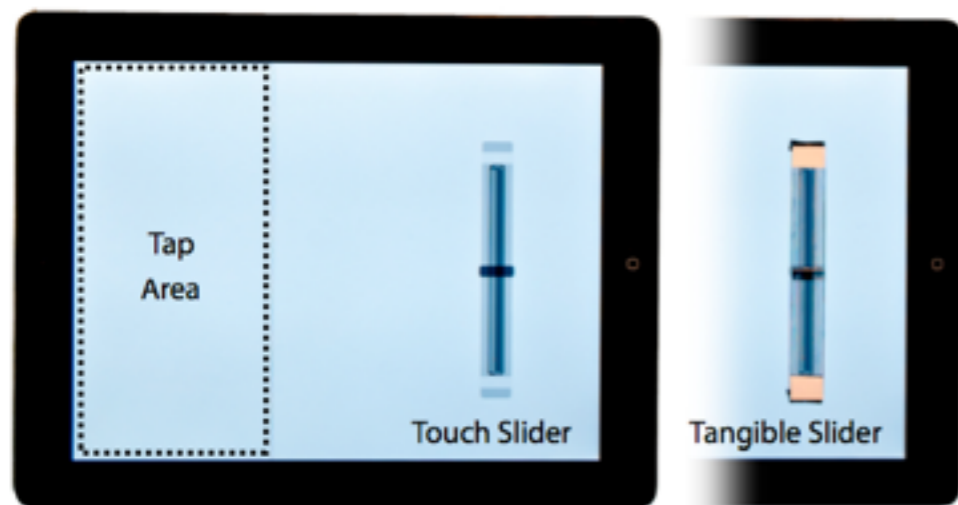number of contact points increase ⇒ more accurate

+ greater variability within and between participants

Tangible User Interfaces: What are they good for?

Several experiments demonstrated their benefits

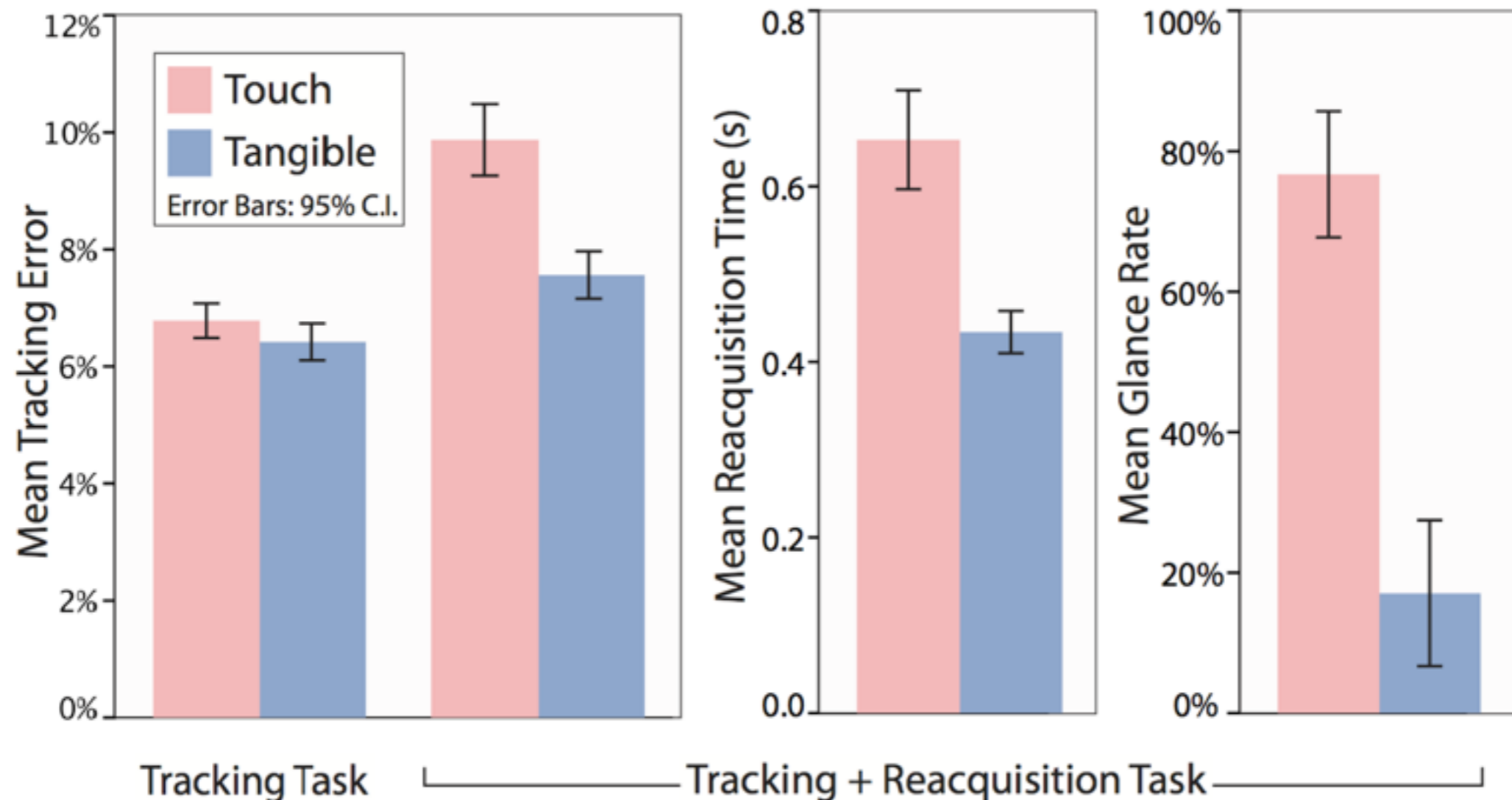# Tangible User Interfaces: Benefit for distant interaction

