A Psychophysical Investigation of Size as a Physical Variable

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IEEE Transactions on Visualization and Computer Graphics,
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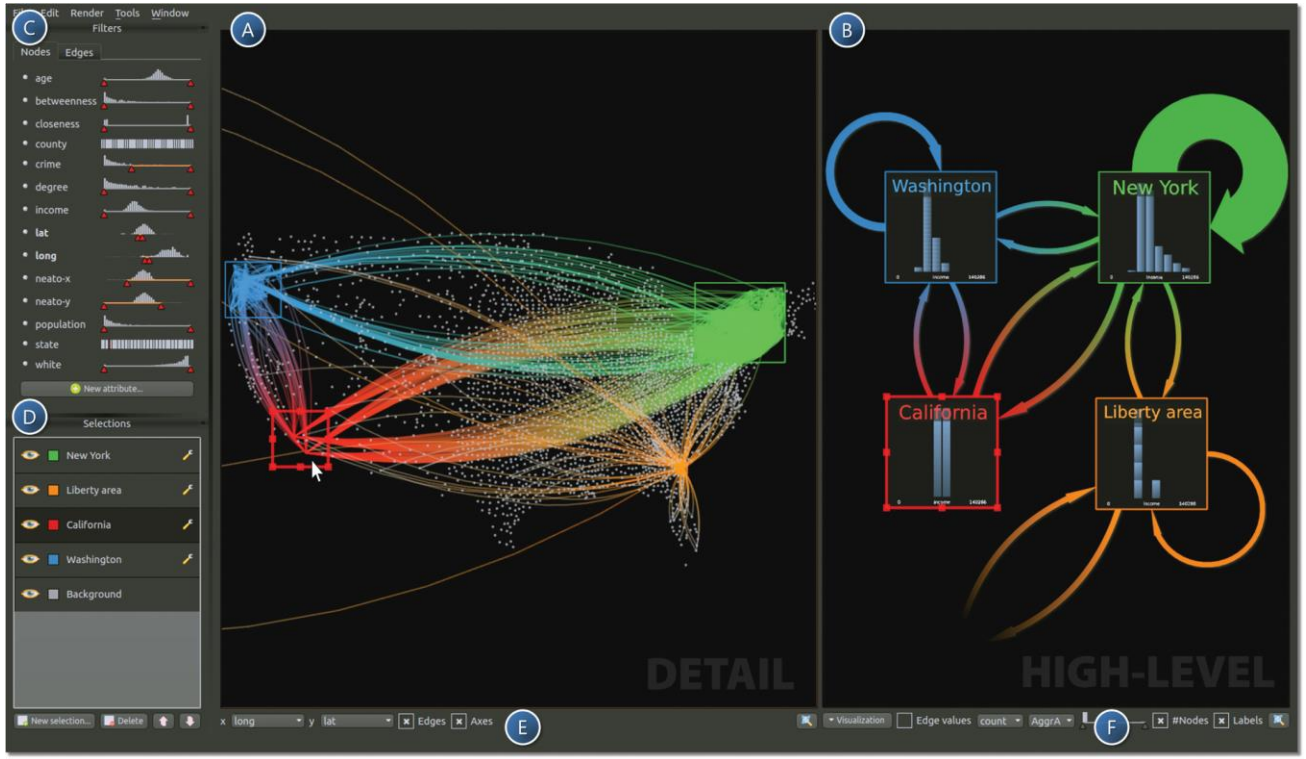
Fig 1

What is data physicalization?

"computer-supported physical representations of data can support cognition, communication, learning, problem solving, and decision making"

Data Visualizations



Visual Variables

Van den Elzen and Wijk, *Multivariate Network Exploration and Presentation*, 2014

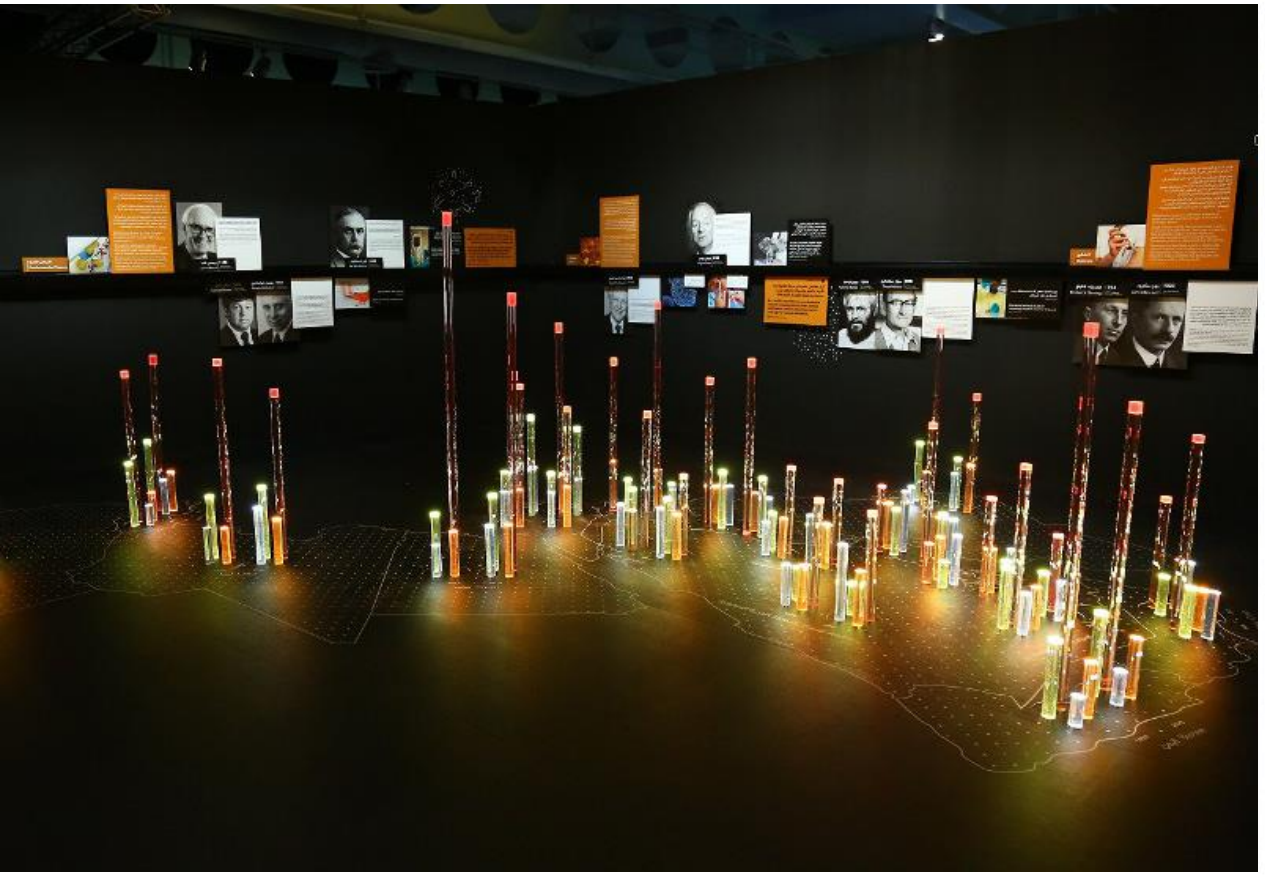
Data Physicalizations

Physical Variables

Hsiang and Mendis, *City of 7 Billion*, 2015

Why data physicalization?

- information retrieval in comparison to on-screen 3D visualizations
- memorability of data compared to paper viz

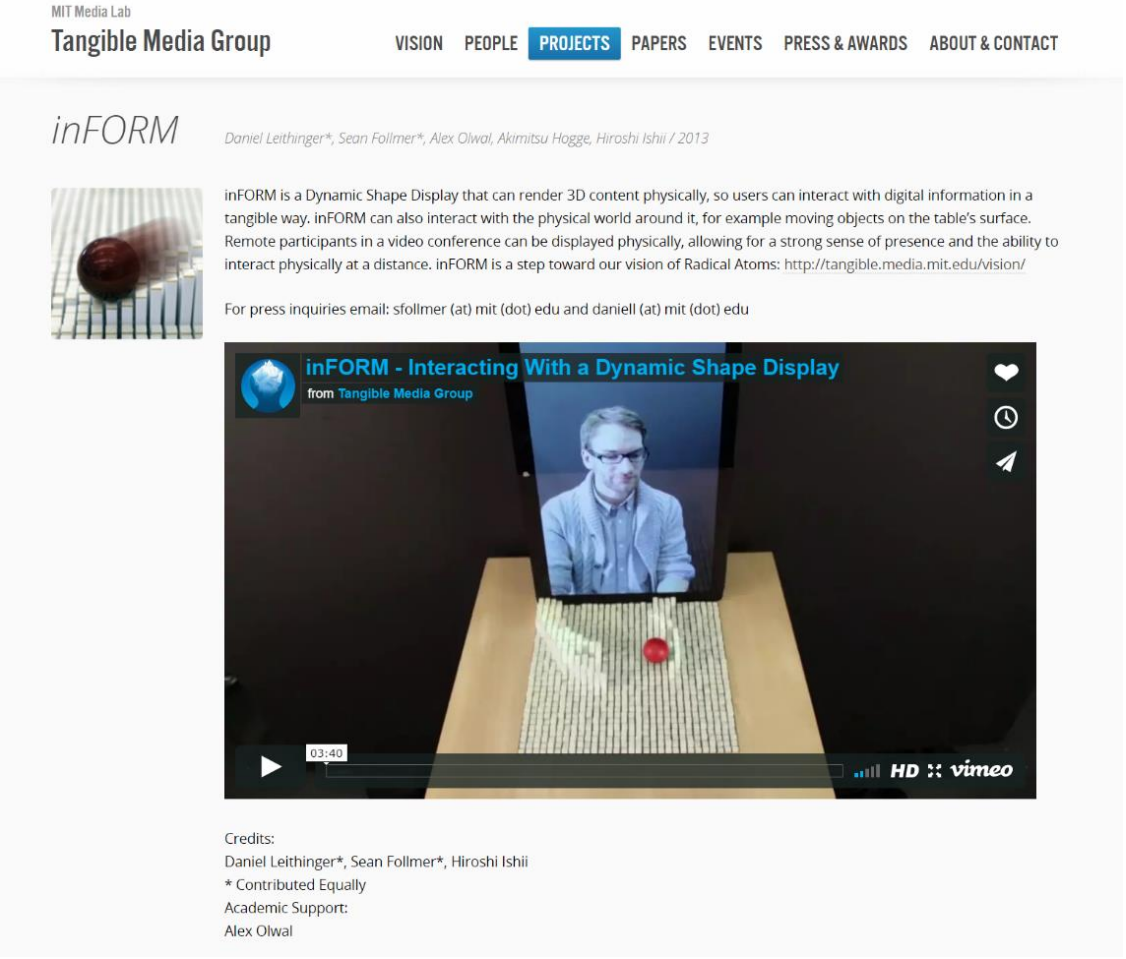


Nobel Museum Exhibition, 2016

Hsiang and Mendis, *City of 7 Billion*, 2015

Why data physicalization?

