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# DISCRIMINATING ENGINEERING INFORMATION INTERACTION USING EYE TRACKING AND AN INFORMATION OPERATIONS MODEL

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*Keywords: information interaction, information processing, eye tracking, design cognition*

## 1. Background

In engineering design a set of initial requirements are transformed into a finished product in what is commonly viewed to be an information processing activity [Pahl et al. 2007, p.52]. How good an engineer is at processing and managing this information heavily influences the quality of the finished product [Baya and Leifer 1997, p.151]. To assist engineers during design and improve product quality, information management tools and techniques have been developed. However, broad information requirements and poor understanding of how engineers fundamentally process information frustrates attempts to support them in this critical activity [Dieter and Schmidt 2012, p.151].

The information processing behaviour of engineers has primarily been investigated using “think-aloud” studies. Inferences about an engineer’s cognition, including evaluation of facts, information assimilation, and knowledge structuring, are made from the transcripts of their self-reported thought process. The generalizability of these results can be problematic as sample sizes are often small and interpretations are post-rationalised (e.g. [Baykan 1997], [Ullman, Dietterich, and Stauffer 1988], [Cross 2011]). Capacity limitations of working memory introduce an additional issue as behaviour is affected by an increased cognitive load from concurrent verbalising during a task [Ullman 2010].

Alternative methods for characterising information processing exist that do not impose an additional cognitive load or require self-reporting. Eye tracking is an example of a passive technique, exploiting the link between gaze and attention to allow inferences about cognitive processes to be made [Duchowski 2007], [Holmqvist et al. 2011]. The signal generated by eye-trackers are considered as cognitive outputs for an individual and correspondingly embody and represent an individual’s *information interaction*.

A novel model of information interaction is proposed based on eye movements described in a previous paper [Boa and Hicks 2014]. In the model, a set of fundamental operations are used to manipulate the information space during a design problem and progress the development of a product. The *Information Operations* model is based on understanding from design theory, problem solving theory, and cognitive psychology. The model hypothesises that information interaction can be characterised with four key operations: *familiarisation*, *finding*, *comprehension* and *review*. *Review* is considered broader in scope than other operations and has two modes, *review selection* and *review critique*. The model adopts the view of Newell and Simon that (in constrained problems) humans are representable as information processing systems [Newell and Simon 1972].

Characterisation and discrimination of the Information Operations are made by measuring differences in eye movements during each operation. Subsequently, established cognitive interpretations of gaze

can be used to elucidate the information processes of engineers based on their eye movements, without the need for them to self-report.
Interpreting gaze to infer cognitive processes is highly dependent on the context under which eye movements occur. Existing cognitive interpretations of gaze have predominantly been formulated in non-engineering disciplines and hence there is a need to translate them into an engineering design specific context. To do so, a series of experiments involving basic information interaction has been conducted. In the main experiment detailed in section 2 of this paper forty-two trainee engineers participated. From the data five gaze metrics are statistically modelled to compare and contrast the individual information interaction of the participants. This analysis is used to characterise and to discriminate the Information Operation model. This paper presents the results of one of those measures, the saccade amplitude fixation duration ratio.

### 1.1 Information operation model

Five Information Operations (IO) have been hypothesised as a means to characterise information interaction during the design process. The operations are limited to the consideration of interacting with pre-existing information and deliberately make no declaration regarding creative processes. Each operation is a manipulation of the information space carried out by the designer and is of the most primitive order. Definitions of the IOs are given in Table 1.

**Table 1. Information operation (IO) definitions**

| IO | Definition |
|---|---|
| Familiarisation | The acquisition of information on a subject area or topic where a specific goal has not, or has yet to be set/developed. |
| Finding | The process of targeted information acquisition for a specific goal. |
| Comprehension | The learning of information with understanding. |
| Review critique | Information beyond that which is presented in the external environment is assessed for its for its quality, validity or appropriateness. |
| Review selection | Information in the external environment is assessed for its quality, validity or appropriateness against explicitly stated requirements or constraints |

### 1.2 Eye movements

Eye movements arise from a combination of environmental, physiological and cognitive factors. Where gaze is directed is predominantly determined by what arouses the attention of the individual within the environment [Holmqvist et al. 2011, p.23].

**Table 2. Commonly exhibited types of eye movement events and typical values**

| | Definition | Duration (ms) | Amplitude (°) | Velocity (°$s^{-1}$) |
|---|---|---|---|---|
| Fixation | A period of time over which the eye remains relatively still [Holmqvist et al. 2011]. | 200 – 300 | . | . |
| Saccade | The fast ballistic movements of the eye to relocate gaze [Gilchrist 2011]. | 30 – 80 | 4 – 20° | 30 – 500 |

The range and types of movements exhibited by the eye are classified into gaze events, with fixations and saccades making up the majority by duration (see Table 2 for definitions and typical values of each measure). Gaze events are idiosyncratic with substantial variation in the duration, amplitude, and velocity between individuals. Classification of eye movements into gaze events is generally calculated automatically using algorithms. Event detection algorithms typically only classify fixations and saccades. The remaining events require specialist equipment to record and analyse.

