Visuomotor Integration & Eye-Hand Coordination for Functional Vision Rehabilitation (FVR)

John-Ross (JR) Rizzo, M.D.
Objectives

• Introduce eye-hand coordination and related pathology

• Define key aspects of visual processing

• Explain the posterior parietal cortex and its contribution to spatial information processing and motor planning

• Highlight the idea of multiple coding and/or motor planning systems within the reaching system

• Describe motor planning differences between stroke and controls

• Explain the potential implications and future directions as it relates to the visual system
Why study Eye-Hand Coordination?

• **Vision (Eye):**
  • In 2010, the WHO estimated that there were **285 million** globally with visual impairment

• **Stroke (Hand):**
  • Leading cause of adult long-term disability in the US with **>7 million** survivors. Hemiparesis is the most common motor impairment
  [Roger et al, Circulation, 2011]
  • **85%** of survivors with hand dysfunction that limits ADLs

• **Stroke (Hand) Vision (Eye):**
  • It is estimated that between **30-85%** of stroke patients will experience some type of visual dysfunction following stroke.
  [Kerkhoff et al, J Neurol Neurosurg Psychiatry, 2000] [MacIntosh et al, Br Orthop J, 2003]

• **Stroke (Hand) Vision (Eye) Function:**
  • Vision problems in stroke are associated with problems with ADLs, falls, and rehabilitation, affecting quality of life, and functional independence.
  [Khan et al, Top Stroke Rehabil, 2008]
The Scientific Gaps

• Why? Stroke: the return of motor ability does not necessarily lead to gains in function.

• Why? Planning of arm and hand movements is impaired post-stroke* and contributes to functional deficits**

• How? Eye-hand coordination may involve the integration of:
  • planning of eye movement
  • planning of limb movement (our initial focus)
Visual Stream Processing & Motor Planning

• Two stream hypothesis for visual processing proposed by Ungerleider & Mishkin in 1982
  [Mishkin et al, Behav Brain Res, 1982]

• The two streams:
  • VENTRAL- traveling to the temporal lobe and involves the “what”- object identification
  • DORSAL- traveling to the parietal lobe and involves the “where”-spatial location

• Posterior parietal cortex (PPC) participates in the planning of visuospatial behaviors, including reach movements, in gaze centered coordinates.
  [Fernandez-Ruiz et al, Cereb Cortex, 2007]

• PPC may be the common substrate for eye-hand coordination or eye-limb motor planning
Visual Processing- The Visual Streams
How to parse reaches: a Top-Down View

When I grab my cup of coffee, I have to break that movement task down into parts

- **First**, I need to have an *internal mapping*, on which I can build a plan
- **Second**, I must develop a *motor plan* to successfully accomplish my goal
- **Third**, I must complete the actual plan with limb movement or *execution*, in this case my arm/hand
How can I get from point A to point B?

• **#1**: I can get from A to B by encoding a *final arm configuration*
  • If you know where you want your finger to be then you can select a set of joint angles that will produce that intended finger endpoint (Notice that #1 does not use information about the start position of the finger in space)

• **#2**: I can get from A to B by encoding a *hand translation*
  • If you know the start position of the finger then you can plan the translation of the finger from that start position in the direction and by the distance that brings you to the intended target

• I can build a motor plan via #1 or #2 or perhaps a combination of #1 & #2 and then execute
Definitions

• We will talk about the arm configuration encoded endpoint in terms of a **Cartesian coordinate system** or a **Target System**
  • specifying each point uniquely in a plane by a pair of numerical coordinates, which are signed distances from the point to 2 fixed perpendicular directed lines, measured in the same unit of length; or for 3-D, with x, y and z

• We will talk about the second option, the hand translation, as using a **polar coordinate system**. In other words, as if the translation were encoded in terms of a **Vector**.
  • a geometric entity endowed with magnitude and direction, or extent and direction
Motor Planning: Dual Codes
Why have two systems for Motor Planning?

• Redundancy is always an ideal, creates a backup system

• In a Vector plan, I do not need to code an endpoint

• In a Endpoint plan, I do not need to code a start point

• In a training routine, if I grouped reaches circumferentially around a goal target, my x, y, z or ENDPOINT code may be the dominant plan

• In a training routine, if I grouped reaches by varying my start position but maintained a common distance and direction, my r, theta, or VECTOR code may be the dominant plan
Target-based

Vector-based
The Experiment and the Evidence

• We utilize a reach paradigm to test whether motor planning reveals a Cartesian (target) or polar (vector) coordinate frame.