- Techniques: Touch vs. Tangible slider

- Tasks: Tracking vs. Tracking + additional tapping

Tangible User Interfaces: Benefit for distant interaction

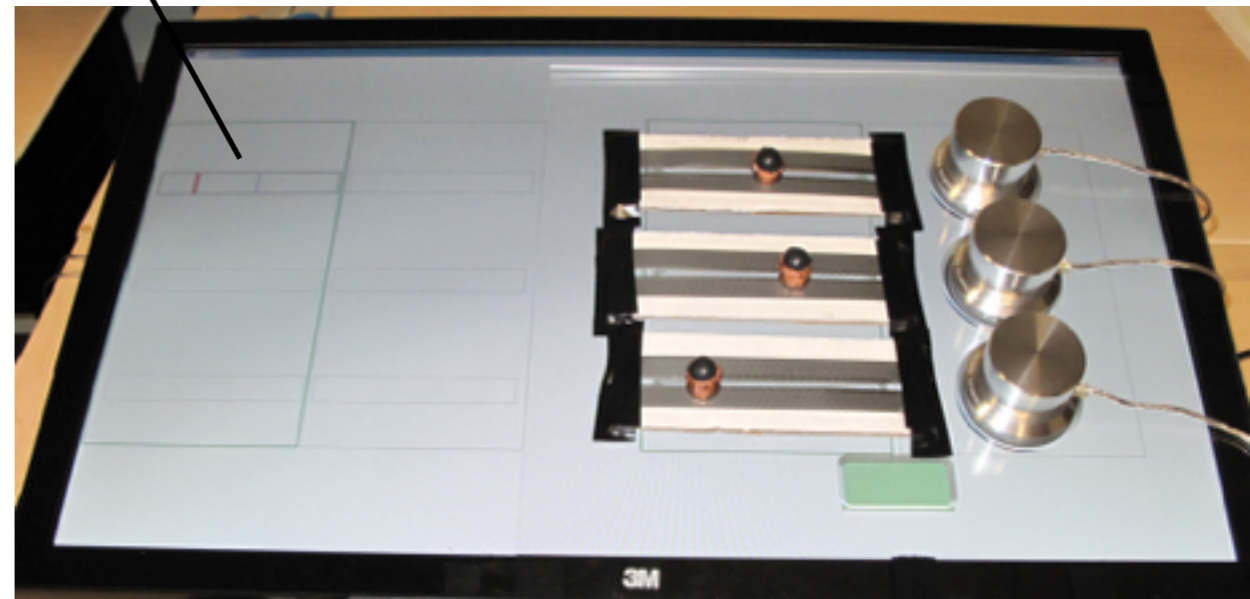- Comparing touch and tangible interaction

Tangible User Interfaces: What are they good for?

Several experiments demonstrated their benefits

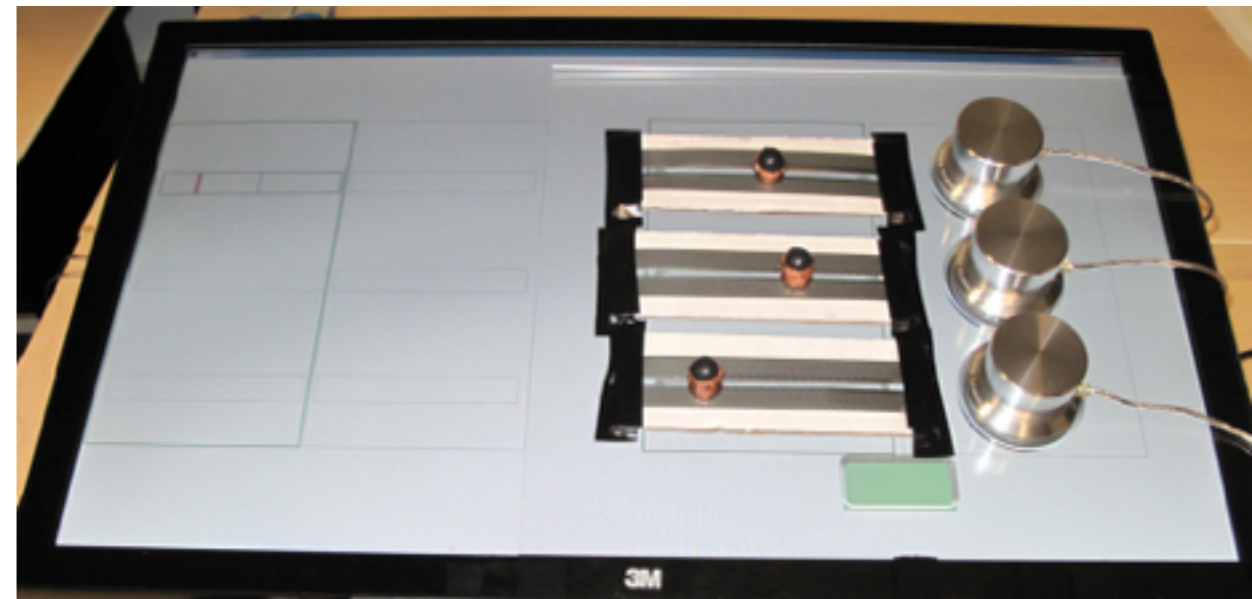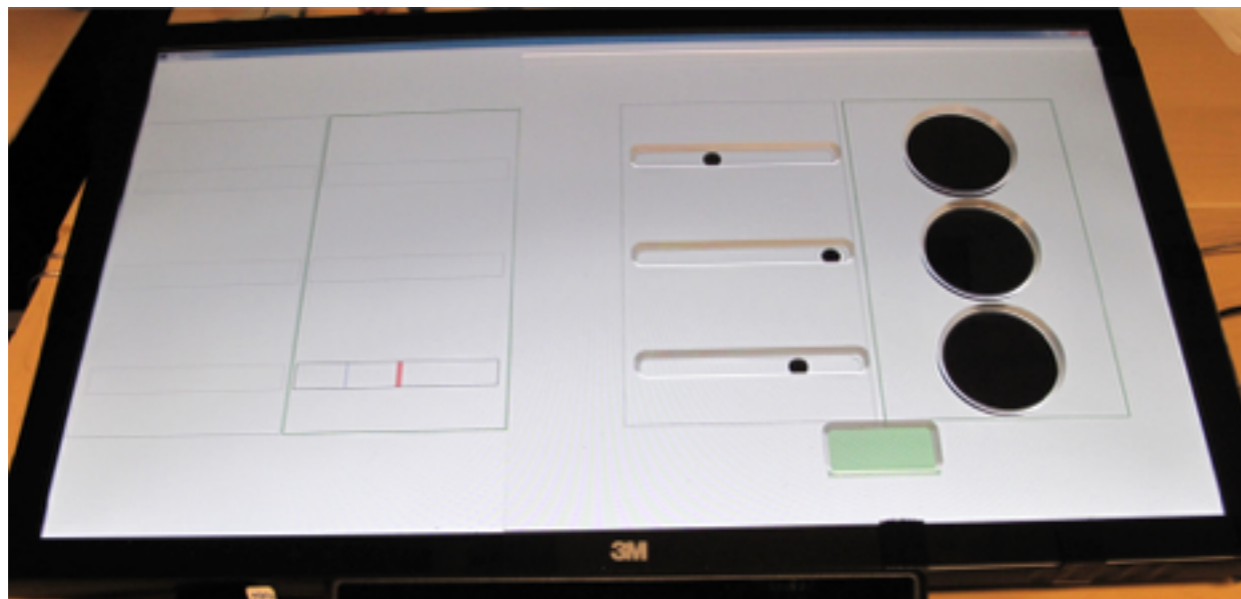# Tangible User Interfaces: Benefit over touch and overlay

