Eye Movements and Cognition

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School of Psychology, University of Sussex, UK.

<table>
<thead>
<tr>
<th>Time</th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
<th>Saturday</th>
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<tbody>
<tr>
<td>09.00-09.45</td>
<td>Introduction (P. Pouget)</td>
<td>fMRI (J.-B. Marsman)</td>
<td>Perception (N. Petrovsky)</td>
<td>Recordings in the Field (T. Foulsham)</td>
<td>Pharmacology (N. Petrovsky)</td>
<td>Biomarkers and Endophenotypes (N. Petrovsky)</td>
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<td>10.30-11.00</td>
<td>Coffee Break</td>
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<td>12.30-14.00</td>
<td>Lunch</td>
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<td>16.00-16.45</td>
<td>Coffee Break</td>
<td>Coffee Break</td>
<td>Keynote 2 (B. Rafal)</td>
<td>Guided Discussions, Workshops</td>
<td>Guided Discussions</td>
<td>Guided Discussions</td>
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Obviously “Cognition” is a very large topic with poorly defined boundaries, and most eye movements involve cognition somehow…

What follows is just a few examples (mainly based on my experience) of different ways in which you can use eye tracking to explore cognitive processes...
Outline

• How can eye movements tell us anything about cognition?
  – Saccades as decisions
  – Eye movements as a proxy for (visuospatial) attention

• Some examples:
  – Eye tracking “Complex” cognitive tasks
  – Attentional Bias
  – Comprehension / Visual World Tasks
  – Consumer Psychology
  – Marketing / HCI

(Some Silly Things I’ve Done With Eye Trackers…)
• Saccades take far too long to ever be called reflexive (with the possible exception of express saccades…)

• Carpenter suggests the extra latency reflects the fact that each saccade is essentially a decision. “The oculomotor system is a microcosm of the brain”.

• The thresholds and rate of rise determine the saccade latency (and variability in latencies across repeated saccades. All of these can be influenced by top down and bottom up factors.
Eye Tracking Cognition

1) We are foveate
2) A basic tenet of cognitive psychology is that we have (or the brain has) limited processing capacity.

Each saccade (and subsequent fixation) represents a decision – and as such reflects our goals, desires, beliefs, expectations, memories, perception etc etc etc…
Eye Tracking Cognition

By measuring / analysing where people look as they perform various tasks, we can gain insights into the cognitive processes involved.

This reasoning underlies a very large percentage of eye movement research…

Researchers are typically interested in scanpaths / dwell time to IAs
Eye tracking measures

Common eye tracking measures

- Saccade metrics
  - Latency
  - Direction
  - Amplitude
  - Accuracy
  - Velocity

- Fixation metrics
  - Duration
  - Location (x,y co-ords)

- IA metrics
  - Dwell time / % dwell time
  - Number of fixations / % N fixations
  - First fixation time
  - First fixation duration
  - Ave fixation duration
  - Run count
  - Re-entries
Matching Familiar Figures Task

Subjects have to indicate which of the images on the right matches the target on the left.

• Subjects continue until they get the right answer

• (guessing is discouraged)

• Test developed to measure impulsivity (but obviously involves WM processes…)

1 2 3 4 5 6
Matching Familiar Figures Task

Subjects have to indicate which of the images on the right matches the target on the left.

Subjects continue until they get the right answer

(guessing is discouraged)

Test developed to measure impulsivity.
Eye Tracking MFFT

A group of people who took large quantities of ecstasy in their youth were complaining of short term memory problems in their late 20s / early 30s…

But MFFT performance was normal

Create IAs around “Target”, “Match” and “Distractors”
Multiple measures:
Dwell Time; N Visits; Dwell per Visit; N Fixs per Visit; Fixation Dur;
Time Before RefixTarget
Decision Making Task (DMT)

Decision Making Task (Rogers et al, 2002):
4 Blocks of 20 decisions between an “experimental” vs “control” gamble. Figures represent pennies, and any profits from £5 advance are kept as subject payment.
Primary measure = proportion of trials on which the “experimental” gamble was chosen in preference to the control gamble.

As a function of:

Wins: (High vs Low)
Losses: (High vs Low)
Odds: (High vs Low)

Decision time (DT) is also measured.

Data from Win Only and Loss Only trials analysed separately.
Defined several ROIs using DataViewer.