• The evidence points to 2 systems existing in control populations for reaches [Hudson and Landy, J Neurophysiol, 2012].

• The evidence is divided between polar and Cartesian for reaches while the evidence is overwhelming that saccades are planned in polar coordinates. How does this translate?

• Well we know that stroke patients have motor planning deficits.

• Could it be that the vector or endpoint based system or both is/are injured following acquired brain injury (ABI) and could this speak to motor plan or coordinate-specific rehabilitation?
The Hypotheses

• #1 - Stroke patients demonstrate 2 types of motor planning

• #2 - Despite a duality in motor planning, stroke patients reveal deficiencies in one or both planning systems

• #3 - Motor-planning specific training in either limb or eye effector, reaching or saccades, may improve motor learning or re-learning and stroke recovery
Motor Planning

Reaching

Saccade

Eye-Hand Coordination

Target-based reaches

Target-based saccades

Vector-based reaches

Vector-based saccades
The Reaching Task

3x2x6

3 columns

2 rows

6 starts
Methods- How are the trials randomized?

• Start 75 practice reaches to a target; based on the practice session, the target size is calculated (how we determine hit rate)

• The experiment begins, there are 2 blocks → target & vector or vector & target, the order is randomized (864 reaches, 432 each)

• The array has 6 targets; each target has 6 start positions every 60 degrees

• Target: 1 of 6 in the array is chosen and 12 reaches for each of the six start positions are randomly completed (total 72), then on to a randomly ordered 2nd target and another until all 6 targets are completed (total 432)

• Vector: 1 start to target direction or vector is chosen in the array, e.g., start position 1 in targets 1-6; 12 repetitions of the same vector at each target is randomly completed (total 72), then a 2nd vector is randomly selected and another until all 6 are completed (total 432)
Targeted Reach Flipbook- Let’s generate errors
Targeted Reach Flipbook- Let’s generate errors
Targeted Reach Flipbook
Targeted Reach Flipbook
Targeted Reach Flipbook
Targeted Reach Flipbook
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Targeted Reach Flipbook
Targeted Reach Flipbook
Targeted Reach Flipbook
Targeted Reach Flipbook
Targeted Reach Flipbook
Targeted Reach Compilation
Targeted Reach Compilation

Averaged Reach Ellipse

Variance Ratio (VR)

Averaged Reach Ellipse

Post-Practice

Variance Ratio (VR)
Vector Reach Flipbook - Let’s generate errors
Vector Reach Flipbook - Let’s generate errors
Vector Reach Flipbook
Vector Reach Flipbook
Vector Reach Flipbook
Vector Reach Flipbook
Vector Reach Flipbook
Vector Reach Flipbook
Vector Reach Flipbook
Vector Reach Flipbook
Vector Reach Flipbook
Vector Reach Flipbook
Vector Reach Flipbook
Vector Reach Compilation
Vector Reach Compilation

Averaged Reach Ellipse

Variance Ratio (VR)

Averaged Reach Ellipse
Post-Practice

Variance Ratio (VR)
Results: Control Reach Trajectories & Precision

Average reaches (stereogram):
- Endpoint-grouped
- Vector-grouped

Grouped by endpoint

Grouped by vector
Results: **Controls** Hitting the Target

- **Vector**
- **Target**

![Graph showing Hit Rate vs. Reach Number](image)

**Hit Rate (Cumulative)**

**Hit Rate (Relative)**
Hypothetical Error Ellipses or Variance for Vector
Hypothetical Error Ellipses or Variance for Target

- **A**: low variance position-coding
- **B**: concentric circles
- **C**: rectangular orientation
Covariance Ellipse according to grouping: Controls

V as V

V as T

T as T

T as V
The Experimental Breakdown for Stroke

• Reduced Design for Stroke Patients- 4 targets, 4 start position and reach orientations, and 9 iterations

• NOT 3x2x6 rather 2x2x4

• 2 columns, 2 rows, 4 start positions

• Breaks are built into the experiment

• At any point a rest can be self-initiated and the task is paused
# Stroke Subject Breakdown

