Thinking with Hands and Body

David Kirsh
Cognitive Science
UCSD
Topics

Case Study: Dance
What is Marking?
What we found with super-expert dancers
Why is Marking so effective?
Four Major Claims about thinking
Riffing: body thinking for creativity
CASE STUDY: DANCE MAKING
Timeline – ‘Dyad’ 2009

UCSD
Jan 26th  Feb 13th
Total = 6 weeks

London
Aug 25th  Sept 7th  Oct 13th

Premiere

Wayne McGregor

Random Dance
Timeline – ‘Far’ 2010

Total = 6 weeks

London Premiere

Sept 13th Nov 13 Nov 17th
Timeline – ‘Undance’ 2011

Total = 6 weeks

London

Aug 30th

Premiere

Oct 23rd  Nov 30th
Dyad UCSD
Field Notes

- Observations for 5 hours/day, for 27 days
  - Online coding of activity in FIELD NOTES
    - Includes: Time of activity, Activity code, and Description of activity
Interviews

After session each day usually in two’s

Before and after session
2 hours/day, for 23 days
Marking and Riffing

TWO PHENOMENA IN DANCE
Body thinking in dance

‘Marking’ shows that dancers use their body as simulation engines – they use them representationally – they think with their body.
Body thinking in dance

‘Riffing’ shows that a choreographer can increase his creativity by switching between modalities – running movements through his body to see different possibilities
MARKING
Marking

A dance phrase is practiced, explored or reviewed in a less energetic manner than doing it ‘full-out’.

Dancer abstracts from full phrase & focuses attention on some specific aspect of the complete form.
Marking - during practice
Marking: a universal phenomenon

- Tennis swing – by aspect
- Cello – on the arm
- Staged Plays – an Italian run-through
- Imperfect modeling – aspectual – as a learning/practice technique
What it is

• Represent a full dance phrase by a less energetic, less detailed one

A form of physical sketching
Marked aspect anchors projection

Marked aspect in world

Anchors Mental Projection

‘Imagery” in mind
Antoine: Full
Antoine: Large marking
Agnes: Full vs. marked
Agnes: large vs. small marking
Experiment to show the power of marking
Which conditions facilitate learning most?

- Full-Out
- Mark

Simulate in the head
Performance Measures

1. Technicality
   - Precision of positions

2. Memory
   - Completeness of detail

3. Dynamics
   - Speed, Force, Acceleration

4. Timing
   - Tempo, duration
## Experimental Design

<table>
<thead>
<tr>
<th>Trail One</th>
<th>Teach Phrase 1</th>
<th>Baseline Measure</th>
<th>Practice Phrase</th>
<th>Final Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 mins</td>
<td>10 mins</td>
<td>10 mins</td>
<td>10 mins</td>
<td>10 mins</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BREAK 5 mins</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trail Two</th>
<th>Teach Phrase 2</th>
<th>Baseline Measure</th>
<th>Practice Phrase</th>
<th>Final Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 mins</td>
<td>10 mins</td>
<td>10 mins</td>
<td>10 mins</td>
<td>10 mins</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BREAK 5 mins</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trail Three</th>
<th>Teach Phrase 3</th>
<th>Baseline Measure</th>
<th>Practice Phrase</th>
<th>Final Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 mins</td>
<td>10 mins</td>
<td>10 mins</td>
<td>10 mins</td>
<td>10 mins</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BREAK 5 mins</td>
</tr>
</tbody>
</table>
Mean Improvement From Practice

Mean (raw delta)

Condition
- Full
- Marking
- Simulation
Learning broken down by dimension

Measure

<table>
<thead>
<tr>
<th></th>
<th>Memory</th>
<th>Technicality</th>
<th>Timing</th>
<th>Dynamics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Marking</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Simulation</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>

Higher is better

<table>
<thead>
<tr>
<th>Measure</th>
<th>Mark &gt;Full</th>
<th>Full&gt;Mark</th>
<th>Mark&gt;Sim</th>
<th>Full&gt;Sim</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memory</td>
<td>.7334</td>
<td></td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Technicality</td>
<td>.0029</td>
<td></td>
<td>&lt;.0001</td>
<td>.0005</td>
</tr>
<tr>
<td>Timing</td>
<td>.0194</td>
<td>.145</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Dynamics</td>
<td>-</td>
<td></td>
<td>.0003</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Mem, Tech, Timing</td>
<td>.0189</td>
<td>-</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>
Why this is interesting

• Three ways of practicing

- Regular Practice
- Repeat real thing
- Marking
- Small scale model
- Mental Simulation
- Imagination

Realistic movements

- Real skiing, tennis games and shots, practice music on violin, dance the real phrase...
Issue