Measures include:
- N Fixations
- % N Fixations
- Duration of Fixs
- N Visits
- Dwell time
- % Dwell time

Data from "wins" and "losses" will be presented.
## DMT - Eye Movement Data

### Summary:

<table>
<thead>
<tr>
<th>Measure</th>
<th>Wins</th>
<th>Losses</th>
<th>t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Fixations</td>
<td>1.086</td>
<td>0.841</td>
<td>P &lt; 0.01</td>
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<tr>
<td>Dwell Time</td>
<td>220.2</td>
<td>163.6</td>
<td>P &lt; 0.01</td>
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<tr>
<td>% N Fixations</td>
<td>14.22</td>
<td>9.46</td>
<td>P &lt; 0.05</td>
</tr>
<tr>
<td>% Dwell Time</td>
<td>13.69</td>
<td>8.61</td>
<td>P &lt; 0.01</td>
</tr>
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</table>

- In general subjects preferentially fixate the win values over the loss values.
- Possibly because gambles are “framed” positively.
- However, there were large individual differences in eye movements…
DMT - Eye Movement Data

Individual data:

<table>
<thead>
<tr>
<th>Subject</th>
<th>Wdwell%</th>
<th>Ldwell%</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>0.23</td>
<td>0.06</td>
</tr>
<tr>
<td>2</td>
<td>0.05</td>
<td>0.04</td>
</tr>
<tr>
<td>3</td>
<td>0.31</td>
<td>0.11</td>
</tr>
<tr>
<td>4</td>
<td>0.15</td>
<td>0.10</td>
</tr>
<tr>
<td>5</td>
<td>0.22</td>
<td>0.08</td>
</tr>
<tr>
<td>6</td>
<td>0.05</td>
<td>0.07</td>
</tr>
<tr>
<td>7</td>
<td>0.19</td>
<td>0.09</td>
</tr>
<tr>
<td>8</td>
<td>0.24</td>
<td>0.05</td>
</tr>
<tr>
<td>9</td>
<td>0.26</td>
<td>0.11</td>
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<tr>
<td>10</td>
<td>0.05</td>
<td>0.11</td>
</tr>
<tr>
<td>11</td>
<td>0.21</td>
<td>0.19</td>
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<tr>
<td>12</td>
<td>0.15</td>
<td>0.12</td>
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<tr>
<td>13</td>
<td>0.01</td>
<td>0.03</td>
</tr>
<tr>
<td>14</td>
<td>0.01</td>
<td>0.05</td>
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<tr>
<td>15</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>16</td>
<td>0.21</td>
<td>0.01</td>
</tr>
<tr>
<td>17</td>
<td>0.10</td>
<td>0.14</td>
</tr>
<tr>
<td>18</td>
<td>0.04</td>
<td>0.02</td>
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<td>19</td>
<td>0.30</td>
<td>0.10</td>
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<tr>
<td>20</td>
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<td>25</td>
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<td>0.18</td>
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<td>0.04</td>
<td>0.04</td>
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<tr>
<td>27</td>
<td>0.19</td>
<td>0.2</td>
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Three main gaze strategies were defined with respect to %dwell times on Win and Loss ROIs:

1: Sample both win and loss values equally (>5% of dwell time on both wins and losses ROIs)
   (Pink, N=8)

2: Preferentially sample wins over losses (>5% of dwell time on both wins and losses ROIs and dwell% on wins > twice dwell% on losses)
   (Yellow, N=7)

3: Ignore both wins and losses (<5% of dwell time on both wins and losses ROIs)
   (Blue, N=7)

Do these OM sampling strategies lead to differential task performance?
Does OM strategy effect performance?

Yes - participants who tended to ignore the win and loss values did not modulate their decision making with respect to win and loss values to the same extent as participants who fixated wins and losses equally, or fixated wins more often than losses.

(Wins x Gaze Strategy, $F(2,20) = 5.97, p = 0.01$; Losses x Gaze Strategy, $F(2,20) = 4.69, p = 0.022$)
Results

 Does the strategy of ignoring wins and losses reflect impulsivity?

- Significant difference in MFFT performance ($F(2,19)=8.80, p =0.002$)
  
  \[ I\text{-score} = Z(\text{errors}) - Z(\text{latency}) \]
  
  High score = most impulsive

![Graph showing I-score for different gaze strategies: Equal Pref, Win Pref, Ignore Both](image-url)
Attentional Bias

Visual Search – attentional bias / phobias etc

Different layouts can be used (e.g. Circular)

Visual search in naturalistic scenes

Quokkas and Quolls…
Attentional Bias

Dot-probe type studies - eye tracking attention to relevant stimuli / associated stimuli

- One of the stimuli replaced by dot – eye tracker measures gaze duration / first fixation time / first fixation duration etc etc.

- Also works with learned / acquired associations
Dot Probe Studies

Attentional bias to food...

