Today

• Discuss different media through which people acquire spatial information (i.e., sources of information)
• Especially environmental or large-scale space
• Discuss an empirical study of individual differences in spatial learning and thinking via different media:
Four Classes of Media

1. Direct environmental experience
   - locomotion or stationary sensing
   - mechanically-aided locomotion or not
2. Static pictorial representations
   - graphs, maps, drawings, photos
3. Dynamic pictorial representations
   - movies, animations
4. Language
   - spoken, written, sung, signed
Virtual Environments?

• Different types closer to direct experience or dynamic pictorial representations
  - Projected v. head-mounted
  - Desktop (typical computer games)
  - Large screen, caves, etc.
  - Fully immersive, with varying amounts of full body locomotion possible

• May include sensory information besides visual and proprioceptive
Multiple Media for Spatial Information

- Often? Usually?
- Either simultaneously or sequentially
- How are they combined or integrated?
- Are they combined or integrated?
- Augmented reality an interesting new example
Factors That Differentiate Media

- Sensory/motor systems involved
- Static vs. dynamic information (2 senses)
- Sequential vs. simultaneous access
- Symbols and their abstractness
- Scale translation and flexibility
- Viewing perspective
- Precision
- Detail
Potential Implications of Differences

• Speed and accuracy of information acquisition
• Efficiency and effectiveness of spatial communication
• Spatial memory — content
• Spatial memory — form and recall flexibility
• Style and effectiveness of problem-solving
• Individual differences in spatial thinking, i.e., variations in spatial abilities across media
Traditional Pictorial Approaches to Measuring Spatial Abilities

• Long tradition in psychology and education (~150 years)
• >100 published tests, many more unpublished
• Many tasks: Visual searching, mentally rotating shapes, solving mazes, imagining folding and unfolding sheets of paper, etc.
• Small-scale, paper-and-pencil tests (computer monitor too), shapes and manipulable objects
• Small set (3 or 4) of partially distinct abilities that underlie variations in task performance
Which two on the right match the target on the left, given rotation in 2D or 3D?

Mental Rotation Test
(spatial ability)
Environmental Spatial Abilities and Their Measurement

- Relatively recent (<40 years); few studies
- Tasks include learning the layout of new environments (buildings, cities, woodlands), navigating in novel and familiar places, giving and interpreting verbal navigation directions
- How many underlying abilities? > 1?
Pictorial v. Environmental Abilities

• A few studies; found only weak relation
• Both involve ability to encode, maintain, and mentally transform spatial representations
• Environmental involves integration of information over time; representations constructed from locomoting within environment; integration of body motion, sensed through proprioception
• Same, different, or partial overlapping abilities? Other abilities predict environmental skills?
Large Study with Hegarty et al.

• Media via which environment is learned:
  1. Direct experience walking and viewing
  2. Video of walk
  3. Desktop virtual environment (VE)

• Media vary in display size, visual field, proprioceptive sensing, active control

• Three outcome measures of learning:
  1. Distance estimates
  2. Direction estimates
  3. Map-sketching (only nonmetric errors)
Participants

- 286 participants, mostly students (paid $40 for ~ 3.5 hours, two sessions)
- Because of missing data and prior familiarity, 221 in final analyses: 135 female, 83 male, 3 declined to state
- mean age 22.0 years (17-59, 80% 17-22)
Tasks and Measures

- Pictorial tests of spatial abilities
- Tests of verbal and general abilities
- Tests of environmental spatial abilities
- Self-report sense-of-direction (SOD) survey
SANTA BARBARA SENSE-OF-DIRECTION SCALE

Sex:  F  M                                                                   Today's Date:________________
Age:_______                                                               V . 2

This questionnaire consists of several statements about your spatial and navigational abilities, preferences, and experiences. After each statement, you should circle a number to indicate your level of agreement with the statement. Circle "1" if you strongly agree that the statement applies to you, "7" if you strongly disagree, or some number in between if your agreement is intermediate. Circle "4" if you neither agree nor disagree.

strongly agree  1   2   3   4   5   6   7  strongly disagree

1. I am very good at giving directions.
2. I have a poor memory for where I left things.
3. I am very good at judging distances.
4. My "sense of direction" is very good.
5. I tend to think of my environment in terms of cardinal directions (N, S, E, W).
6. I very easily get lost in a new city.
7. I enjoy reading maps.
8. I have trouble understanding directions.
9. I am very good at reading maps.
10. I don't remember routes very well while riding as a passenger in a car.
11. I don't enjoy giving directions.
12. It's not important to me to know where I am.
13. I usually let someone else do the navigational planning for long trips.
14. I can usually remember a new route after I have traveled it only once.
15. I don't have a very good "mental map" of my environment.
Three Environments, Three Media