<table>
<thead>
<tr>
<th>Subject ID</th>
<th>DOB</th>
<th>Date of CVA</th>
<th>Age</th>
<th>Gender</th>
<th>CVA Territory</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>9/24/52</td>
<td>9/19/09</td>
<td>59</td>
<td>male</td>
<td>left MCA (BG/IC)</td>
</tr>
<tr>
<td>S2</td>
<td>7/15/73</td>
<td>6/1/06</td>
<td>38</td>
<td>female</td>
<td>right pons</td>
</tr>
<tr>
<td>S3</td>
<td>3/7/74</td>
<td>6/5/07</td>
<td>38</td>
<td>male</td>
<td>left MCA</td>
</tr>
<tr>
<td>S4</td>
<td>6/12/67</td>
<td>9/11/09</td>
<td>44</td>
<td>female</td>
<td>right MCA</td>
</tr>
<tr>
<td>S5</td>
<td>9/6/48</td>
<td>3/14/10</td>
<td>63</td>
<td>female</td>
<td>right MCA</td>
</tr>
<tr>
<td>S6</td>
<td>3/8/48</td>
<td>1/1/05</td>
<td>64</td>
<td>male</td>
<td>left MCA</td>
</tr>
<tr>
<td>S7</td>
<td>3/15/44</td>
<td>8/25/05</td>
<td>68</td>
<td>male</td>
<td>left MCA (BG/IC)</td>
</tr>
<tr>
<td>S8</td>
<td>8/4/67</td>
<td>2/8/10</td>
<td>45</td>
<td>male</td>
<td>left MCA</td>
</tr>
<tr>
<td>S9</td>
<td>8/16/78</td>
<td>4/13/07</td>
<td>32</td>
<td>female</td>
<td>right MCA/AVM</td>
</tr>
<tr>
<td>S10</td>
<td>12/1/70</td>
<td>4/23/09</td>
<td>41</td>
<td>female</td>
<td>right MCA</td>
</tr>
<tr>
<td>S11</td>
<td>5/22/88</td>
<td>7/25/11</td>
<td>23</td>
<td>female</td>
<td>right MCA</td>
</tr>
<tr>
<td>S12</td>
<td>6/22/70</td>
<td>12/23/08</td>
<td>41</td>
<td>male</td>
<td>right MCA</td>
</tr>
<tr>
<td>S13</td>
<td>5/6/53</td>
<td>9/3/10</td>
<td>59</td>
<td>male</td>
<td>right MCA</td>
</tr>
<tr>
<td>S14</td>
<td>8/29/23</td>
<td>9/1/05</td>
<td>89</td>
<td>female</td>
<td>right MCA</td>
</tr>
<tr>
<td>S15</td>
<td>1/12/64</td>
<td>5/19/06</td>
<td>48</td>
<td>female</td>
<td>right MCA</td>
</tr>
</tbody>
</table>

**Average Age:** 50.1333333

**Gender Distribution:** F 8 : M 7

**CVA Territory Distribution:** 14 MCA : 1 Brainstem

**Range:** 23-89
## Stroke Subject Breakdown cont.

<table>
<thead>
<tr>
<th>Subject ID</th>
<th>Extra-Ocular Muscles</th>
<th>Confrontational Field</th>
<th>Pupillary Reflex</th>
<th>Distance Acuity (Snellen Eye Test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>EOMI</td>
<td>VFFTC</td>
<td>PERRLA</td>
<td>20/20</td>
</tr>
<tr>
<td>S2</td>
<td>TBP</td>
<td>TBP</td>
<td>TBP</td>
<td>TBP</td>
</tr>
<tr>
<td>S3</td>
<td>TBP</td>
<td>TBP</td>
<td>TBP</td>
<td>TBP</td>
</tr>
<tr>
<td>S4</td>
<td>EOMI</td>
<td>VFFTC</td>
<td>PERRLA</td>
<td>20/20</td>
</tr>
<tr>
<td>S5</td>
<td>EOMI</td>
<td>deficits in LLQ and LUQ on Left</td>
<td>PERRLA</td>
<td>20/20 (as per Ophtho)</td>
</tr>
<tr>
<td>S6</td>
<td>EOMI</td>
<td>deficit in RUQ on Right</td>
<td>bilateral miosis, b/l nonreactive</td>
<td><em>not tested</em></td>
</tr>
<tr>
<td>S7</td>
<td>EOMI</td>
<td>VFFTC</td>
<td>PERRLA</td>
<td>20/20</td>
</tr>
<tr>
<td>S8</td>
<td>EOMI</td>
<td>VFFTC</td>
<td>PERRLA</td>
<td>20/20</td>
</tr>
<tr>
<td>S9</td>
<td>EOMI</td>
<td>VFFTC</td>
<td>PERRLA</td>
<td>20/20</td>
</tr>
<tr>
<td>S10</td>
<td>EOMI</td>
<td>VFFTC</td>
<td>low amplitude of constriction</td>
<td>20/20</td>
</tr>
<tr>
<td>S11</td>
<td>TBP</td>
<td>TBP</td>
<td>TBP</td>
<td>TBP</td>
</tr>
<tr>
<td>S12</td>
<td>EOMI</td>
<td>VFFTC</td>
<td>PERRLA</td>
<td>20/20</td>
</tr>
<tr>
<td>S13</td>
<td>EOMI</td>
<td>VFFTC</td>
<td>PERRLA</td>
<td>20/30</td>
</tr>
<tr>
<td>S14</td>
<td>EOMI</td>
<td>VFFTC</td>
<td>PERRLA</td>
<td>20/30</td>
</tr>
<tr>
<td>S15</td>
<td>EOMI</td>
<td>VFFTC</td>
<td>PERRLA</td>
<td>20/20</td>
</tr>
</tbody>
</table>