3D printing, laser cutting, mechanical actuation, shape-changing technology, TUIs (tangible user interfaces)



Tangible Media Group, *inFORM,* MIT Media Lab, ongoing

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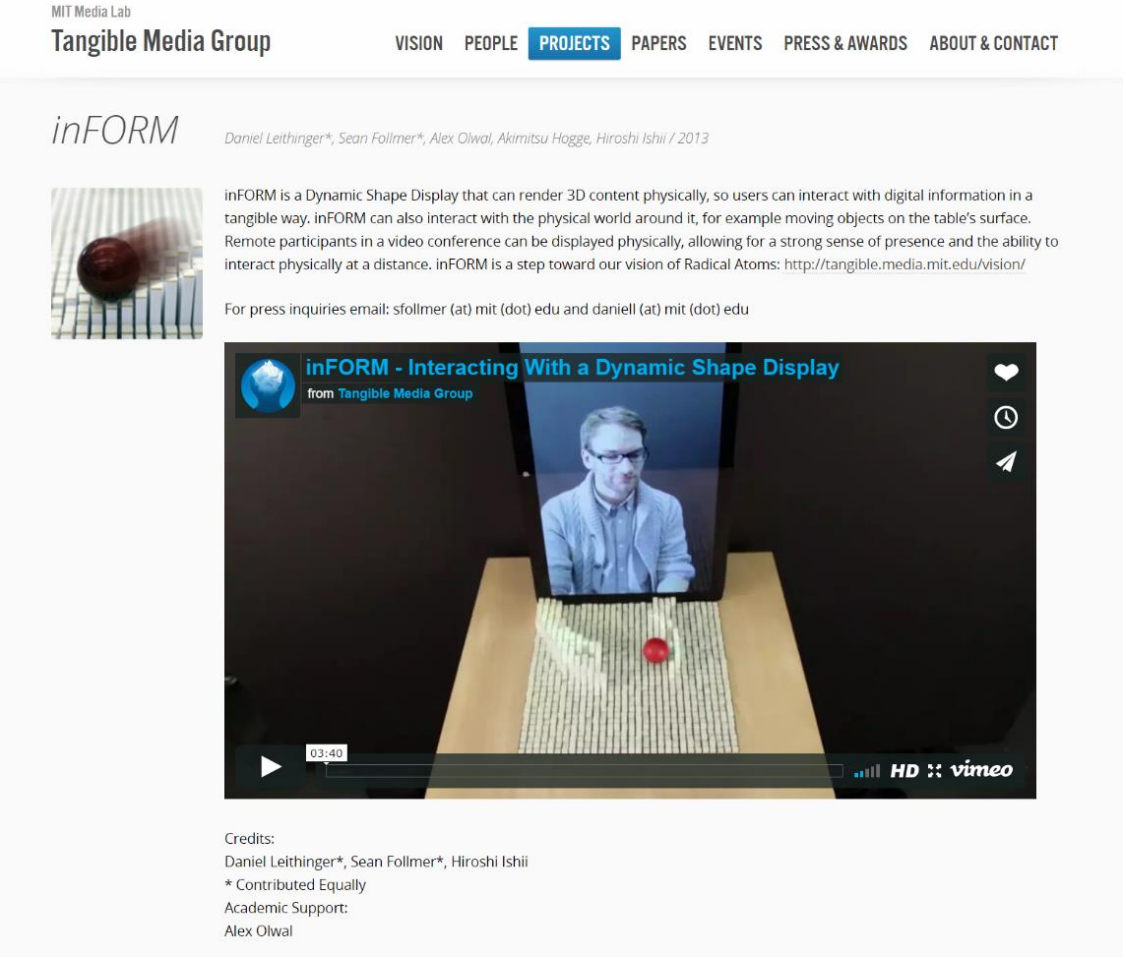

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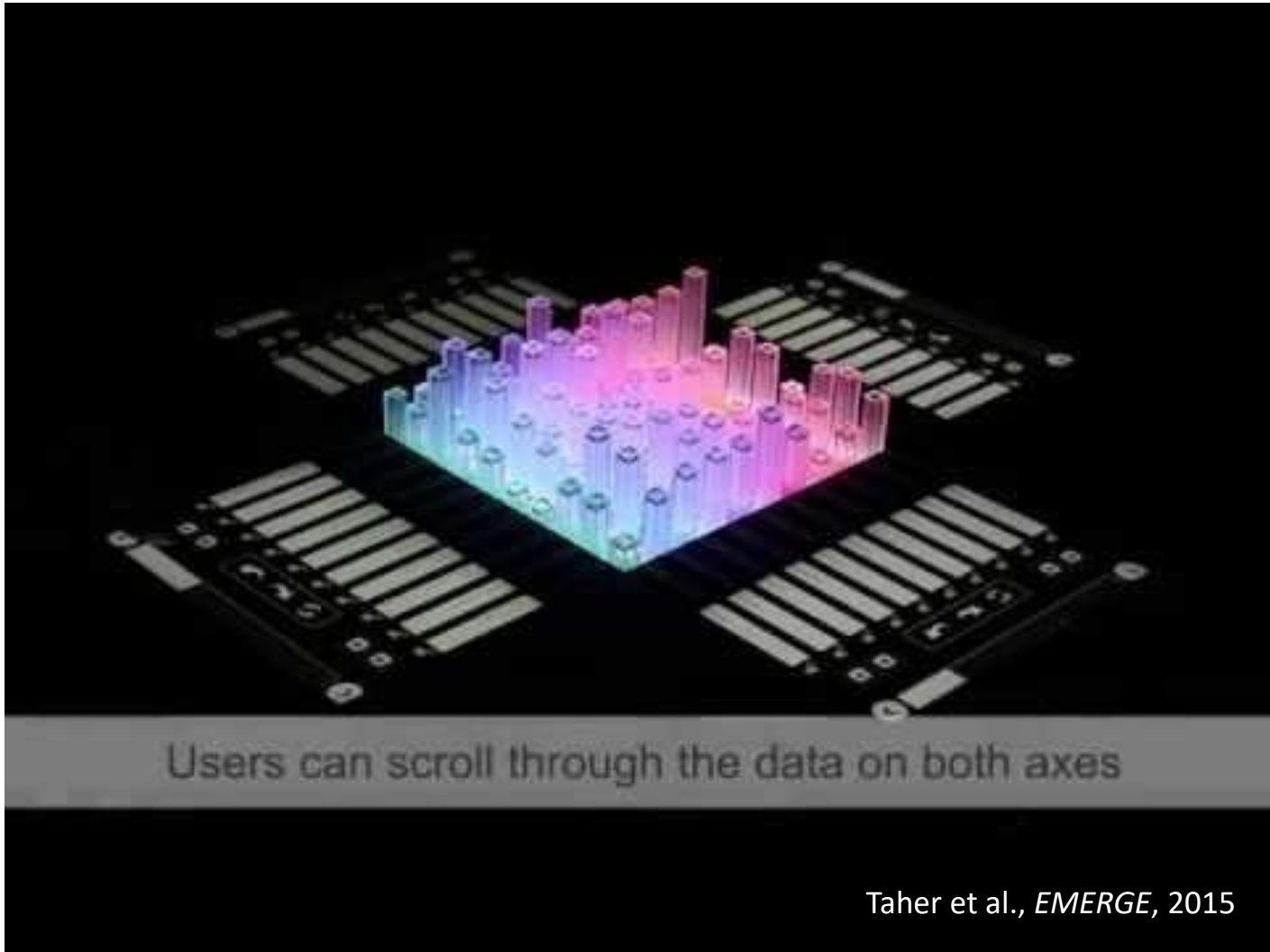
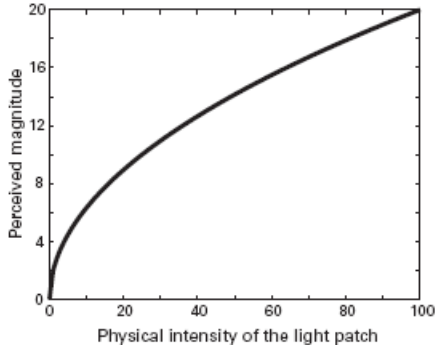
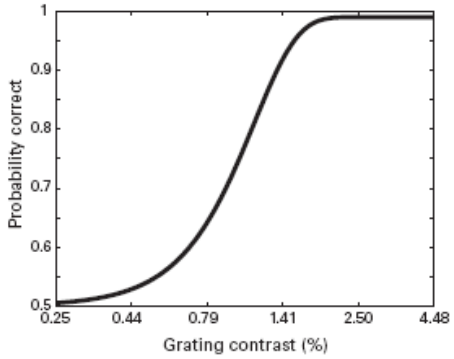


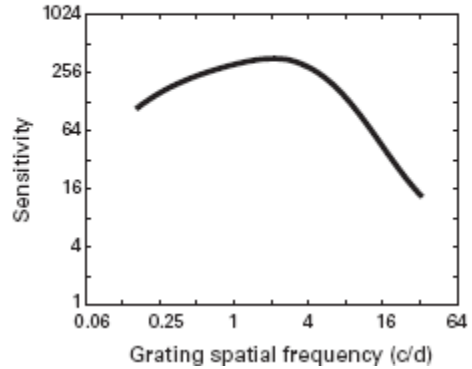
Taher et al., *EMERGE*, 2015

What is psychophysics?