• Three ways of practicing

- Regular Practice
- Repeat real thing
- Marking Small scale model
- Mental Simulation Imagination

Partial model of real thing

- Italian run-through, Cello on arm, marking in dance, slow practice, aspectival practice, vocalize tabla rhythm
Issue

• Three ways of practicing

Regular Practice
Repeat real thing

Marking
Small scale model

Mental Simulation
Imagination

Mental simulation

- Cyber skiing, mental run-throughs, imaginary dancing ...
Upshot of marking study

- Marking confers cognitive benefits during the rehearsal process
  - Sometimes people learn faster by producing simplified or distorted models of the real thing
    - E.g. practice getting the notes right at slow speed, or just the rhythm with wrong notes – or saying the rhythm (bols in tabla)
- Marking is a movement reduction system
- Other movement reductions might also facilitate:
  - whispering or subvocalizing
  - Gesturing
THEORETICAL CLAIMS
Theoretical Claims

1. We can think by moving things

2. Mental Projection is more powerful than mental imagery alone, if supported

3. Project $\rightarrow$ Create $\rightarrow$ Project is our core interactive cognitive strategy

4. The practice of Marking in dance exploits supported projection – it is facilitating

5. Running ideas through the body facilitates creativity
Claim one

THINKING IN MOTION
Claim One

We can think by moving things body movement including gesture and moving external objects can be recruited to simulate processes, they help us draw inferences, and move thought forward – physical movement is a type of computation
Will these pieces make this image?
Oops!
Advantages of physically moving?

Operating on the world as its own model guarantees truth
Rotating and translating are computations whether done in mind or world
Advantages of mentally moving?

We can usually move simple pieces faster in mind
Internal Rotation slows with complexity

- Mental speed depends on complexity of object
- Reliability is a function of both complexity and speed

Complex objects are no harder to rotate externally but they are internally.

Proviso: The more complex object the longer
the longer it may take to verify that it is aligned to 2D start and finish
What about a Mixed Strategy?

Partly in the head

Partly in the world

MIXED strategy: how much in the world & how much in the head?
Tetris: Mixed strategy requires precise timing

• The world must change at just the moment we need it to help us decide
  • Piece recognition – physical rotation
  • Placement decision – physical rotation
  • Placement certainty – translation

• Interactive strategies involve millisecond coordination
Cognition flows to wherever costs are lower

In closely coupled systems, process and structure migrates.
Case One: summary

• Thought can be moved along by moving things in the world

• But inner representation and outer movements must be coordinated

• Whether a mental transition occurs because of inner or outer depends on cost-benefits:
  – Speed, accuracy, reliability …

• Harder problems rely more on outer structures, processes
Claim two

PROJECTION
Claims Two: Projection

Mental Projection is more powerful than mental imagery alone.

Movement and external structures enable projection. We can project beyond what we can readily imagine.
What is Mental Projection?

Move the colored balls, one at a time in a minimum number of moves, from the start state to the goal state.
Projection vs. Imagination (pure imagery)

- Project an image onto the external structure
- Projection is imagination anchored to structure
Projection is a component of visual thinking

_Actively looking_ at external representations and projecting onto them makes us more powerful thinkers than just thinking in our heads.

Prove: \[ \frac{1}{2} + \frac{1}{2^2} + \frac{1}{2^3} + \ldots \frac{1}{2^n} = 1 \]
Prove: \[ \frac{1}{2} + \frac{1}{2^2} + \frac{1}{2^3} + \ldots + \frac{1}{2^n} = 1 \]
Visual Proof

In a visual proof you convince yourself by recreating the moves yourself. So you partly ignore what is there.

**Controlled ‘visual’ process**

Project next cut or subtract an existing cut.
Visual Proof

Build a visual narrative

Cut this in half
Visual Proof

Build a visual narrative
Visual Proof

Build a visual narrative

\[
\begin{array}{c}
\frac{1}{2} \\
\hline
2
\end{array}
\quad \begin{array}{c}
\frac{1}{2} \\
\hline
2
\end{array}
\]
Visual Proof

Build a visual narrative

\[
\frac{1}{2}
\]
Visual Proof

Build a visual narrative

\[
\begin{array}{c}
1 \\
2
\end{array}
\quad
\begin{array}{c}
\frac{1}{4} \\
\frac{1}{4}
\end{array}
\]
Visual Proof

Build a visual narrative

\[
\begin{array}{c|c}
\frac{1}{2} & \frac{1}{2^2} \\
\hline
\frac{1}{2^2} & \hline
\end{array}
\]
Visual Proof

Build a visual narrative

\[
\begin{array}{c}
\frac{1}{2} \\
\frac{1}{2^3} \\
\frac{1}{2^2}
\end{array}
\]
Visual Proof

Build a visual narrative

\[
\begin{array}{c}
\frac{1}{2} \\
\frac{1}{2^3} \\
\frac{1}{2^4} \\
\frac{1}{2^2}
\end{array}
\]
Visual Proof

Build a visual narrative

\[
\frac{1}{2} \quad \frac{1}{2^3} \quad \frac{1}{2^4} \\
\frac{1}{2^2}
\]
Prove: \( \frac{1}{2} + \frac{1}{2^2} + \frac{1}{2^3} + \ldots \frac{1}{2^n} = 1 \)

The clever thing was to think of cutting a square 1 x 1 in half.