Tasks: set horizontal position of cursor

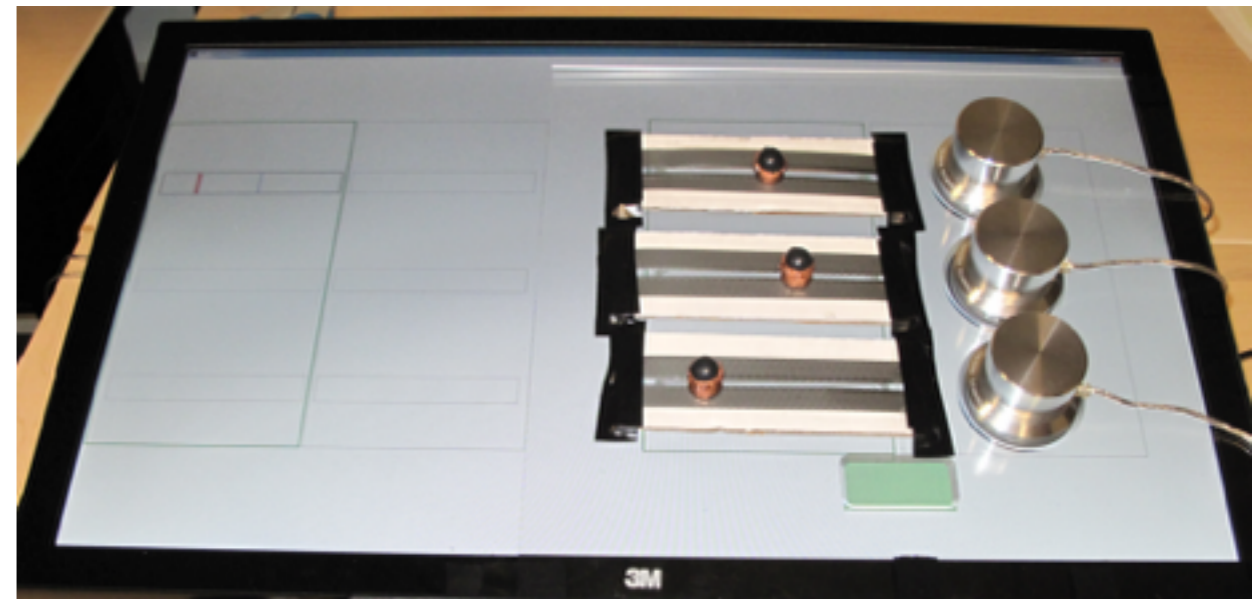# Tangible User Interfaces: Benefit over touch and overlay

Tasks: set horizontal position of cursor

1. Press green button;
   Acquisition of required tool;
   Move towards and stay in target for 1 second;

2. Move cursor back and forth 5 times
   between two targets

Tangible User Interfaces: Benefit over touch and overlay

	Touch	Overlay	Tangible
Slider			
Single-turn dial			
Multi-turn dial (Task 2 only: with CD gain 3x)			