Psychophysics quantitatively investigates the relationship between physical stimuli and the sensations and perceptions they produce



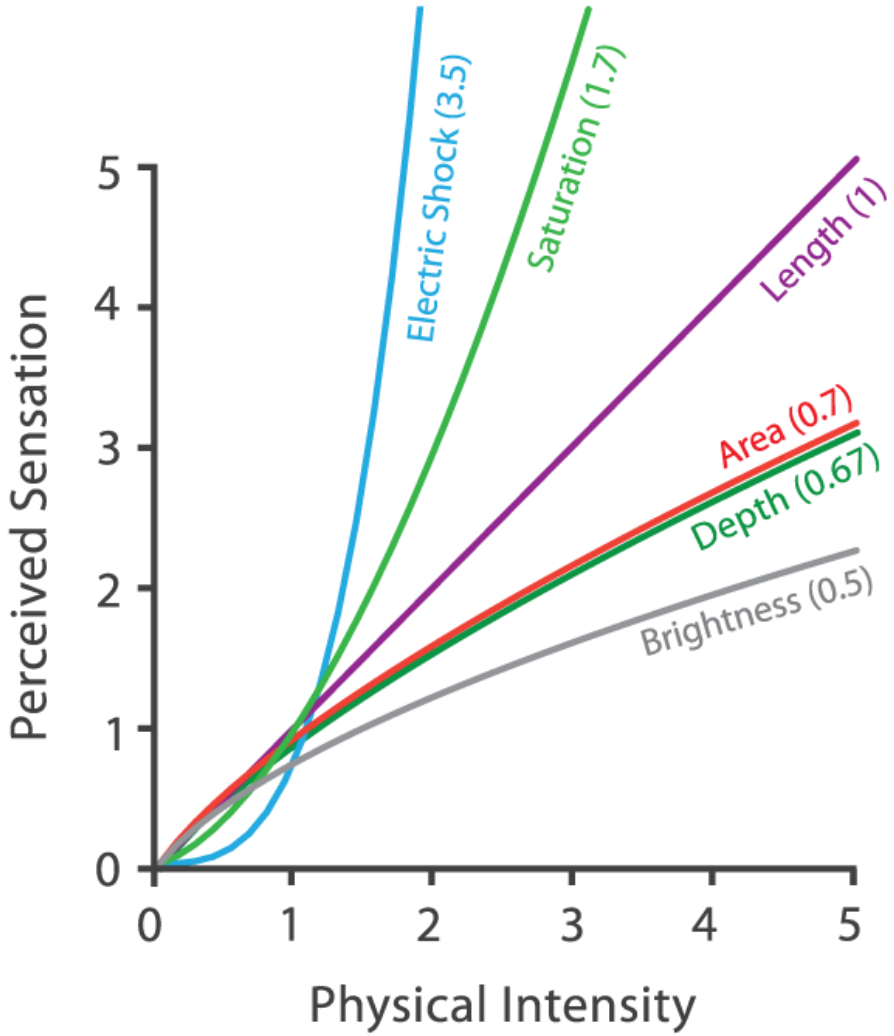




Lu and Dosher, *Visual Psychophysics*, 2013

Why Psychophysics?

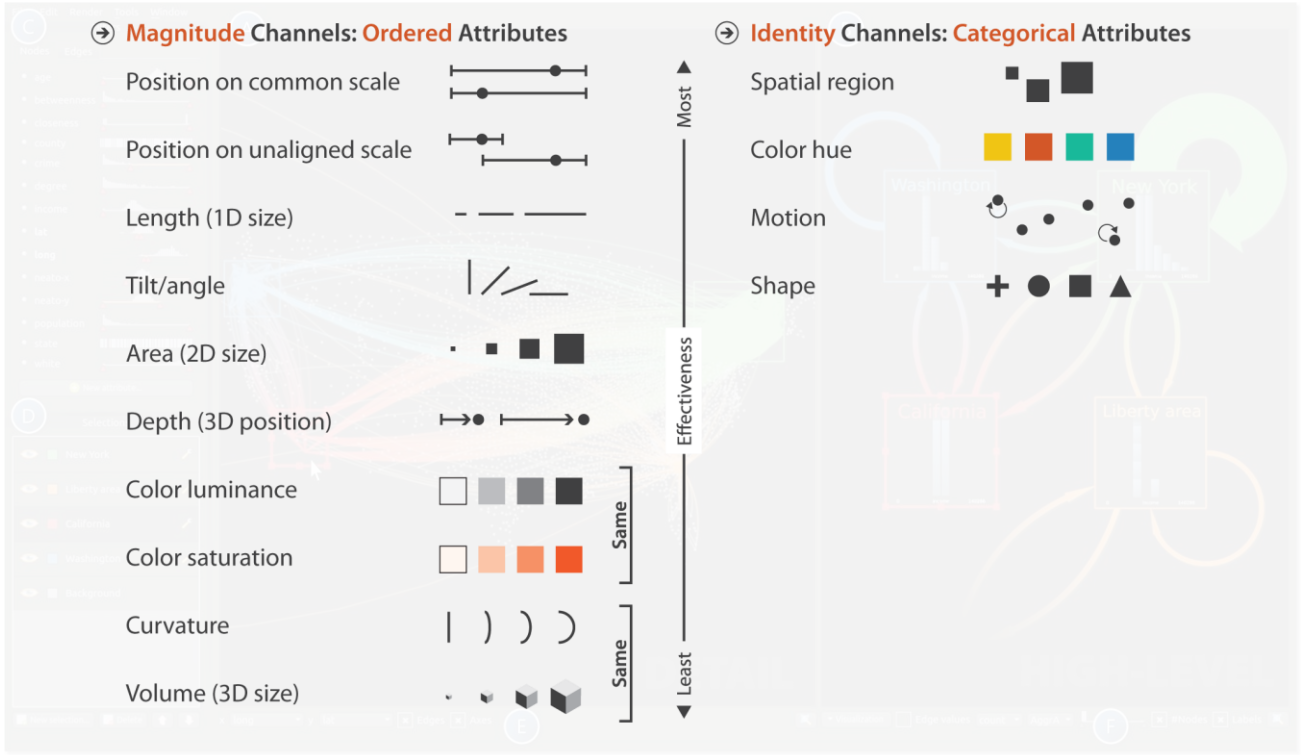
Stevens' Power Law: relationship between the magnitude of a stimulus and its perceived intensity or strength, some are magnified (electric shock), others are compressed (brightness) and some are completely accurate (length)



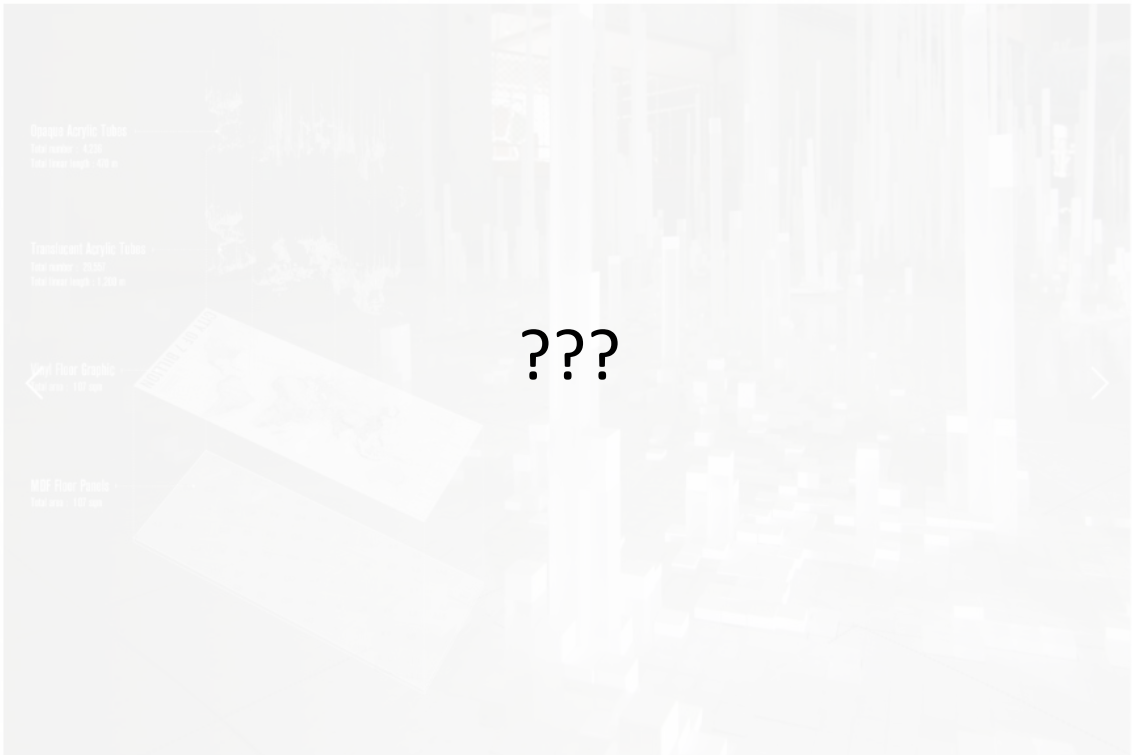
Munzer, *Visualization Analysis and Design*, 2014

Why psychophysics?