Seeing the validity of the proof is easier.

Projection is part of visual thinking.
Experiment to explore projection
Tic tac toe experiment – 3 by 3

**Imagination Condition**
- Blank Sheet

**Projection conditions**
- X O
- Table
- Table + X O

Experimental Conditions
Imagination Condition

Blank Sheet

No external structure to help Projection

Many people closed their eyes: no projection at all.
Projection $\neq$ Memory Offload of State

No state change in the environment

Board remains the same over time
Within Subject, practice first

<table>
<thead>
<tr>
<th>practice</th>
<th>Imagination Condition</th>
<th>Projection conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blank Sheet</td>
<td>X O</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
</tbody>
</table>
**Results 3 by 3**

**Overall Means**
- Blank: 4.8
- Table: 4.9
- Table + XO: 4.6

Not significant
N = 25

**>50% preferred Blank**
- Blank: 4.4
- Table: 5.8
- Table + XO: 4.7

Significant p = .002

**Surprise!**
Table Costs more than it helps

But lots of individual differences
Projection requires anchoring

Anchoring is a form of inner-outer coordination

Good Match

Mental effort and time to register
Hence benefits of projecting may not overcome costs of anchoring.
Bad Match: problematic anchoring

- Bad Orientation Match
- Bad Size Match
- Coloring strategy in head
- Bad Structural Match
You must factor in anchoring Costs

- Cost of anchoring process must be factored in. Cost of coupling with the world.
- The tighter the coupling the lower the mediating cost of ‘anchoring’
- Gestures, registration and other processes are often involved as we situate ourselves – help us couple.

Anchoring processes
Can we find cases where benefits always overcome anchoring costs?
Conjecture:
if the imagery task is hard enough
everyone
will benefit.
**4 by 4 Experiment: harder imagery task**

<table>
<thead>
<tr>
<th>Practice</th>
<th>Imagination Condition</th>
<th>Projection conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Blank Page</td>
<td>X O</td>
</tr>
<tr>
<td></td>
<td>Blank</td>
<td>Table</td>
</tr>
<tr>
<td></td>
<td>Table</td>
<td>Table + X O</td>
</tr>
</tbody>
</table>

3 Conditions
Results 4 by 4

Implication:

Once task is hard enough
Table is worth the cost of coordination

Grid faster than Blank
mean difference
1.6s, \( p = .002 \)
Grid faster than XO \( p = .01 \)

N = 25
Is it better for everyone

Bad visualizers are helped much more!

<table>
<thead>
<tr>
<th>Visualization Ability</th>
<th>Weak</th>
<th>Strong</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blank</td>
<td>10.1</td>
<td>10.1</td>
</tr>
<tr>
<td>XO</td>
<td>9.4</td>
<td>9.4</td>
</tr>
<tr>
<td>Grid</td>
<td>9.3</td>
<td>9.3</td>
</tr>
</tbody>
</table>

Weak grid > blank
p = .014

Strong > weak
p = .05
Upshot

• Projection is a real process distinct from perception and imagination

• As problems get harder we cannot easily imagine the answer so we rely on projection more
  – Imagination has memory limitations that are partly overcome by external supports

• Projection and imagination are driven by the actions you are familiar with
  – Different people will be able to project different outcomes
CLAIM THREE - INTERACTIVITY
Major Claim - Three

Project → Create → Project

Core interactive strategy: project structure, create that structure, project
Issue is the relentless force of the visible – data driven
Project → Create → Project Cycle

Timing is important

Interact with letters

grant up

g ant pru

Pant g ur

g ant pur

grant up
Prove: all three medians of a triangle always intersect at a single point.

Projection

Create figure

Project 1\textsuperscript{st} construction

Project 2\textsuperscript{nd} construction
If you can’t, draw it in
Prove: all three medians of a triangle always intersect at a single point.