Tangible User Interfaces: Benefit over touch and overlay
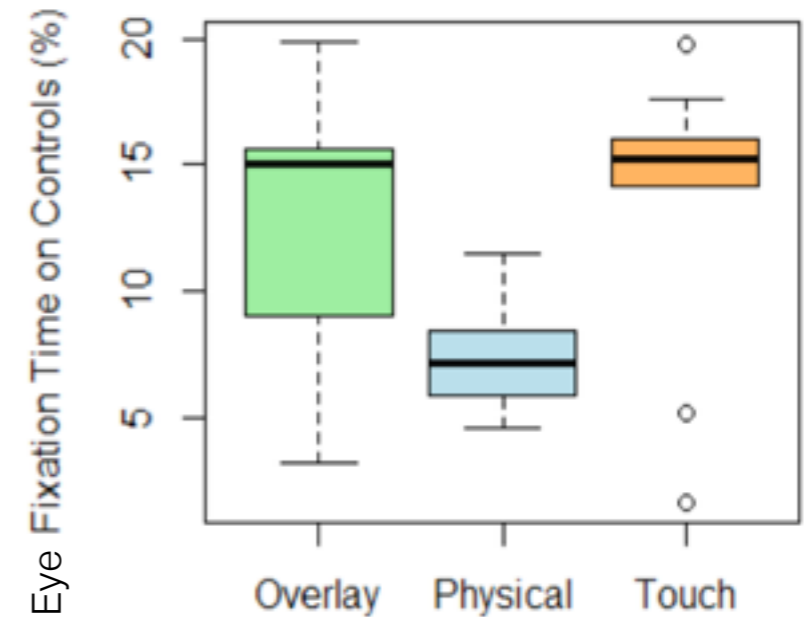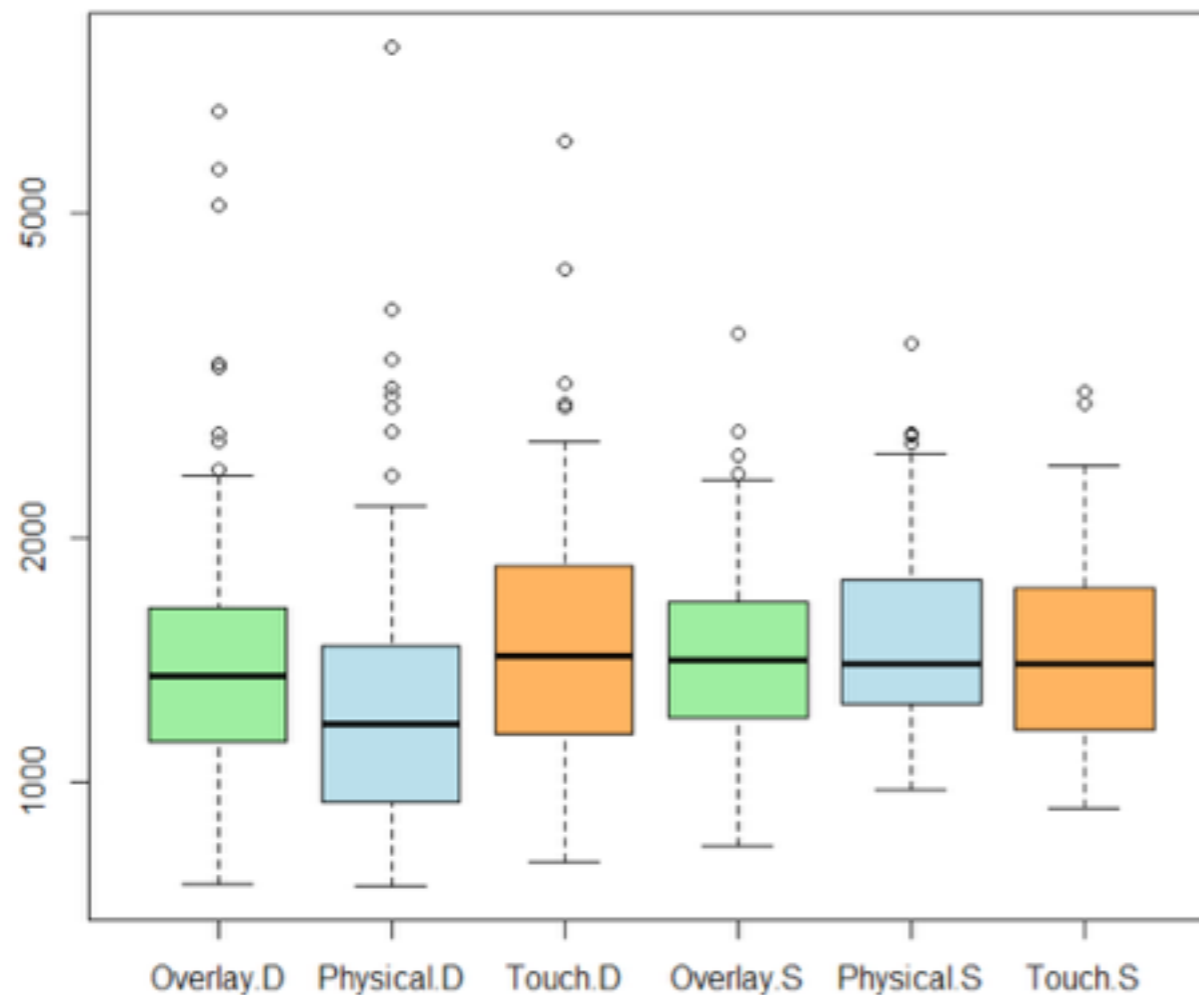
- Task 1: acquisition and movement

	Touch	Overlay	Tangible
Slider		?	
Single-turn dial			

- Task 2: repetitive task

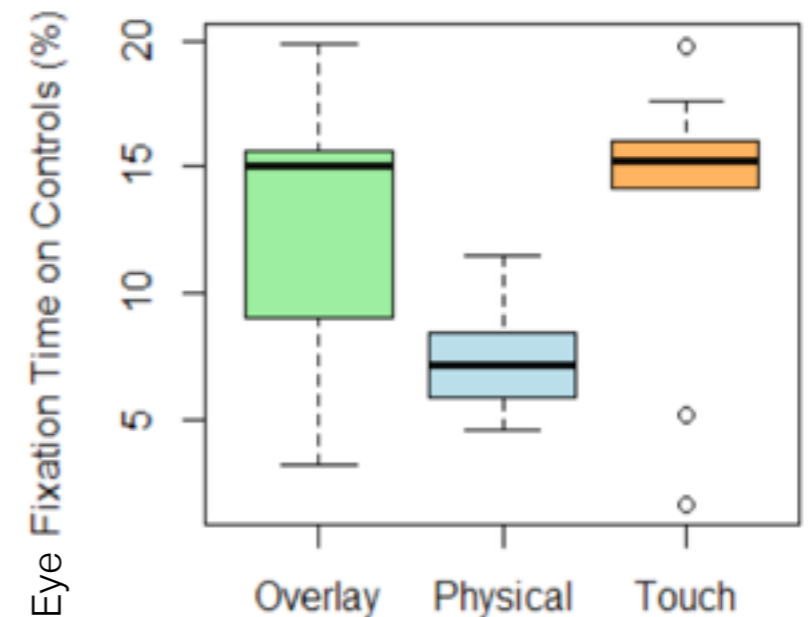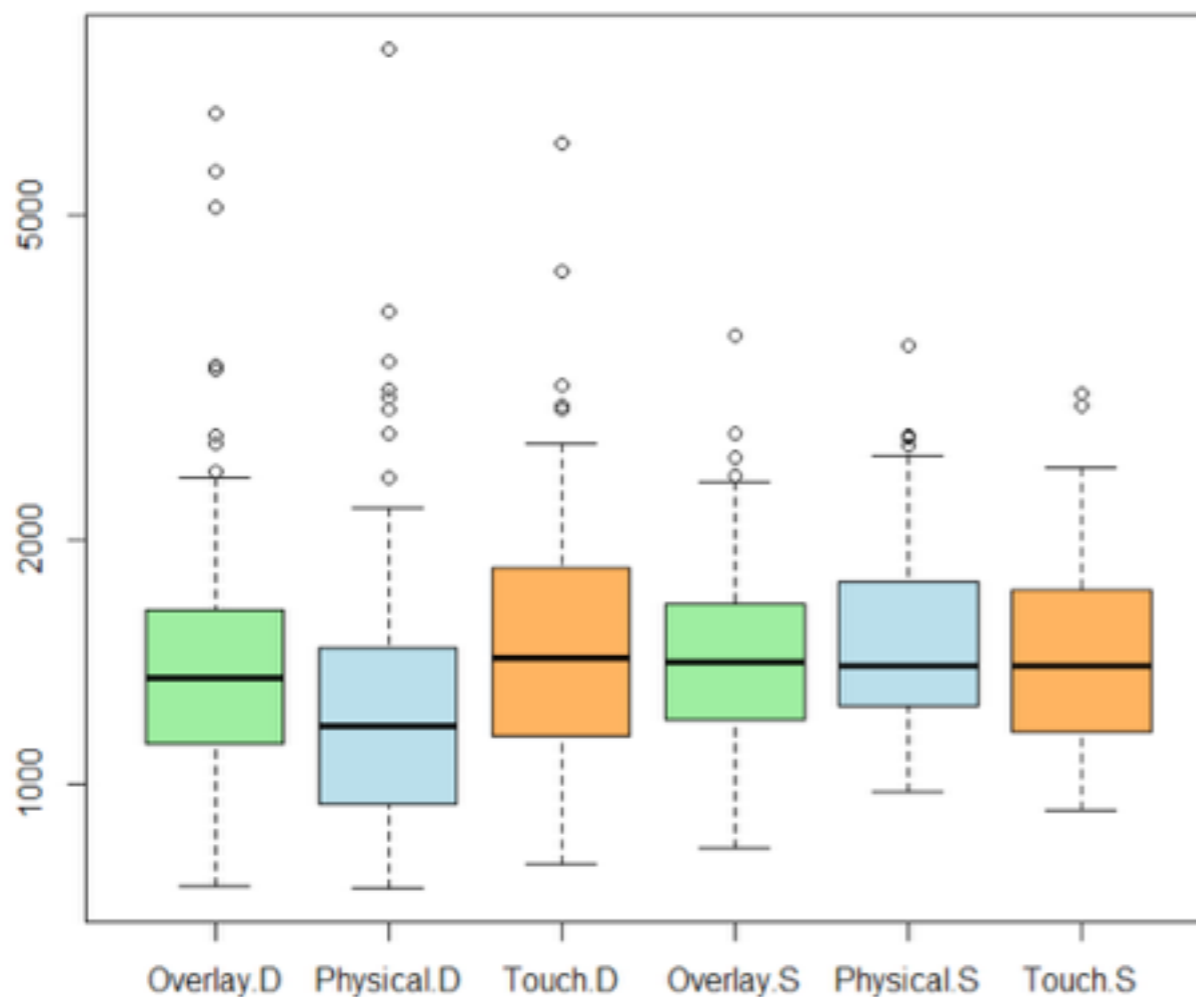|	Touch	Overlay	Tangible
Slider		?	
Single-turn dial			
Multi-turn dial (with CD gain 3x)			