Visual Variables

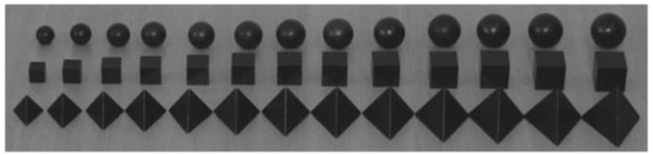


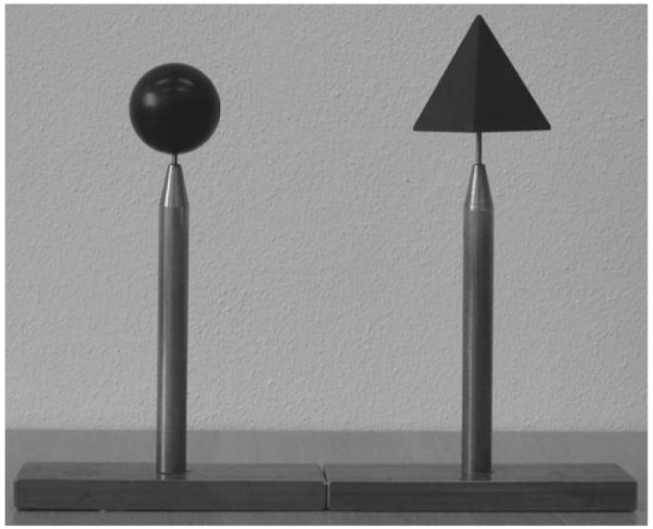
Physical Variables

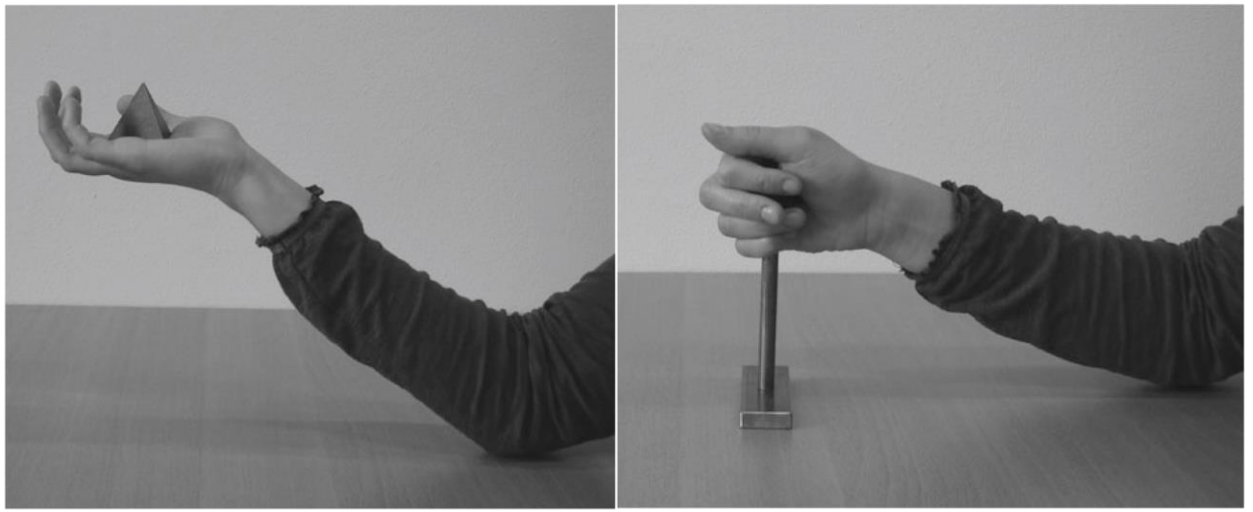


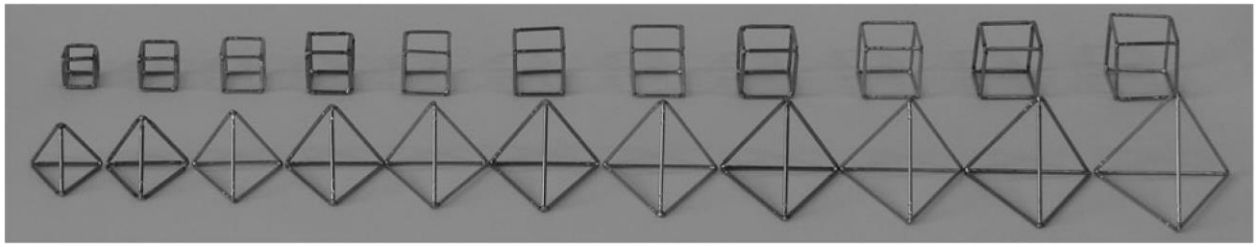
Munzer, *Visualization Analysis and Design*, 2014

Haptic Psychophysics









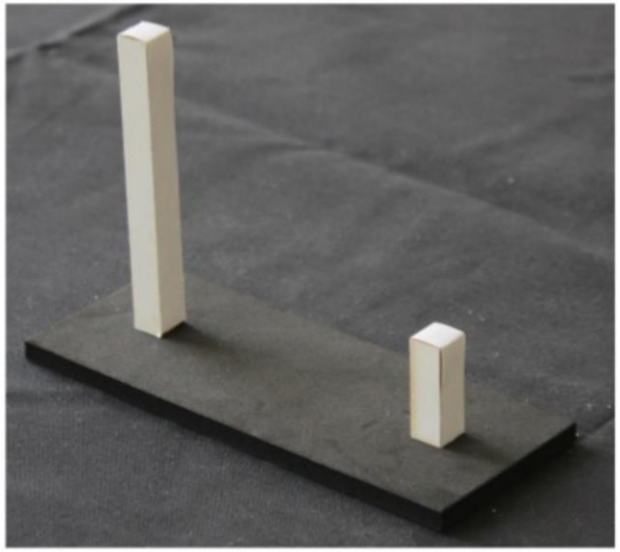
Kahrimanovic et al., *Haptic perception of volume and surface area of 3-D objects*, 2010

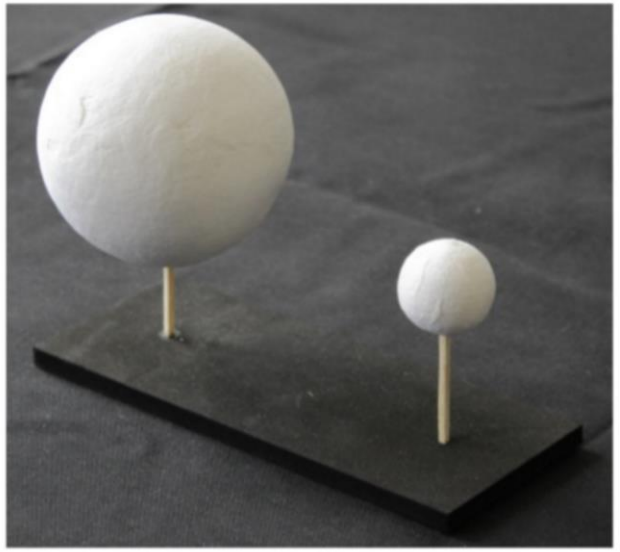
Questions

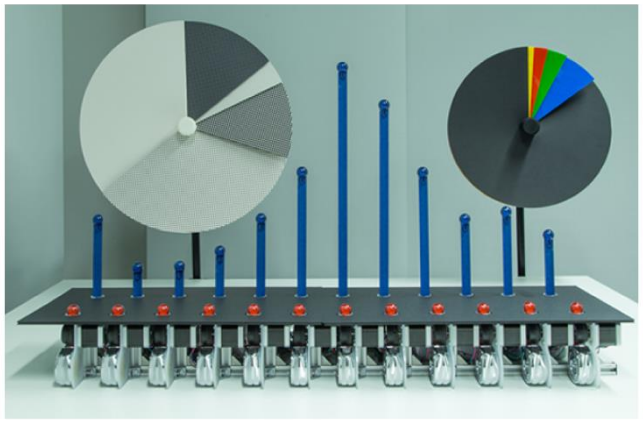
1. How accurately are elementary shapes estimated?
2. How similar are estimates between individuals?
3. Are estimates systematically biased?

Methods

- Bars vary in one dimension, spheres vary in all 3 at once
- Bars can compare to 2D counterparts
- Bars made with salient edges and spheres with some texture to ensure perception of 3D shape







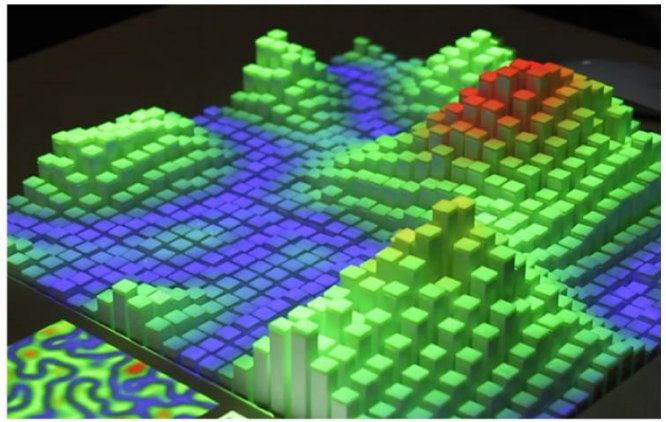
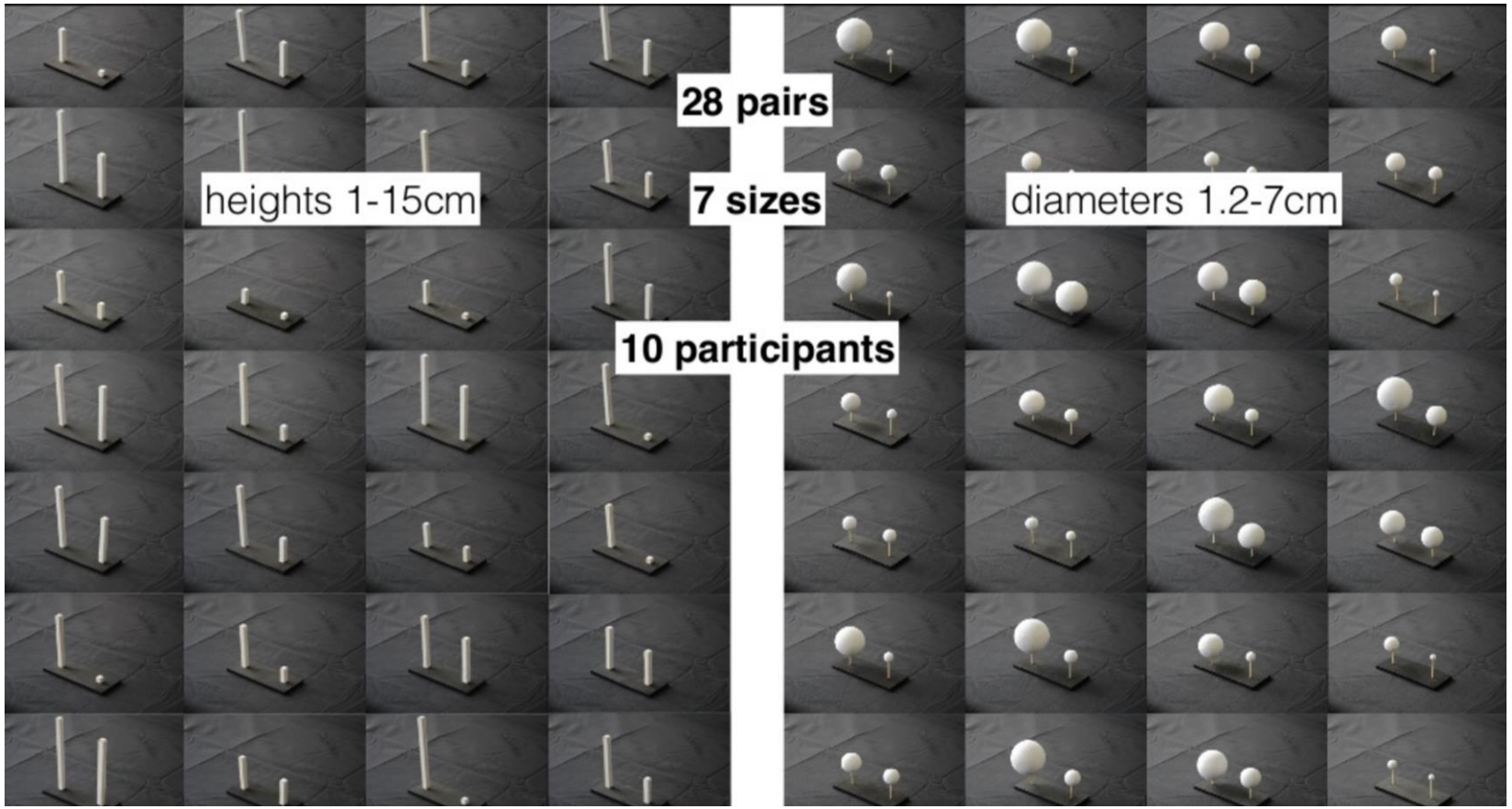