TBP = To Be Performed
## Stroke Screen Breakdown

<table>
<thead>
<tr>
<th>ID #</th>
<th>MMSE</th>
<th><strong>Fugl Meyer</strong></th>
<th><strong>Hand &amp; Wrist</strong> (out of 30)</th>
<th>Barthel Index</th>
<th>GDS</th>
<th>Modified Rankin</th>
<th>Edinburgh Handedness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Upper Extremity (out of 36)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exclusion Criteria:</td>
<td>&lt; 25</td>
<td></td>
<td></td>
<td></td>
<td>&gt; 9</td>
<td>&gt; 4</td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>27</td>
<td>11</td>
<td>4</td>
<td>85</td>
<td>1</td>
<td>1</td>
<td>Right</td>
</tr>
<tr>
<td>S4</td>
<td>28</td>
<td>36</td>
<td>25</td>
<td>100</td>
<td>2</td>
<td>1</td>
<td>Right</td>
</tr>
<tr>
<td>S5</td>
<td>28</td>
<td>26</td>
<td>17</td>
<td>90</td>
<td>10</td>
<td>1</td>
<td>Right</td>
</tr>
<tr>
<td>S6</td>
<td><strong>21</strong></td>
<td>29</td>
<td>21</td>
<td>100</td>
<td>4</td>
<td>1</td>
<td>Right</td>
</tr>
<tr>
<td>S7</td>
<td>29</td>
<td>29</td>
<td>22</td>
<td>95</td>
<td>1</td>
<td>1</td>
<td>Left</td>
</tr>
<tr>
<td>S8</td>
<td>30</td>
<td>17</td>
<td>7</td>
<td>100</td>
<td>8</td>
<td>1</td>
<td>Left</td>
</tr>
<tr>
<td>S9</td>
<td>29</td>
<td>33</td>
<td>16</td>
<td>100</td>
<td>10</td>
<td>1</td>
<td>Right</td>
</tr>
<tr>
<td>S10</td>
<td>29</td>
<td>32</td>
<td>26</td>
<td>95</td>
<td>9</td>
<td>1</td>
<td>Right</td>
</tr>
<tr>
<td>S12</td>
<td>29</td>
<td>23</td>
<td>21</td>
<td>85</td>
<td>0</td>
<td>1</td>
<td>Right</td>
</tr>
<tr>
<td>S13</td>
<td>30</td>
<td>36</td>
<td>29</td>
<td>100</td>
<td>4</td>
<td>1</td>
<td>Right</td>
</tr>
<tr>
<td>S14</td>
<td>26</td>
<td>11</td>
<td>6</td>
<td>85</td>
<td>1</td>
<td>1</td>
<td>Right</td>
</tr>
<tr>
<td>S15</td>
<td>29</td>
<td>4</td>
<td>0</td>
<td>70</td>
<td>5</td>
<td>2</td>
<td>Right</td>
</tr>
<tr>
<td><strong>Average:</strong></td>
<td>28</td>
<td><strong>25.09090909</strong></td>
<td><strong>17.27272727</strong></td>
<td><strong>92.72727273</strong></td>
<td><strong>4.909090</strong></td>
<td><strong>1.090909091</strong></td>
<td></td>
</tr>
</tbody>
</table>
Stroke Screen Breakdown cont.