Tangible User Interfaces: Benefit over touch and overlay

Task 1: acquisition and movement

Tangible User Interfaces: Benefit over touch and overlay
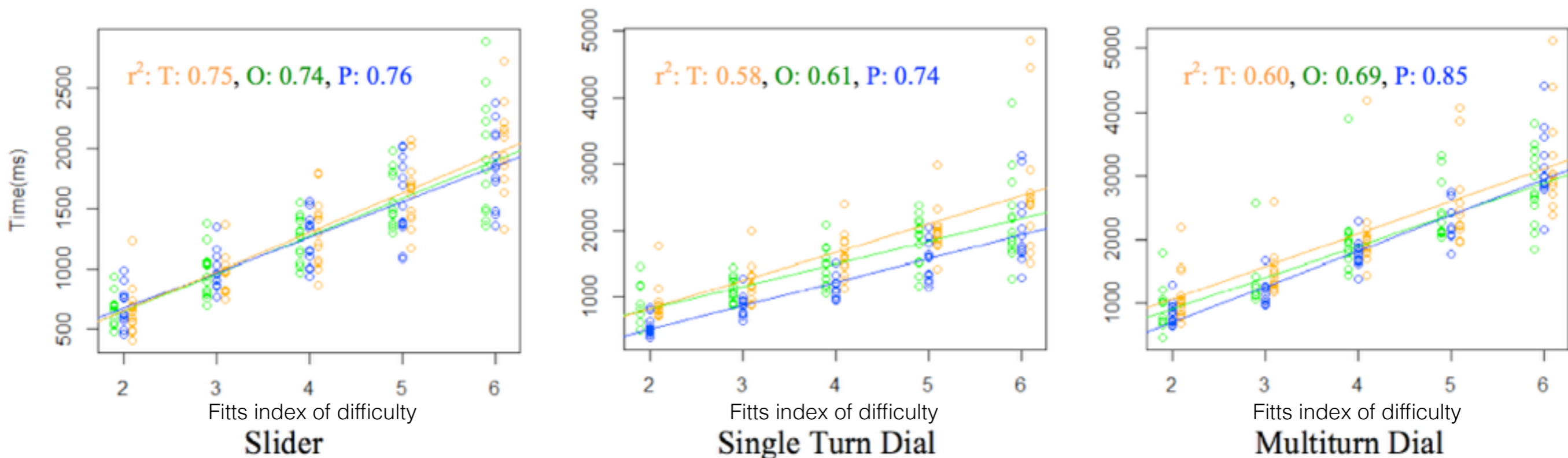
Task 1: acquisition and movement

