Duplex vision in the cerebral cortex
How (and why) the visual control of action differs from visual perception

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For most of us (including many philosophers and scientists), it seems self-evident the actions we perform on visible objects make use of the same visual representation that allows us to perceive those objects.

Assumption of Experience-based Control

But why are there two separate visual systems?
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Size Is Relative.
Virtual Workbench

Real-time vs. Delayed Estimation

“Show me how big the one with the dot is”

Two conditions: No delay vs. 5s delay
Measuring the Size-contrast Effect

Difference Score = “Larger” - “Smaller”
Size-contrast Effect: Estimation

Real-time vs. Delayed Grasping

“Pick up the one with the dot”

Two conditions: No delay vs. 5s delay
Size-contrast Effect: Grasping

Normal Grasping

Object viewing

Automatic visuomotor response

Pantomimed Grasping

Object viewing

Delay Period:
Visuomotor program decays or is never formed.
Image generation takes place

Perceptually driven pantomimed response
James, Culham, Humphrey, Milner, & Goodale (2003) *Brain*
Optic ataxia patient (IG)

Lesion to posterior parietal cortex bilaterally

Conscious form perception *intact*

Grasping visible objects: poor grip scaling
Patient IG

Immediate grasping

Delayed grasping

Pantomimed grasping

Milner et al. (2001) *Current Biology*
Normal Grasping

Object viewing

Automatic visuomotor response

Pantomimed Grasping

Object viewing

Delay Period:
Visuomotor program decays or is never formed.
Image generation takes place

Perceptually driven pantomimed response
Perceptual Illusion and the Real-time Control of Action

No delay

“Vision”

“Occlusion”

500 ms

Delay

“Vision”

“Occlusion”

500 ms
• **Target visible at cueing**
  – Real time visuomotor mechanisms (dorsal)
  – Computations are not stored in memory
  – Absolute size scaling

• **Target not visible at cueing**
  – Access stored target representation
  – Laid down by perceptual mechanisms (ventral)
  – Relative (scene-based) metrics

*Westwood & Goodale, *Spatial Vision* (2003)*
Dual-Task Interference is Greater in Memory-Guided Grasping Than in Visually-Guided Grasping

Singhal, Chinellato, Culham, & Goodale (2005). VSS
Visual Memory

Paired-associate Task

“GO” signal

Movement onset

Target

Movement

Memory

Visual

500 ms

Time

Singhal, Chinellato, Culham, & Goodale (2005). VSS
Performance on Auditory Paired-associate Task

Vocal Reaction Time

Singhal, Chinellato, Culham, & Goodale (2005). VSS
Performance on Grasping Tasks

Total Movement Time

RT (ms)

700
300

Vis Alone  Mem Alone  Aud + Vis  Aud + Mem

Condition

Singhal, Chinellato, Culham, & Goodale (2005). VSS
Memory-guided but not visually guided grasping slowed vocal RT in an auditory memory task.

An auditory memory task interfered more with memory-guided than visually guided grasping.

Singhal, Chinellato, Culham, & Goodale (2005). VSS
Visual Illusions and the two streams
Acting on illusions

Perceptually different
Physically identical

Perceptually identical
Physically different

Perceptually Identical Trials

- Large disk
- Small disk

Aglioni, DeSouza, & Goodale (1995) *Current Biology*
Dyde & Milner (2002)
Trends in Cognitive Sciences

“Low-level” illusion
Affects both perceptual judgements and grasping

“High-level” illusion
Affects perceptual judgements – but not grasping

Dyde & Milner (2002)
Trends in Cognitive Sciences
Hollow face Illusion

courtesy of Heinrich Bülthoff
Hollow-face illusion: Perception and action

1. Perceptual estimates
2. Fast object-directed ‘flicking’

Króliczak, Heard, Goodale & Gregory (in press) Cognitive Brain Research
The flicking task
Defocusing lens acted as a low-pass filter for binocular information, but maintained the illusion within reaching distance.
Perceptual estimates

- Illusory
- Normal
- Hollow

Distance in or out (cm)

Types of face

Króliczak, Heard, Goodale & Gregory (in press) *Cognitive Brain Research*
Flicking task

Króliczak, Heard, Goodale & Gregory (in press) Cognitive Brain Research
The visuomotor system can use bottom-up input about the veridical locations of targets despite the presence of a powerful top-down illusion of depth.