Fig 2

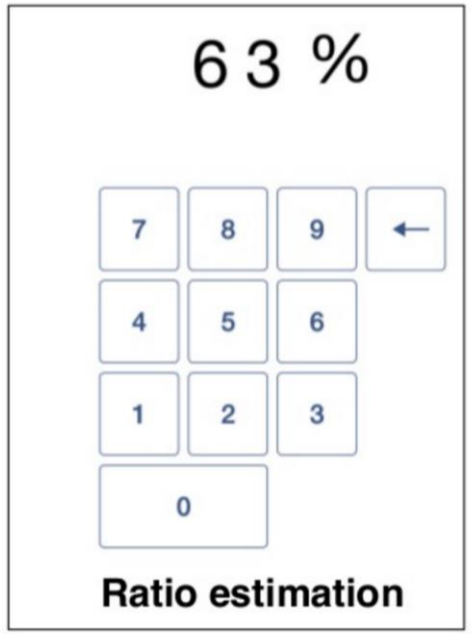
Methods



Jansen et al., slides from this paper

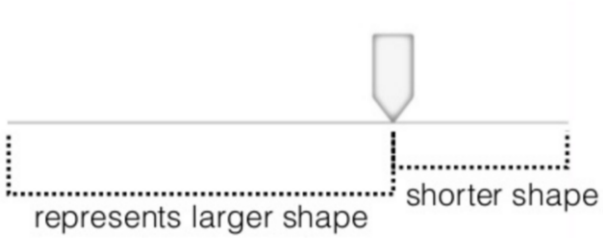
Methods

Told that throughout they are to judge the relative difference between two shapes



e.g., Cleveland & McGill (1984)

Requires conversion from visual domain into numeric domain



Constant sum

e.g., Spence (1990)

Remains in the visual domain but requires conversion from one type of shape to another

Experiment Design

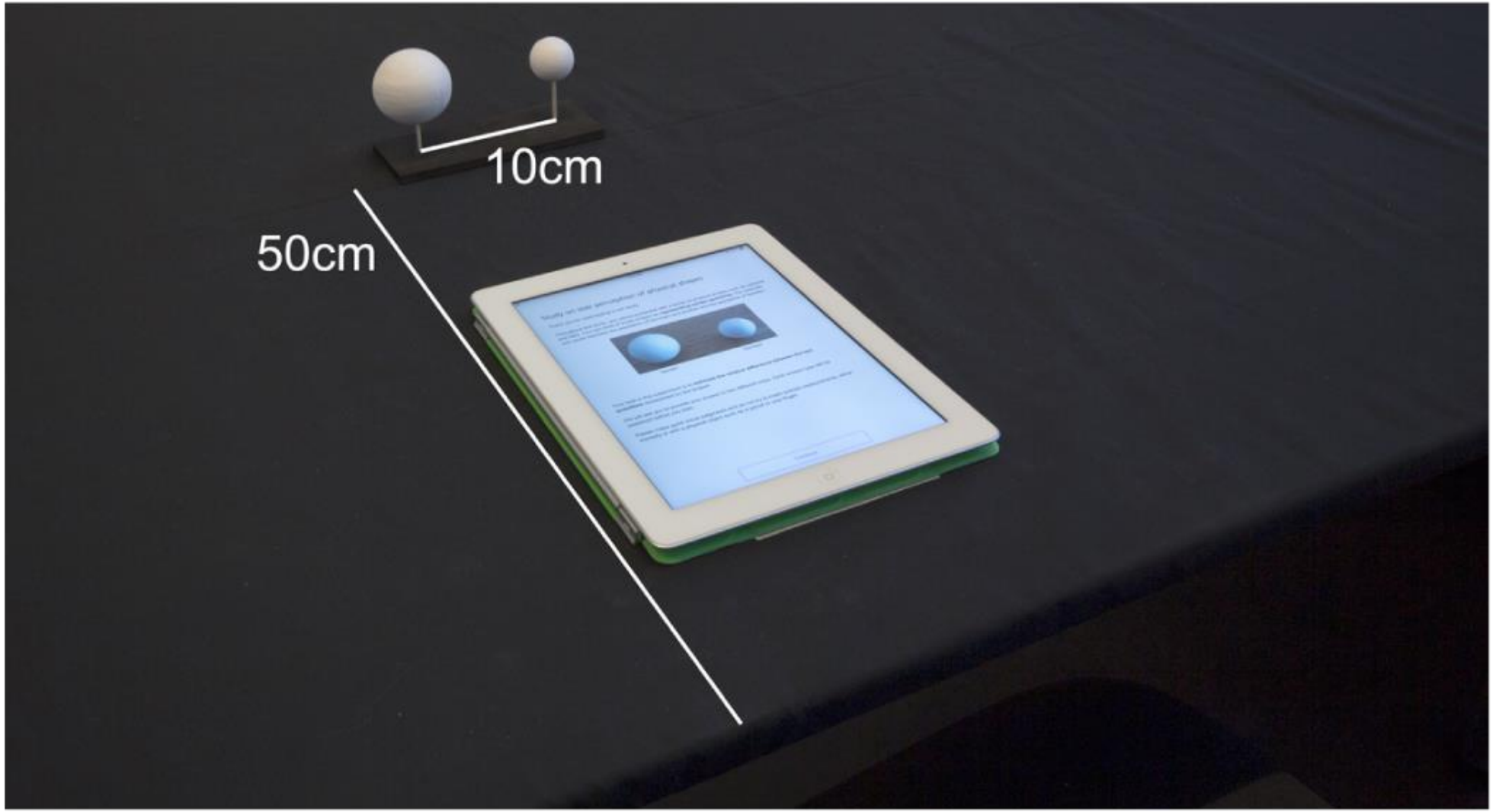


Fig 7

Experiment Design

Type A

During this part of the experiment, your task is to **divide the line such that the left part represents the quantity of the left shape and the right part represents the quantity of the right shape**.
For example, while seeing a pair of shapes like these:

this tablet will show you a line like this:

If the two shapes were exactly of the same size, you would place the marker so that it divides the line in the middle. In the example shown above, the left shape is noticeably larger than the right one, thus the marker should be placed more towards the right as shown below:

left shape right shape

You can move the dividing indicator around to adjust your judgment.

Both shapes will vary in size throughout the experiment. Each judgment should only depend on the sizes that you see in each display.

There are no time constraints for doing this task but try to spend no more than 10 seconds on each pair.

You will now see 28 pairs of spheres and 28 pairs of bars.

Continue

Type B

During this part of the experiment, we ask you to provide your answer by indicating the size of the smaller shape as a percentage of the larger one. For example, while seeing a pair of shapes like these:

100% x%

this tablet will show you a number pad to enter your answer:

Your task is to indicate the percentage of the smaller one to the larger one. The **larger one always represents 100%**. If the two shapes were exactly of the same size, you would enter 100%, if it was half the size of the larger one, you would enter 50%. In the example shown above, the right shape is noticeably smaller than the left one but a bit more than half its size, thus you might enter a value around 56%.

Both shapes will vary in size throughout the experiment. Each judgment should only depend on the sizes that you see in each display.

There are no time constraints for doing this task but try to spend no more than 10 seconds on each pair.

You will now see 28 pairs of spheres and 28 pairs of bars.