No difference found for sliders: because of manipulation problem with tangible sliders: *"participants complained that they were wobbly and required some pressure"*
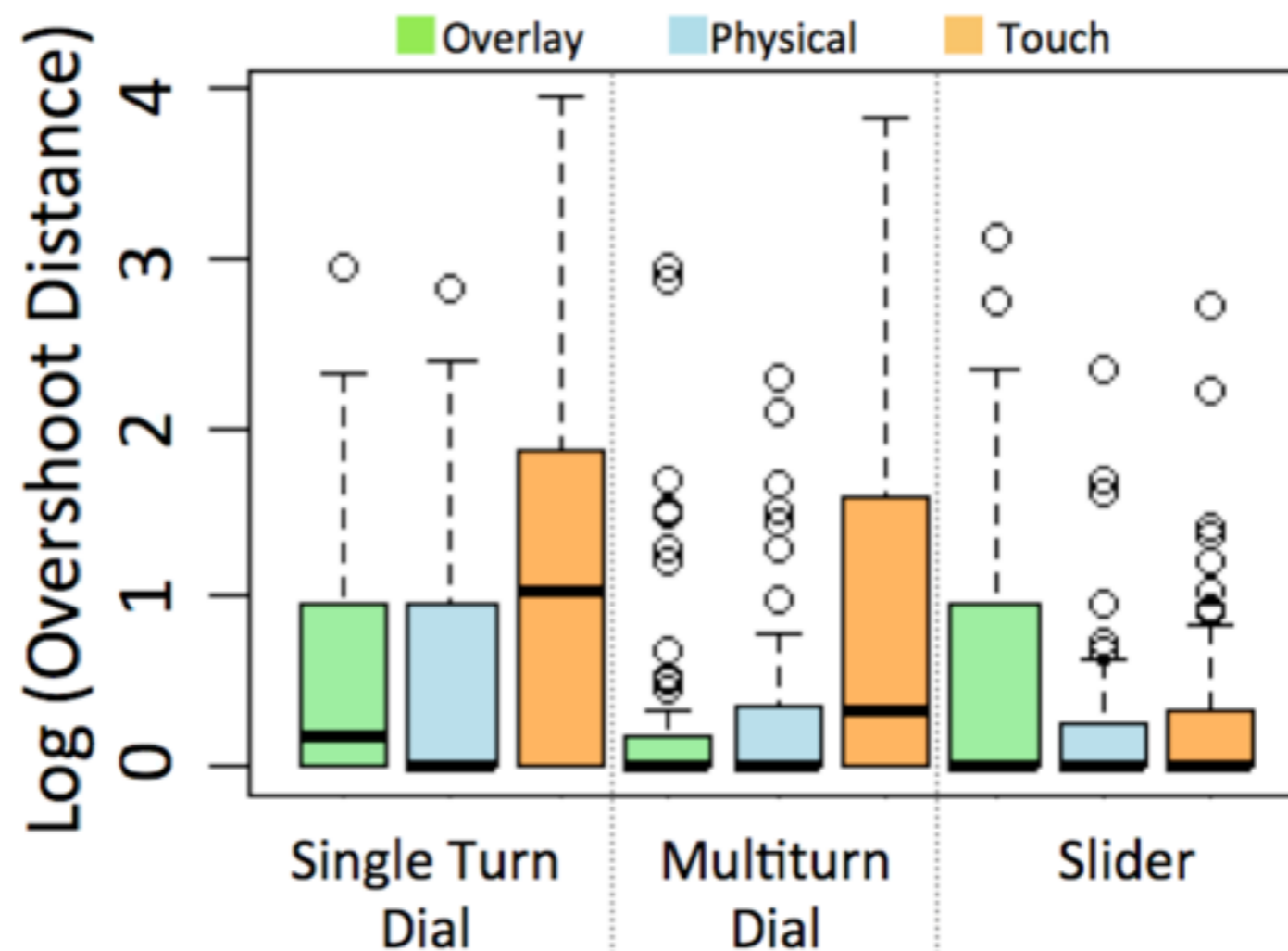
Tangible User Interfaces: Benefit over touch and overlay

Task 2: Repetitive movement

Tangible User Interfaces: Benefit over touch and overlay

Task 2: Repetitive movement
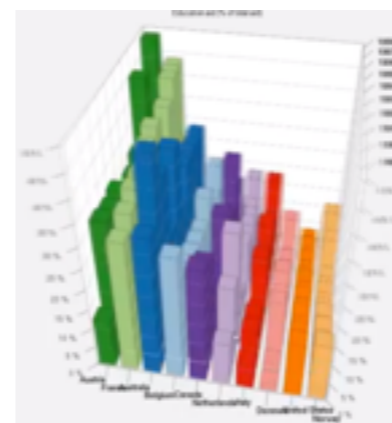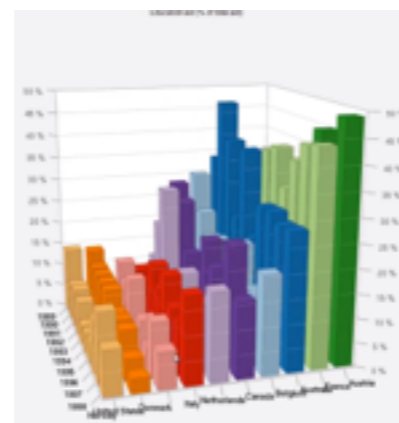
Tangible User Interfaces: What are they good for?

Several experiments demonstrated their benefits

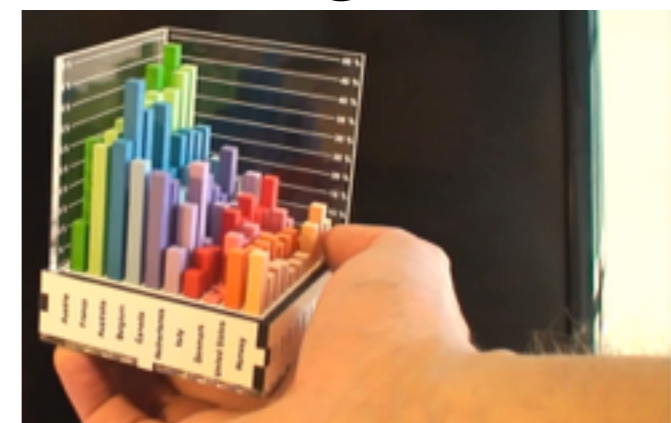# Tangible User Interfaces: What are they good for?

2D   3D Mono 3D Stereo   Tangible

Tasks

Measures

- Find and indicate a range of values

- Find and sort values

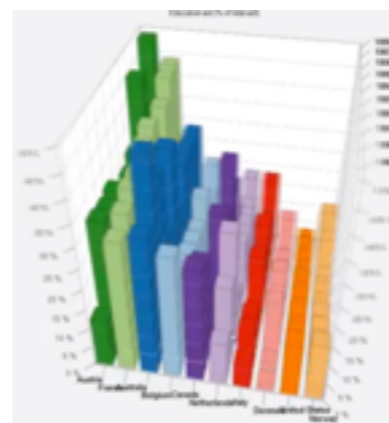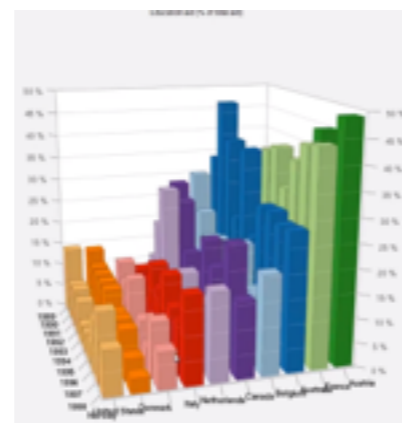- Find and compare values

- Time

- Error rate

Tangible User Interfaces: What are they good for?