Króliczak, Heard, Goodale & Gregory (in press) *Cognitive Brain Research*
But how do the two streams work together in the production of adaptive behaviour?
Bottom-up

- Size
- Overall form
- Location
- Orientation

Top-down

- Weight
- Compliance
- Fragility
- Friction coefficients
- Temperature
- Function
- …
Functional grasps
Awkward grasp, but ready to hammer

Efficient grasp, but poorly prepared to hammer
Semantically demanding task

Stuff and things

With thanks to Doug Coupland
“It’s made out of metal – is it aluminium? It’s got red plastic on it.”

“Is it some sort of kitchen utensil?”

Humphrey, Goodale, Jakobson, & Servos (1994). *Perception*
120 common objects

Humphrey, Goodale, Jakobson, & Servos (1994). *Perception*
3-D objects

- Full vision
- Monocular vision
- Monochromatic vision
- Monocular and monochromatic vision

Slides

- Full colour
- Black and white
- Line drawings

Humphrey, Goodale, Jakobson, & Servos (1994). *Perception*
3-D objects

Percent correct

DF

full
monocular
monochromatic
monocular + monochromatic
colour
black and white
line drawing

Slides
DF identified all the natural objects correctly under full viewing

...but only one of them when they were presented as line drawings

Humphrey, Goodale, Jakobson, & Servos (1994). *Perception*
Ventral surface of DF’s cerebral cortex

Intact Line Drawings minus scrambled

Intact Colored Pictures minus scrambled

James, Culham, Humphrey, Milner, & Goodale (2003) *Brain*
Stuff
Stuff
Stuff

Hand cream  Cream cheese

Stuff vs. things

Cant, Valyear, & Goodale, in prep.
Block design: Attending to different properties

Material properties

Respond when attending to material properties

Object form

Respond when attending to form

Orientation

Respond when attending to orientation

Cant, Valyear, & Goodale, in prep
Design

4 T whole body fMRI scanner (Varian/Siemens)

9 subjects

18 coronal slices

Blocked experimental design

Anatomical Scan

Cant, Valyear, & Goodale, in prep.
Whole volume analysis: Lateral Occipital Area (LO)

Transverse

\[ p < .001 \] vs

Coronal

Sagittal

Cant, Vallyear, & Goodale, in prep.
Whole volume analysis: Fusiform and Parahippocampal Cortex

Transverse

L R

Sagittal Coronal

p < .001

form
material properties
orientation

Cant, Valyear, & Goodale, in prep.
Whole volume analysis: Caudal intraparietal sulcus (clIPS)

Transverse

L R

Sagittal

Coronal

p < .001

form

material properties

orientation

Cant, Valyear, & Goodale, in prep.
Whole volume analysis: Anterior intraparietal sulcus (AIP)

Transverse

L R

Sagittal

Coronal

Cant, Valyear, & Goodale, in prep.
Overlap of whole brain and localizer data

Lateral Occipital Area (LO): Object Form

Coronal

Transverse

Whole volume data

Localizer data (intact – scrambled objects)

Cant, Valyear, & Goodale, in prep.
Overlap of whole brain and localizer data

Parahippocampal Place Area (PPA) and Fusiform Face Area (FFA): Material Properties

Cant, Valyear, & Goodale, in prep.
Bottom-up

Size
Overall form
Location
Orientation

Top-down

Weight
Compliance
Fragility
Friction coefficients
Temperature
Function
...

Bottom-up

Top-down
The primary division of labour between the ventral and dorsal streams

- The ventral stream identifies goals and (together with prefrontal cortical areas) plans an appropriate action

- The dorsal stream (in conjunction with related circuits in premotor cortex, basal ganglia, and brainstem) programs and controls those actions.

...an engineering metaphor
Autonomous Robot
Tele-operation

Human Operator

Slave Robot
Tele-assistance

Human Operator

Semi-autonomous Robot

‘Flagged’ Object
Biological tele-assistance
Biological Tele-assistance

Ventral stream processing (Human operator)

Marked by re-entrant signals in area V1+ and/or by activity in LIP+

Dorsal stream processing (Robot)
The contributions of action to perception

Active

Passive
Limiting viewing angles during exploration

Harman, Humphrey, & Goodale (2001). *Canadian J. Exp. Psychology*
Studying only cardinal views resulted in faster object recognition at all views than did studying only canonical views.

Harman, Humphrey, & Goodale (2001). *Canadian J. Exp. Psychology*
‘Wobbles’ around each of the canonical views

Angle: Degree of rotation about the y-axis
Radius: Number of ‘wobbles’ about the y-axis
Vision-for-perception

With thanks to Alex Colville
“To Prince Edward Island” 1965
“Berlin Bus” 1978

Vision-for-action
The great end of life is not knowledge but action.

Thomas H. Huxley
1825-1895