Continue

Fig 6

Results

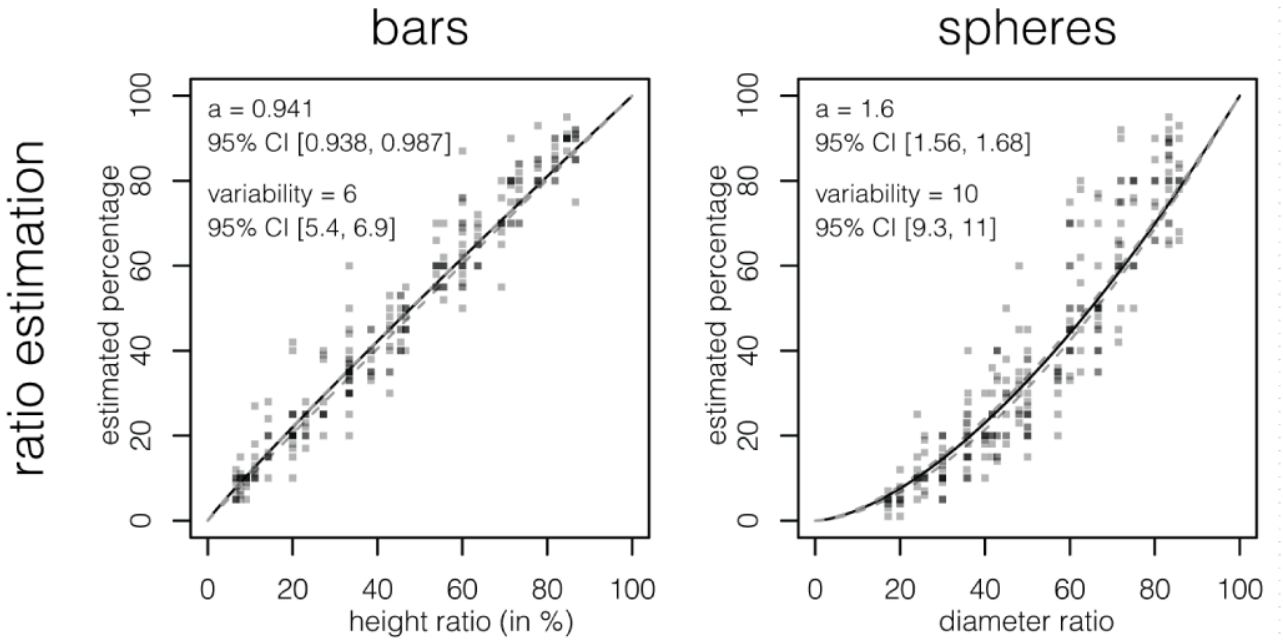
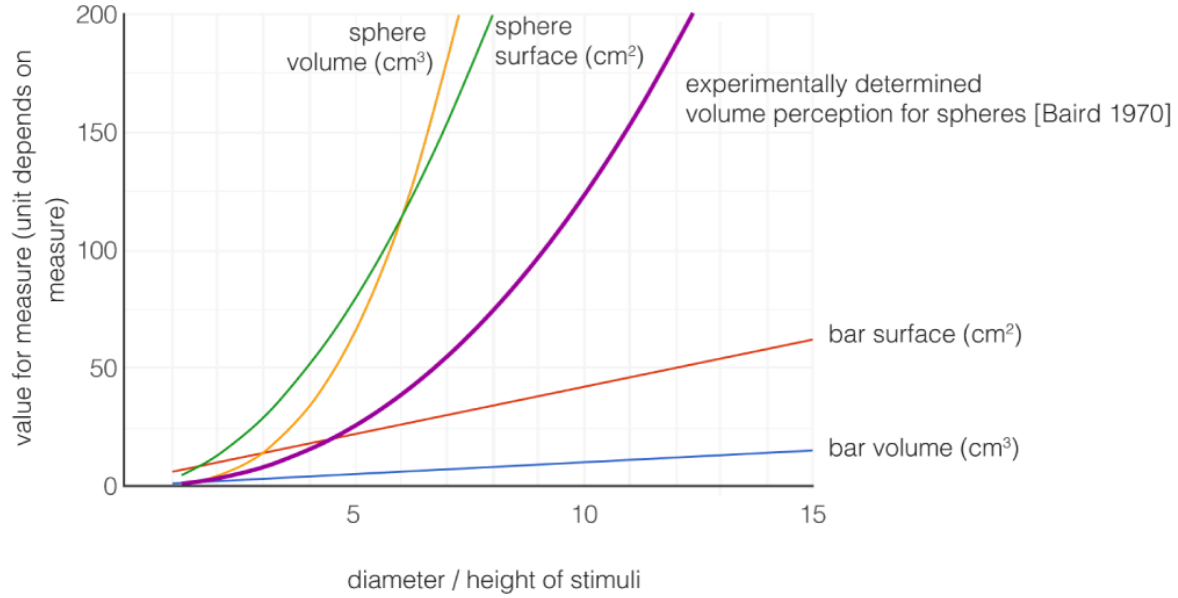
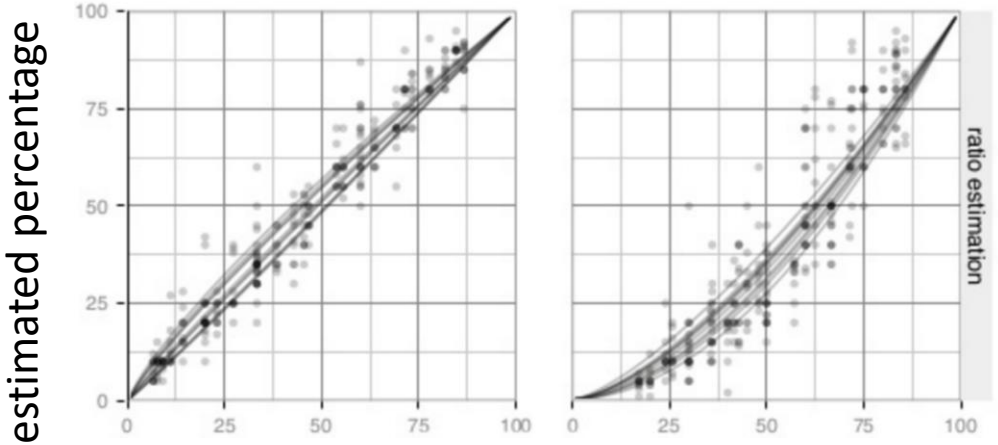


Fig 8

Results



bars spheres

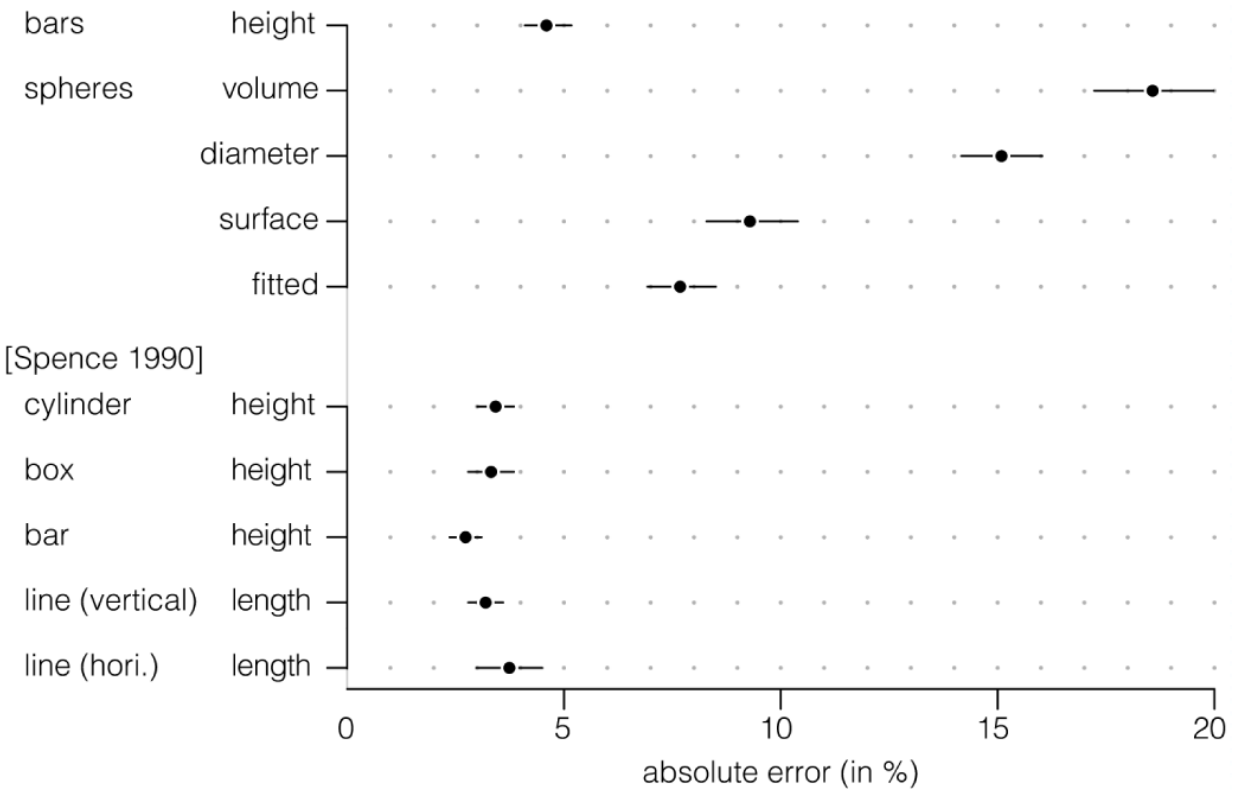


$$y = x^a$$

(Stevens' law)