Gesture - ephemeral structure

Create figure
Project 1\textsuperscript{st} on top of gesture
Project 2\textsuperscript{nd} gesture again
Project 3\textsuperscript{rd} gesture again
Interim conclusion

• Sometimes it is easier to manipulate an aspect outside than through imagination or projection

• It all depends on the cost structure of:
  – Imagination
  – Projection
  – Manipulation

• The project-create-project cycle lets us think farther because physical manipulation carries some of the load
Claim four

GESTURE AS ANCHORING AND REGISTERING PROJECTION
Hands help register map to world

Establishing the right reference or interpretation relation between map and world.
Hand as pacer
Gestures help tie us to the world

Hands drag our eyes. Regulate attention.
Registration gestures help situate us.

Count the dots
Claim Five

THINKING BETWEEN MODALITIES
WHAT EXTRA DOES MOVING ADD?

Why not just mentally simulate?
Key Conjecture

- Creativity is enhanced by modality switching
  - Switching between different types of imagination is useful
  - Imagine visually vs. imagine kinesthetically
  - What is easy to notice in one modality may be hard in another
Different Sensory Codes

- **Poetry**: why speak it instead of just reading it or writing it?
- **Music composition**: why play it instead of just notate it?
- Encounter with music is different when mediated by **playing** an instrument vs. **listening** alone.
Sensory codes differ in dance

• Motor code:
  – ‘resistance’, ‘about to fall’, ‘feel gravity’, ‘stretching till it hurts’ … terms intrinsically meaningful kinesthetically
  – ‘Start a movement more deeply’ trivial to understand kinesthetically but harder to understand and recognize visually
Motor vs. Visual Code

• Visual code:
  – Imagine liberty bell
  – You see its structure, you ‘see’ that it is heavy
  – But motor feeling is different than visualization
HOW DOES IT WORK?
Explicitness of information

43,610
43,610

Is this divisible by 10?
43,610

The attribute `divisible-by-10` is *explicitly encoded* in the base 10.
34,77
6
Divisible by 7 ?
34,77

6

Divisible-by-7 is NOT explicitly encoded in the base 10
\[ 34,776_{10} = 63,620_{7} \]
63,620

7

Divisible by 7 ?
Explicitness of information

- Inferential distance in geometry vs. algebra determines how easy or hard to prove something to discover new theorems.
- Changing representation space increases the probability of generating new candidates.
- Connections are visible in one representation and not in another.
By analogy

Encoding in each modality make different things visible – each has its own metric of goodness.

Changing encoding increases the probability of generating new candidates.
Attributes have different computational distances in different modalities
Aesthetic Judgements

Seems right in $\text{Sense}_1$

seems right in $\text{Sense}_2$
Major Claims

• Dancers and choreographer use their bodies as a thing to think with
  – By using their sensory systems as engines to simulate ideas non-propositionally

• There are sensory specific codes that encode dance relevant attributes differently -

• This increased expressive range enlarges the candidate space of dance ideas – therefore, translate between modalities

• Metrics of goodness may also be sensory specific
Conclusions

• Our study of dance revealed two highly general methods of physical thinking:
  Marking – imperfect simulation
  Riffing – appropriation in a multiple modalities
Conclusions

• Marking shows that an external simulation can be used as constituent in thinking as well as an internal simulation
  – Externalizing provides a physical understructure that supports projection
  – Simplifying the simulation focuses attention on aspectival elements enabling better practice

• Riffing shows that translation between modalities such as kinesthesia and vision can be used for creative thought
Conclusions

• The principles at play are:

1. Thinking can be pushed forward by physical movement

2. Projection onto external structures or processes is a method of visual thinking

3. Projection is part of an extendable interactive method of thinking – Project◊ Create ◊ Project

4. Projection needs to be anchored and gestures are sometimes used to foster anchoring

5. Modality translation is powerful when the explicitness landscape of modalities differs
Acknowledgements

- Dafne Muntany (post-doc)
- Wayne McGregor
- Scott delaHunta

Support
- UCSD core grant
- R-Research, London
- NSF: CreativeIT

UCSD classes and Random Dancers
THE END
Two dance phenomena

1. Marking
   - Body movements are used representationally or as mediating elements supporting projection

2. Riffing
   - Kinesthetic encoding is more revealing than visual encoding
Highly general

• We ‘mark’ or do ‘partial practice’ all the time

• Why is marking helpful?
  – We seem to be practicing the wrong thing
  – Sometimes people learn faster by producing simplified or distorted models of the real thing

• E.g. practice getting the notes right at slow speed, or just the rhythm with wrong notes – or saying the rhythm (bols in tabla)
Why is marking so good for practice?

1. Like interactive sketching: marking helps dancers focus on specific aspects of their phrase

   – It helps to manage attention on target issue
Why is marking so good for practice?

2. Projection is better than imagination:
   
   – movement carries thinking forward – physical priming
   
   – It recruits the body to **fill in timing**, balance
   
   – Think about the end point and get trajectories for free