2D   3D Mono 3D Stereo   Tangible
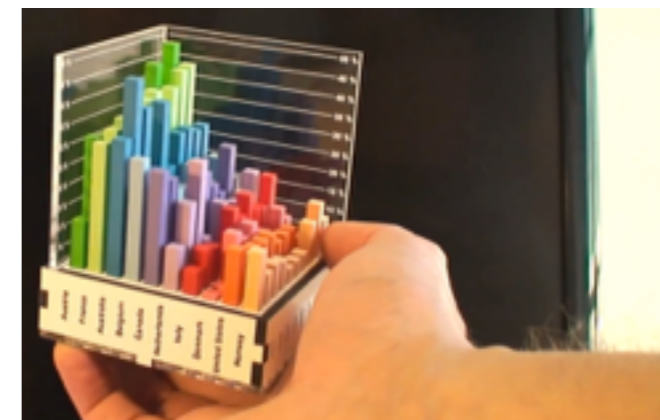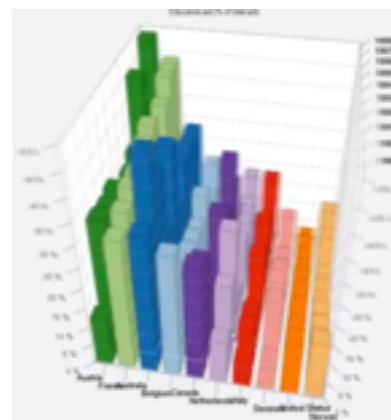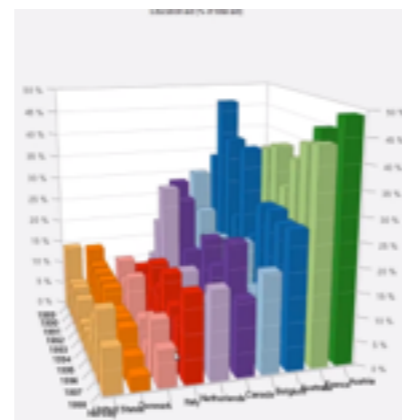

Users are:

- Around 20% faster with Tangible than with 3D

- Around 40% faster with 2D than with Tangible

  - however, effect weaker if the task cannot be solved by one 2D cut

Tangible User Interfaces: What are they good for?

2D   3D Mono 3D Stereo   Tangible

Among possible explanation: Touch & Proprioception

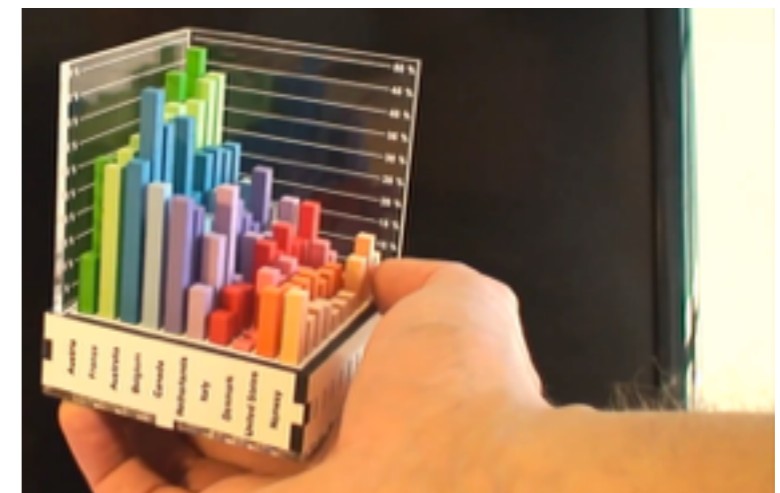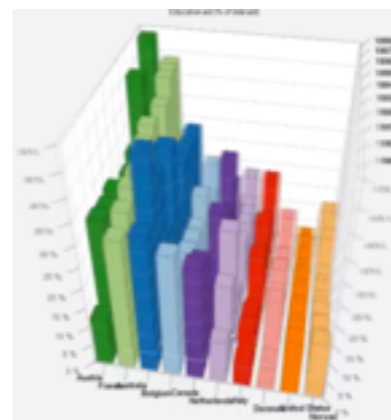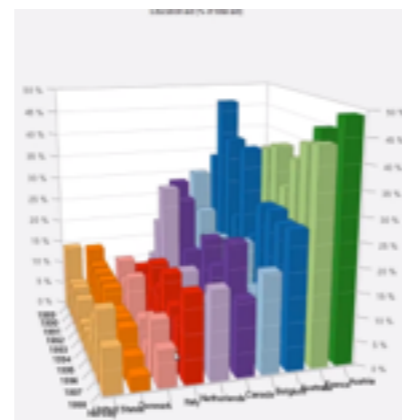| 3D mono/stereo	Tangible
sequential: rotate; mark; rotate; etc.	parallel: rotate // mark*
occluded bars impossible to reach with the mouse cursor	occluded bars reachable with the fingers
mouse cursor does not occlude the bars	proprioception compensate for fingers that occlude the bars

Proprioception

Definition:

- Perception of our own body

- Sense of the relative position of our limbs through our skin, muscle, joints and inner ear

Tangible User Interfaces: What are they good for?

2D   3D Mono 3D Stereo   Tangible

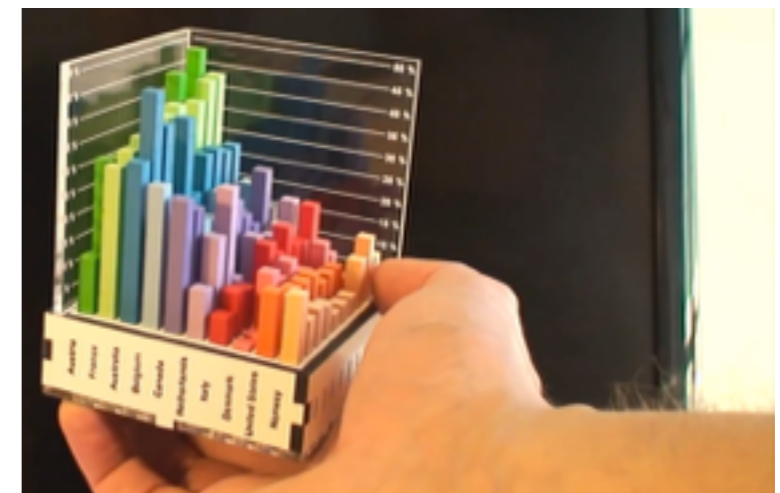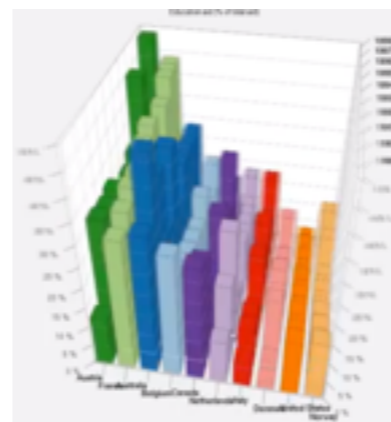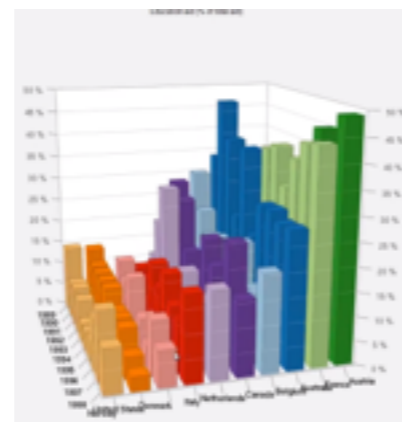Among possible explanation: Direct rotation