Fig 4 & Jansen et al., slides from this paper

Accuracy



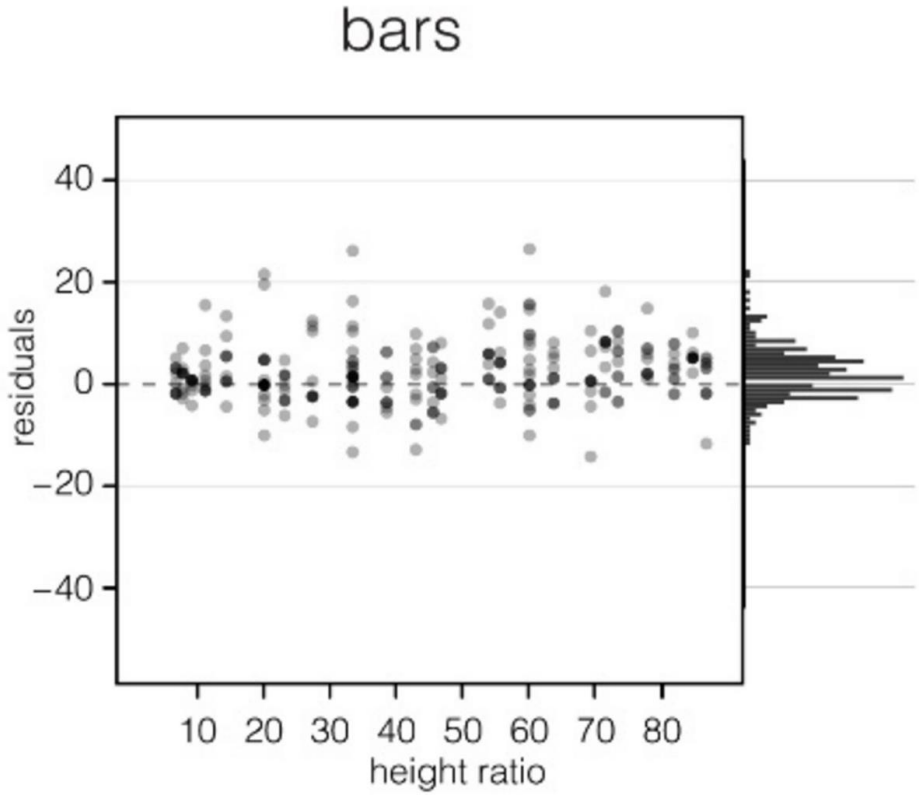
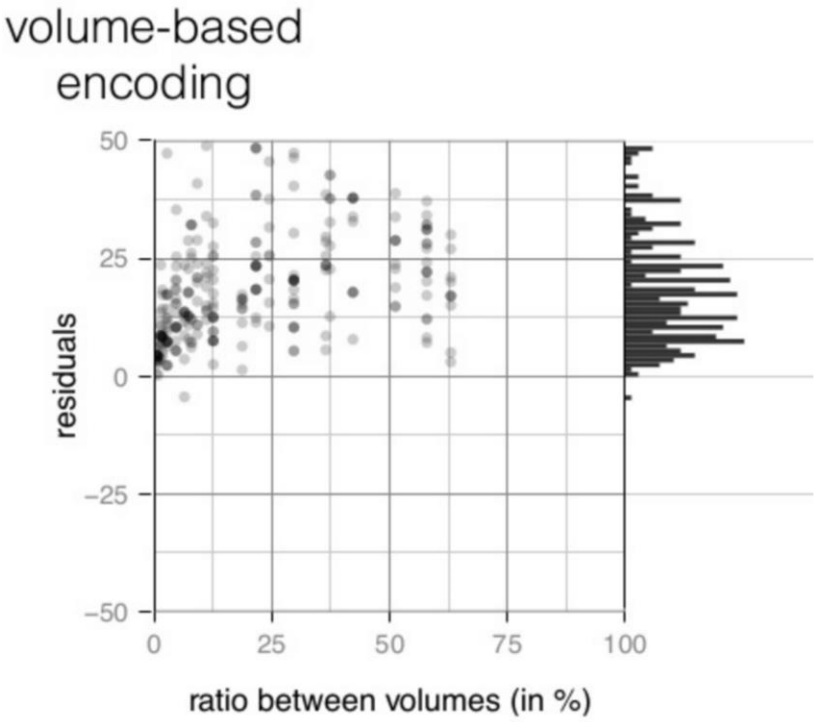
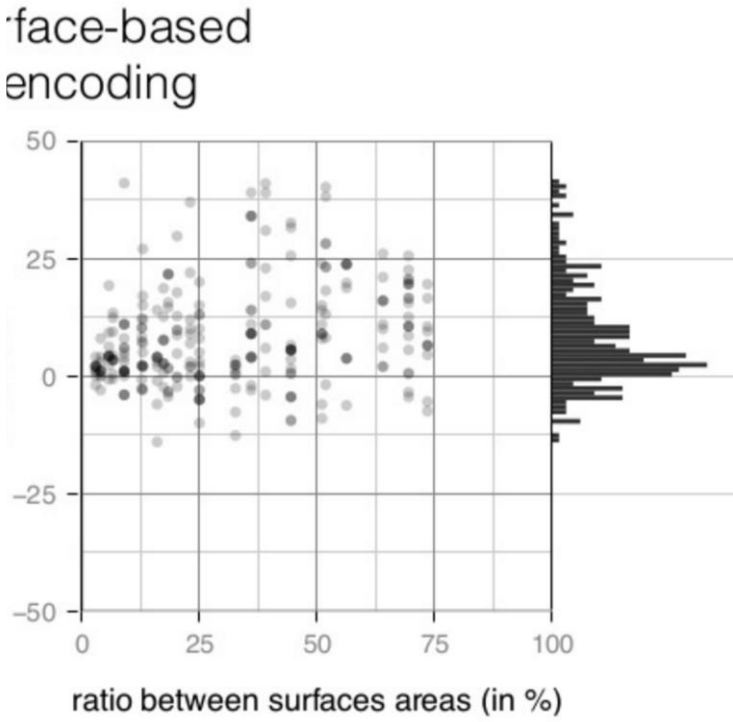


Fig 11

Jansen et al., slides from this paper

Accuracy

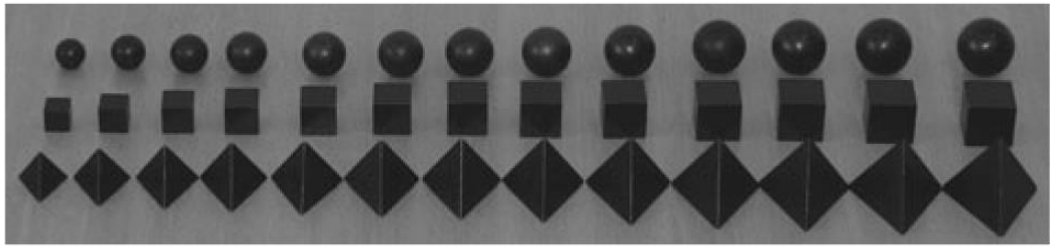


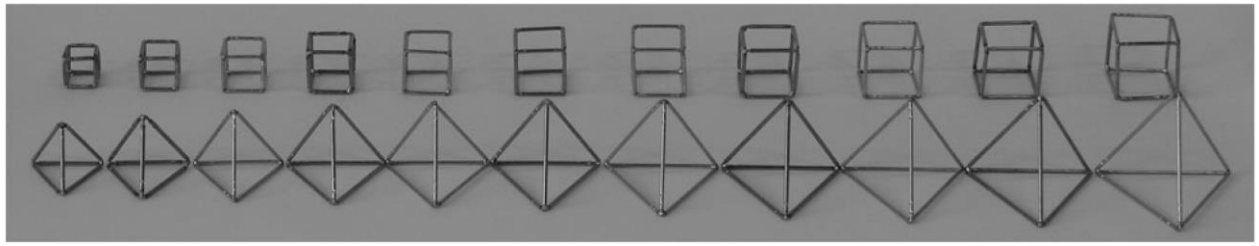


Jansen et al., slides from this paper

Discussion

- Chose bars and spheres as representative of marks that vary in only one dim vs. all 3 at once
  - —next need to test if these 2 are indeed representative
- Recent work on haptic perception of cubes, spheres, pyramids, also show surface area as best predictor
- 2 methods had significantly different results
  - —CS method of interest as it is purely visual method whereas RE method is a cross-modality matching task
  - —in future work with CS recommend verifying all participants have adopted same mental model of the task

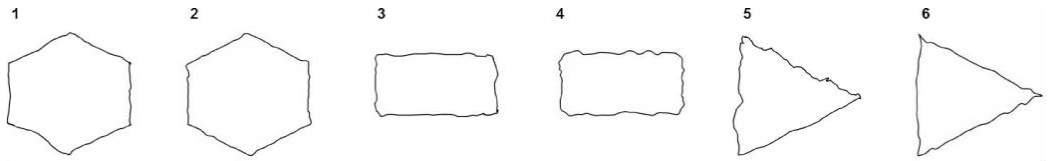


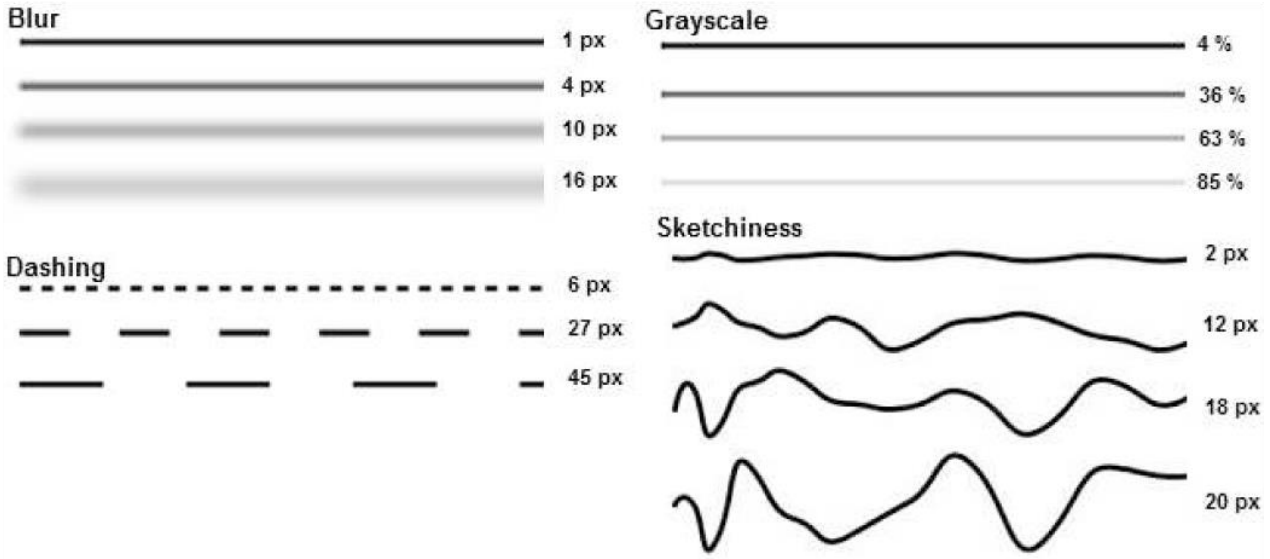


Kahrimanovic et al., *Haptic perception of volume and surface area of 3-D objects*, 2010

Discussion

- If can identify physical marks (or graphical marks) within acceptable error margins but for which participants feel little confidence in their estimates, such marks could encode uncertainty or “sketchiness”





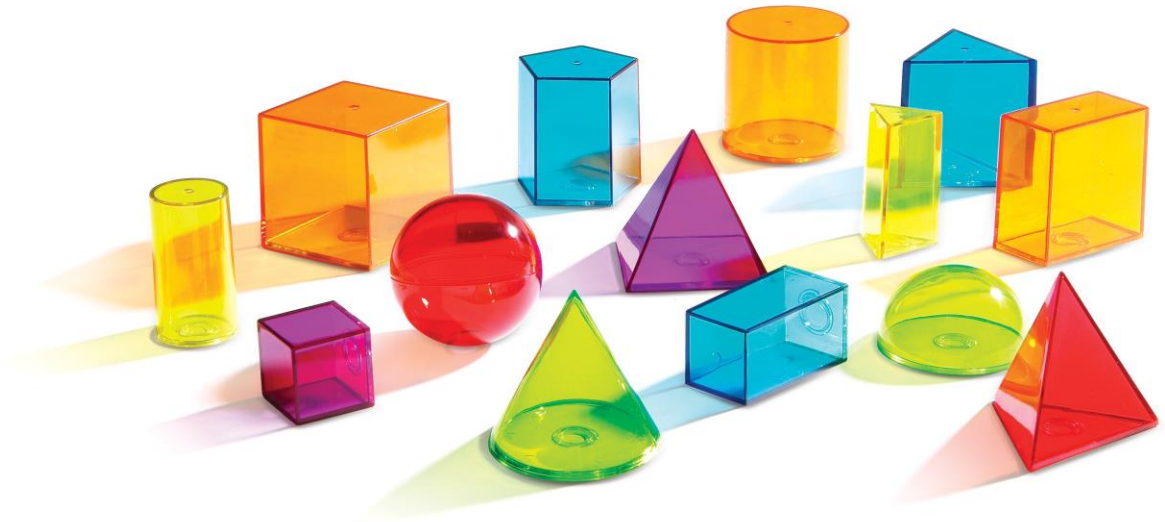
Boukhelifa et al., *Evaluating Sketchiness as a Visual Variable for the Depiction of Qualitative Uncertainty*, 2012