Endless variants – eg. Comparing hungry vs non-hungry / dieters vs non-dieters etc etc

Other obvious uses are attentional biases in anxiety / phobias / stereotypes? / in-groups / out-groups? / own race? Etc etc etc.
Language Comprehension

• Visual World Paradigm.

Sentences played over headphones / speakers:

“The dog hated the shark at the boxing match because he...”
Visual World Task

Analysis is complex....

Create las around the images (NP1, NP2, PP, DIST)

Audio software used to identify the onset of key words within the sentence (e.g. pronoun).
All samples (e.g. 1000 per second) for each trial for each participant are output and then “binned” (20ms bins are typical). After this processing it is possible to determine the proportion of “looks” to each of the four ROIs across all the bins.
Psycholinguistics

All samples from start of trial

3000 msec from “because”

NP1 Verb

NP2 Verb
Embedded Cognition

Sentences played over headphones / speakers: Eye movements are recorded whilst participants look at blank screen.

“Imagine you are sitting at a bus stop. Opposite you is a fence and a bird is sitting on it. Sitting about 5 meters to the left is a cat, and 3 meters to the left of the cat is another bird. The cat walks towards this bird.”
Consumer Psychology

The “Online Magazine” experimental design:
- Scan in interesting pages from popular magazines
- Use photoshop to embed your adverts in various positions
- Aim for about 10-25% of the content to be your experimental stimuli – the rest should just be normal magazine content
- Load the pages into a script that allows “page turning”
- Create interest areas for your stimuli
- Invite participants to the lab and invent a “cover story” – you are interested in what content appeals to readers or something...
- Tell them to read the magazine as if they were waiting for an appointment with the doctor or dentist.
- Track their eyes during this procedure
- Give them lots of questionnaires – do they remember any adverts / what products do they like etc etc
- Analyse the results!
An example: Eye tracking materialism

Individual differences (IDs) – differences in personality, motivation, IQ, ability, interests, values etc that make us who we are.

Concept of IDs enjoying something of a renaissance within experimental psychology / cognitive neuroscience.

Perhaps a similar thing is happening in advertising research?
Individual Differences

Certain broad individual differences widely used to target advertising:

- Gender
- Socio-economic status
- Age

Other IDs clearly relevant but not much studied.

One ID that is studied extensively in social psychology (and which might be expected to impact on advertising effectiveness) is materialism
Materialism

“The importance a consumer attaches to worldly possessions. At the highest level of materialism, such possessions assume a central place in a person’s life and are believed to provide the greatest sources of satisfaction and dissatisfaction” (Belk, 1984)

Materialistic individuals also strive to gain external approval through attempting to achieve financial success, social recognition and an appealing image.
Eye tracking and individual differences in materialism

Aspiration Index
Average Purchase Intention

Extrinsic Aspiration Score
Number of Fixations

Extrinsic Aspiration Score
Total Dwell Time (seconds)

Eye tracking and individual differences in materialism
Consumer Psychology

Eye tracking TV ads (moving images)
- Technically challenging (particularly at the analysis stage)
- Needs dynamic regions of interest.
- “Moving” heatmaps can be created
- Repeat viewing is interesting...

Number of fixations as a function of repeat viewing and “consumer type”.

Consumers the brand was aimed at remain engaged / interested.
Consumer Psychology

Skinny vs Healthy models: - image manipulation.
- Magazine browsing + questionnaires – purchase intent / product liking etc etc.
“Deviant” images

Adverts are placed in an onscreen “magazine” that participants browse at their own pace.
HCI / Usability

Another very large literature
- Comparing website designs
- Software design
- Gaming industry (lots of apps, including control)

Participants set a series of tasks – read headline story / find cricket scores etc etc.

Measures include timings / mouse tracking and eye tracking.

“Gaze-prompted talk aloud protocols” quite interesting...
Marketing Research

Engagement with advertising / marketing material

- Pack design companies –
  - Shelf stand out
  - Promo / diet info
  - Brand awareness

- Ad agencies
  - Brand awareness
  - Which still / moving images work?
  - Ad Comprehension / “visual consumption”.

- Brands
  - Exposure effects
  - Individual differences

- Real world – posters / trade exhibitions / supermarket shopping etc etc etc etc etc....
Summary

• Eye trackers are used by psychologists of every type to explore both low and high level cognitive processes
• Recording eye movements whilst people perform other standard cognitive / neuropsychological tasks can be revealing
• Behind the vast majority of this research lies the assumption that gaze provides clues as to where the participant is choosing to focus their limited visual processing resources
A few of the things I didn’t talk about….

• Eye tracking in the real world (pointing / grasping / driving / making tea / playing sport etc etc)
• Eye tracking and long term memory