- UCSB building, directly walked
- SB Courthouse, video of walk
- Simple hallway, desktop VE

- Individual-difference study requires different environment for each medium, paired consistently, as all participants had to do all conditions and tasks
UCSB building,
Directly walked
Courthouse, Video walk
Simple hallway, Virtual environment
Results
Confirmatory Factor Analyses (CFA)

• Small # of factors underlying pattern of shared variance among variables (maximum likelihood)
• Unlike exploratory FA, CFA tests prior models of factor structure
• Provides indices of fit of model to data:
  - $\chi^2 / df$ (<2.0 good)
  - RMSEA: Root Mean Squared Error Approximation (<.08 fair, <.05 good)
  - CFI: Comparative Fit Index (> .90 fair, > .95 good)
• Balance empirical fit, modeling parsimony, and conceptual coherence
What is the Structure of Environmental Spatial Ability?

• First examined grouping into three outcome measures:
  - Direction
  - Distance
  - Mapping

• Poor fit
\[ \chi^2(df) = 158.71(24) \]
\[ \chi^2/df = 6.13 \]
\[ RMSEA = .16 \]
\[ CFI = .79 \]

Diagram:
- **Direction**
  - \(1.15^*\)
  - \(1.05^*\)
- **Distance**
  - \(.99^*\)
  - \(1.15^*\)
  - \(1.05^*\)
  - \(.99^*\)
- **Map Drawing**
  - \(.57^*\)
  - \(.53^*\)
  - \(.70^*\)
  - \(.32^*\)
  - \(.41^*\)
  - \(.63^*\)
  - \(.52^*\)
  - \(.61^*\)
  - \(.81^*\)

Nodes:
- Dir Exp Pointing
- Video Pointing
- VE Pointing
- Dir Exp. Distance
- Video Distance
- VE Distance
- Dir Exp. Map
- Video Map
- VE Map
What is the Structure of Environmental Spatial Ability?

- Next examined grouping into two media factors:
  - Direct learning
  - Visual-only media

- Fair/good fit, better fit than combining into one spatial-learning factor
- Also, single factor leads to high unexplained inter-correlations within media
Direct Experience

.94*
.71*
.72*

Dir Exp Pointing
Dir Exp. Distance
Dir Exp. Map

Video Distance
Video Map

.74*
.43*
.52*
.66*
.31*
.64*

.31*
.19
.09
.22*
.10
.04

Video Pointing
Video Map
VE Pointing
VE Distance
VE Map

Visual Learning

.66*

χ²(df) = 34.47 (20)
χ²/df = 1.73
RMSEA = .06
CFI = .98
Structural Equation Modeling

- Allows testing hypothesized models of causal relations with nonexperimental data
- Predictive relations among “latent factors” from CFA (maximum likelihood again)
- Original measured variables are “manifest variables”
What Causes Environmental Spatial Ability?

Full model

• Potential causes:
  - pictorial spatial ability, verbal ability, self-report SOD

• Effects:
  - direct learning, visual learning (video, VE)

• Good fit, but verbal does not predict
$\chi^2(df) = 119.00(80)$
$\chi^2/df = 1.49$
RMSEA = .05
CFI = .96
What Causes Environmental Spatial Ability?

Reduced model (verbal removed)

• More parsimonious but good fit, with all paths significant
• Pictorial spatial ability causes both direct and visual learning, but visual significantly more
• Self-report SOD causes direct learning significantly more than it causes visual learning, and it causes direct learning over and above its cause by pictorial ability
$\chi^2(\text{df}) = 92.84$ (59)

$\chi^2/\text{df} = 1.57$

$\text{RMSEA} = .05$

$\text{CFI} = .96$
Conclusions

• Very large individual differences!
• >1 ability in environmental spatial tasks
• Directly learned vs. visual only (pictorial): proprioception, distal size, proximal size, field of view (peripheral vision)
• Performance not driven by measure variance (distance, direction, mapping)
• What is environmental spatial ability?: Ability to acquire and infer knowledge of spatial layout from information that is learned visually and proprioceptively through real navigation over time
More Conclusions…

- Pictorial ability shares considerable variance with environmental ability, but it causes visual learning much more than direct learning.
- Self-report SOD independently causes direct learning, more than it causes visual learning.
- Verbal ability does not independently contribute to causing environmental abilities.
- Other environmental tasks (e.g., route tasks) probably show different pattern.
That’s All Folks,
Thanks