Conclusion

Primary contribution is a series of analysis steps to determine suitability of a physical variable to encode data:

1. Fit models
2. Assess variability between subjects
3. Assess accuracy and estimation biases (overestimations and underestimations)
4. Determine scaling if necessary

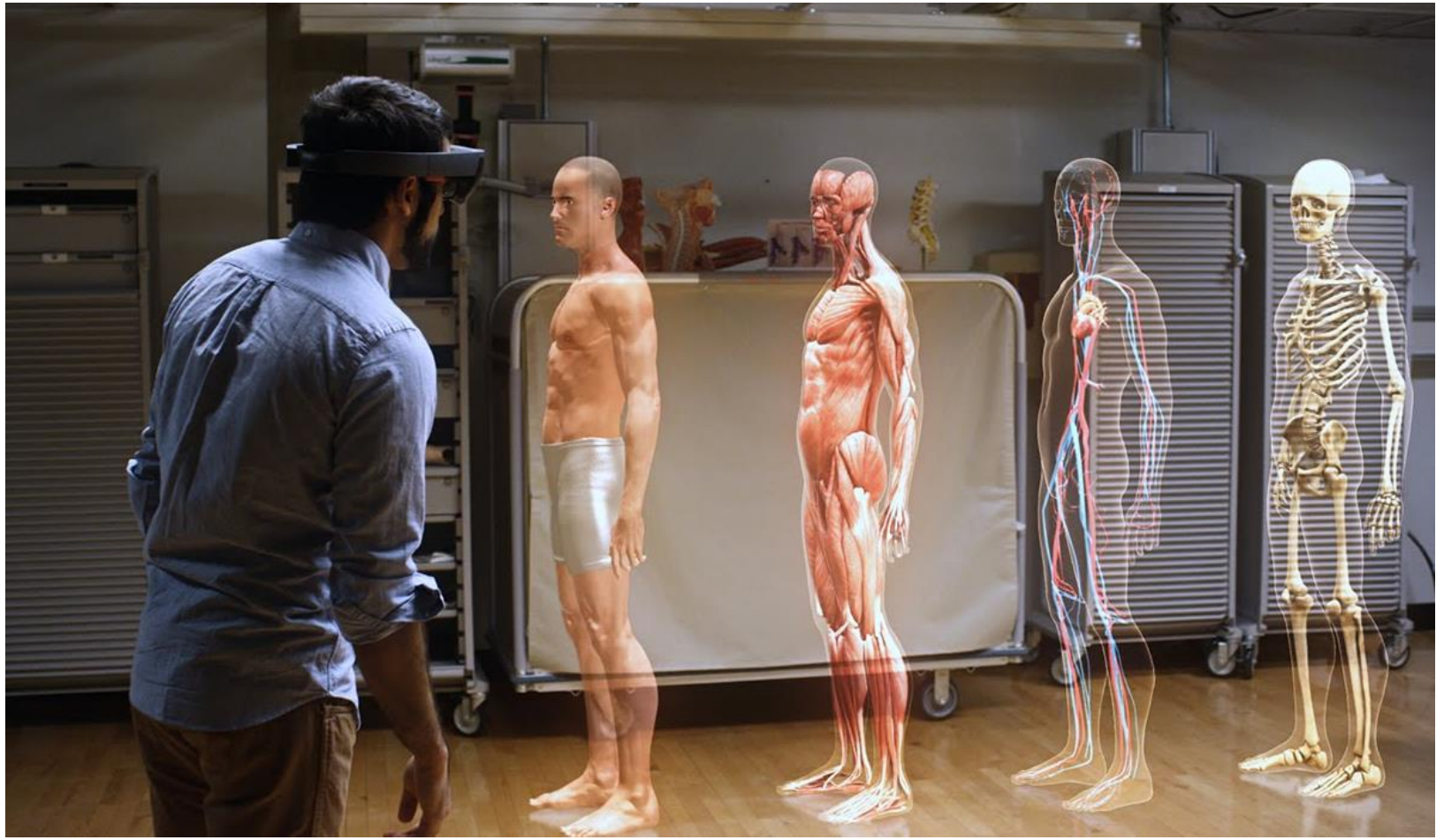
Repeat for all object measures that exist to describe a physical variable being tested for possible predictors for perception of the variable



Other Challenges

VISUAL perception of physical marks only

—argument that active touch is important but first need to collect empirical data on visual perception of physical marks



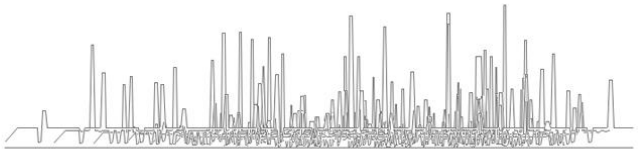
Microsoft Hololens, Case Western Reserve collaboration, 2015

Other Challenges

- Other important haptic variables like friction and temperature, but what about all 5 senses?
- What about interactions between the senses?

  We already know that some visual variables interact with one another in advantageous and disadvantageous ways…

  Probably true of physical variables AND sensory modality…



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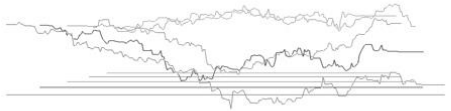
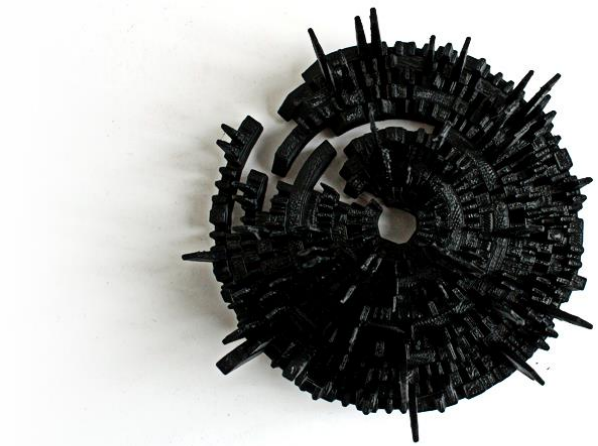
Poritshead



// ANOTHER WORLD
Antony & the Johnsons



Realitat, *Microsonic Landscapes*, 2012

Hamburg, *Whitebook,* annual report for *Arctic Paper*, 2012

Other Challenges

- separating senses could be misleading, for example: flavor
  —many seemingly disparate cues from each of the senses integrates into the single percept
- defining “physical variable” becomes very important (smoothness, hardness, sponginess)
  —do we even have enough language for this?

Janine Antoni, *Lick and Lather*, 1993

Other Challenges

- Perceived actively through exploratory actions involving the body so do you also have to develop “corporeal variables”?

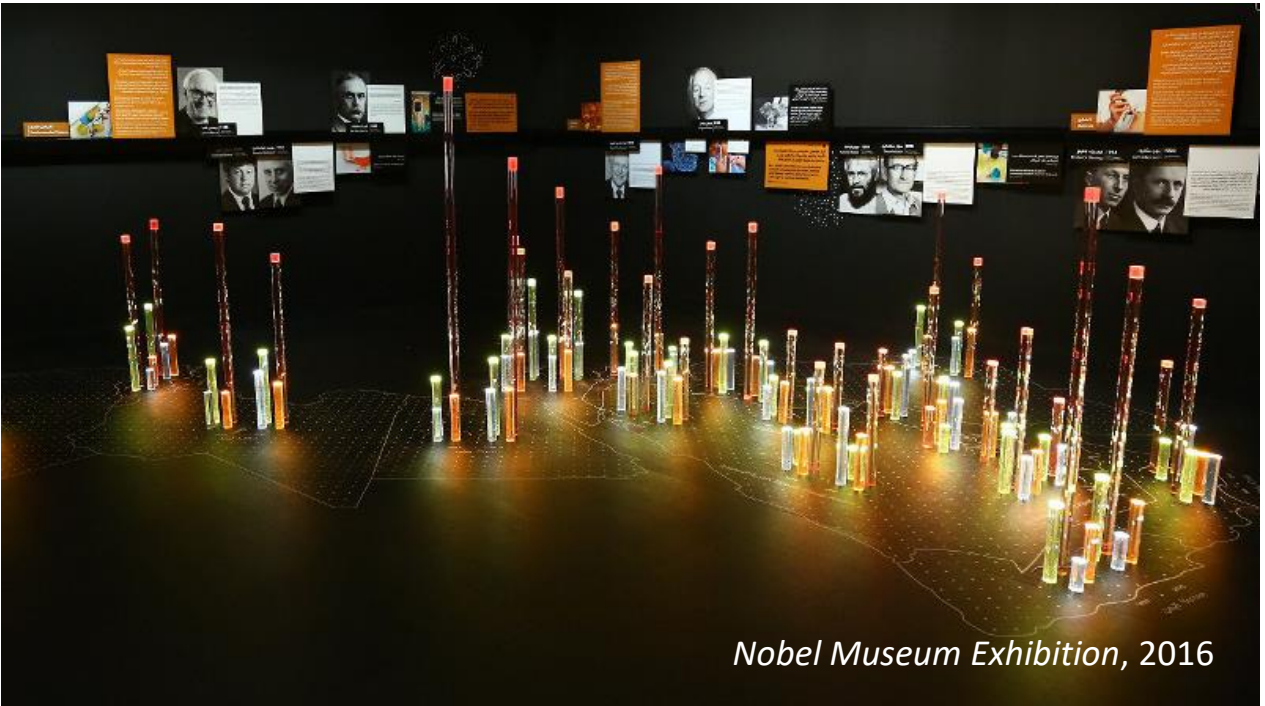
Hsiang and Mendis, *City of 7 Billion*, 2015

Other Challenges

Some of the greatest benefits of data physicalizations may be very hard to measure quantitatively:

- exploratory interactions where no clear task is defined
- pedagogical and persuasive power
- insights gained through interaction
- extent to which they promote engagement and behavior change
- memorability
- affective responses
- understanding how people reason, collaborate and communicate with them

(Jansen, et al. *Opportunities and Challenges for Data Physicalization*, 2015)



Nobel Museum Exhibition, 2016

Expedition Zukunft, 2009