<table>
<thead>
<tr>
<th>ID #</th>
<th>Beery VMI</th>
<th>Single Line Bisection</th>
<th>Single Letter Cancellation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Score (out of 30)</td>
<td>% Incorrect</td>
<td>Deviation (mm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>&gt;</td>
</tr>
<tr>
<td>S1</td>
<td>21</td>
<td>30.0%</td>
<td>2</td>
</tr>
<tr>
<td>S4</td>
<td>23</td>
<td>23.3%</td>
<td>-4</td>
</tr>
<tr>
<td>S5</td>
<td>19</td>
<td>36.7%</td>
<td>-8</td>
</tr>
<tr>
<td>S6</td>
<td>23</td>
<td>23.3%</td>
<td>1</td>
</tr>
<tr>
<td>S7</td>
<td>25</td>
<td>16.7%</td>
<td>-6</td>
</tr>
<tr>
<td>S8</td>
<td>27</td>
<td>10.0%</td>
<td>-1</td>
</tr>
<tr>
<td>S9</td>
<td>27</td>
<td>10.0%</td>
<td>4</td>
</tr>
<tr>
<td>S10</td>
<td>16</td>
<td>46.7%</td>
<td>-16</td>
</tr>
<tr>
<td>S12</td>
<td>24</td>
<td>20.0%</td>
<td>-5</td>
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<td>S13</td>
<td>26</td>
<td>13.3%</td>
<td>2</td>
</tr>
<tr>
<td>S14</td>
<td>25</td>
<td>16.7%</td>
<td>8</td>
</tr>
<tr>
<td>S15</td>
<td>26</td>
<td>13.3%</td>
<td>-3</td>
</tr>
<tr>
<td>Average:</td>
<td>23.72727273</td>
<td>20.9%</td>
<td>-2.545454545</td>
</tr>
</tbody>
</table>
Results: Stroke Hitting the Target Less Affected (LA) Arm
Results: Stroke Hitting the Target More Affected (MA) Arm

Hit Rate (Cumulative)

Hit Rate (Relative)

Reach Number (#)
Covariance Ellipse according to grouping: Stroke LA

V as V

T as T

V as T

T as V
Covariance Ellipse according to grouping: Stroke MA

V as V

T as T

V as T

T as V
Variance Ratio Plots

Control: DomH

Stroke: MA

Stroke: LA

**Vector as Vector**

**Target as Vector**
The Gym Equivalent - How does this potentially translate?

Target-based reaches

Vector-based reaches
What about the motor planning of Eye?
What are the movements and the axes of those movements?

<table>
<thead>
<tr>
<th>Class of Eye Movement</th>
<th>Main Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vestibular</td>
<td>Holds images of the seen world steady on the retina during brief head rotations</td>
</tr>
<tr>
<td>Visual fixation</td>
<td>Holds the image of a stationary object on the fovea</td>
</tr>
<tr>
<td>Optokinetic</td>
<td>Holds images of the seen world steady on the retina during sustained head rotation</td>
</tr>
<tr>
<td>Smooth pursuit</td>
<td>Holds the image of a small moving target on the fovea; or holds the image of a small near target on the retina during linear self-motion; with optokinetic responses, aids gaze stabilization during sustained head rotation</td>
</tr>
<tr>
<td>Nystagmus quick phases</td>
<td>Reset the eyes during prolonged rotation and direct gaze toward the oncoming visual scene</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Saccades</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bring images of objects of interest onto the fovea</td>
</tr>
<tr>
<td>vergence</td>
</tr>
<tr>
<td>Moves the eyes in opposite directions so that images of a single object are placed or held simultaneously on both foveas</td>
</tr>
</tbody>
</table>

X (parasaggital)
Y (transverse)
Z (vertical)
**Future Directions:** Let’s Parallel our Reaching experiment in the Eye and focus on Saccades
Conclusions

• There is new evidence to suggest the idea of more than one motor planning system for reaching

• It is not simply about completing a task and practicing that task completion, but how one learns or re-learns how to complete and practice that task

• It appears that stroke patients have an impairment in these motor planning systems as it relates to new motor learning

• For future directions:
  • Focus on the idea of eye motor planning (saccades)
  • Focus on how motor planning between limb and eye is integrated
  • Focus on motor plan specific, eye-hand coordinated rehabilitation
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**NYU Downtown**: Prof. Michael Landy, Prof. Todd Hudson and Andrew Abdou

**Albert Einstein COM**: Dr. Joe Verghese