3D mono/stereo	Tangible
"Indirect" rotation (mapped to x and y axis of mouse)	"Direct" rotation

Tangible User Interfaces: What are they good for?

2D   3D Mono 3D Stereo Tangible

Among possible explanation: Visual Realism

	3D mono/stereo	**Tangible**
Resolution	1920 x 1080 px for 23"	0.5mm
Stereoscopic cues (Images L and R different)	no / yes	yes
Accomodation cues	at screen distance	at any distance
Shading and shadows	computer-generated	natural
Texture	none	spray paint imperfections

Tangible User Interfaces: What are they good for?

2D   3D Mono 3D Stereo Tangible
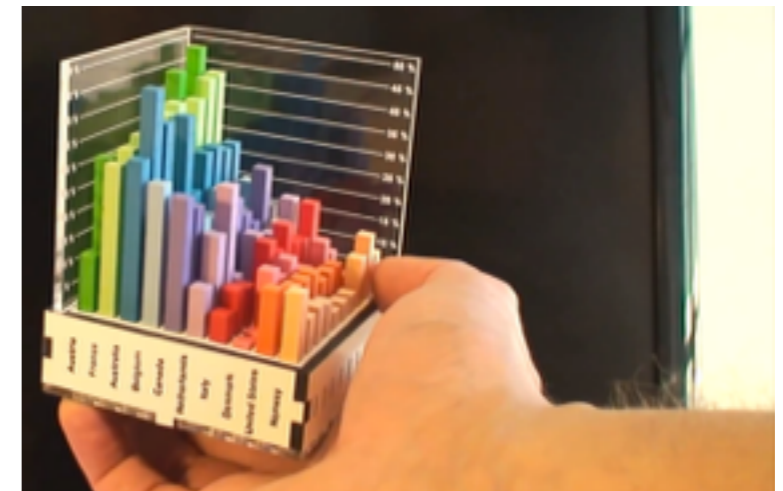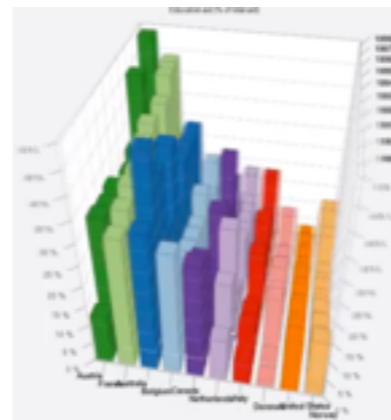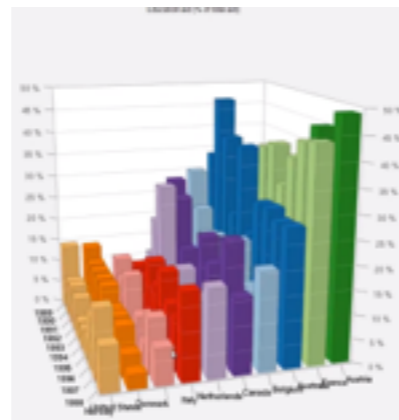
Impact of all possible explanations?

- Touch & Proprioception?

- Direct rotation?

- Visual Realism?

Tangible User Interfaces: What are they good for?

3D Mono &
Indirect mouse rotation &
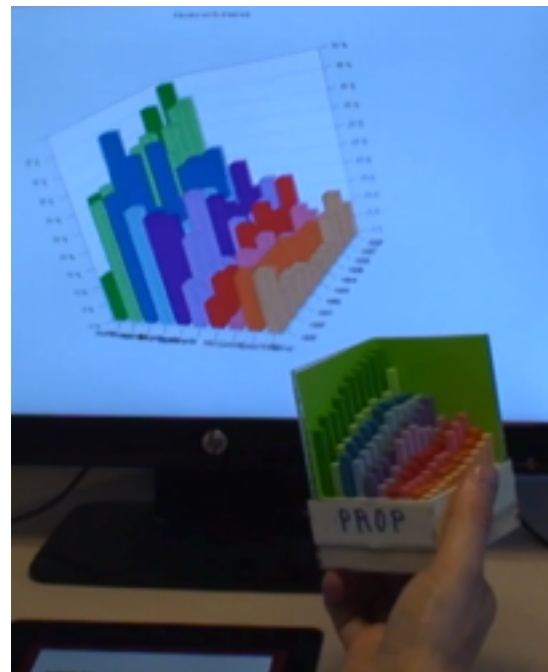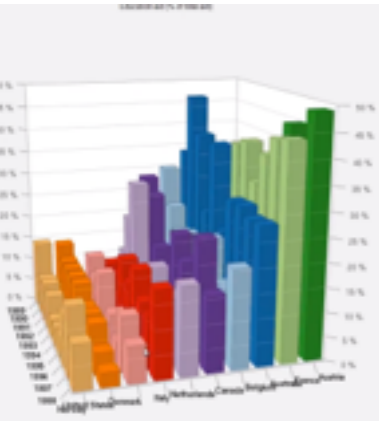No bar marking

Tangible
Direct rotation
& Touch

Direct rotation

Touch & Proprioception

3D Mono &
Prop-based direct rotation &
No bar marking

Tangible
Direct rotation &
No touch

Visual realism

Tangibles User Interfaces: What are they good for?

- Direct rotation: very little faster compared to indirect rotation

- Visual Realism: around 13% faster compared to on-screen

- Touch & Proprioception: around 15% faster than no touch

  - unload cognitive effort into a physical action

Tangible User Interfaces
What are their limitations?