## 2. Method

The experiment requires participants to interact with design information and complete a basic task designed to stimulate each Information Operation. During information integration their corresponding gaze behaviour is recorded. Eye movements are predominantly involuntary, governed by attentional mechanisms that are not always overt. Interpretation of the corresponding gaze events requires a thorough understanding of the context in which they occur. The context in this instance refers to the experiment, including the stimuli over which gaze occurred, the task the gaze is a function of, the means of measurement (eye-tracking equipment), and the individual participating.

### 2.1 Stimuli information

Hubka and Eder [1982, p.76] classify engineering design representations based on the manner in which the product is represented. Although not the explicit intention of their classification system, it can be viewed as attempting to describe the form of information embodied in a design artefact:

- Iconic representations that record the visualisation or the original in true form, as sketches, drawings, photographs or physical models.
- Symbolic representations using assumed or conventional symbols i.e. language, mathematics, and analogues.
- Diagrammatic representations, such as graphs, schematics or diagrams for representing relationships.

Correspondingly, experimental stimuli information sources are separated into symbolic and iconic *information sheets* so as to isolate the effect of information form on information interaction. Diagrammatic information (e.g. orthographic drawings) is combined with iconic information as in the context of engineering design it is considered closer to iconic information than symbolic.
Containing a variety of engineering information the sheets are shown individually on a computer display whilst a participant's information interaction is recorded. An example of symbolic and iconic information sheet is given in Figure 1.

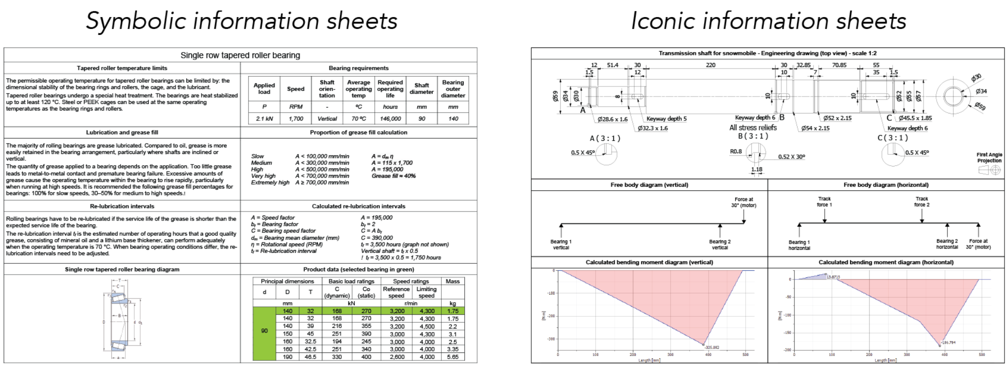


**Figure 1. Example symbolic and iconic information sheets**

The stimuli information sheets are highly controlled and follow a strict format. Each information sheet represents a single iteration of a common design activity with no deliberate errors. A total of 30 information sheets have been created: 15 for symbolic and 15 for iconic information. Development of the stimuli information sheets and the control measures are described in full in Boa and Hicks [2014].

### 2.2 Stimuli tasks

To promote behaviour in line with each Information Operation and generate corresponding gaze responses, a series of stimuli tasks have been developed through exploratory studies and prototyping [Boa and Hicks 2014]. Tasks are designed to be as simple as possible so that description and implementation are unambiguous (Table 3).

**Table 3. IO stimuli tasks (Trial durations in seconds)**

| IO | Task |
|---|---|
| **Familiarisation** (symbolic and iconic 30s) | Participants are informed that they will be asked a series of questions after viewing a stimulus. Clarification of the nature of the questions is given after the trial is completed. Gaze is recorded during stimulus viewing which is limited to a short duration of time. |

| | |
|---|---|
| **Finding** (symbolic and iconic 30s) | Participants are presented with a question prior to viewing the stimulus that requires them to locate an element of information within the stimulus. Gaze is recorded during stimulus viewing which is limited to a short duration of time. |
| **Comprehension** (symbolic 100s, iconic 60s) | Participants are informed that they will be asked a series of questions after viewing a stimulus that require detailed understanding of the stimulus content. Gaze is recorded during stimulus viewing. Trial duration is longer than that of Familiarisation and Finding. |
| **Review critique** (symbolic 100s, iconic 60s) | Participants are asked to determine the appropriateness of a candidate component for which the requirements are presented within the same stimulus. Gaze is recorded during stimulus viewing for which the trial duration is the same as Comprehension. |
| **Review selection** (symbolic 100s, iconic 60s) | Participants are asked to determine which out of a possible three candidate components is the most appropriate. Each candidate component is presented on a separate stimulus with the identical requirements repeated across each stimulus. Gaze is recorded during stimulus viewing for which the trial duration is the same as Comprehension. |

Information Operation tasks are identical for symbolic and iconic information sheets with the exception of Comprehension. For iconic information sheets, Comprehension questions are provided for the participants prior to viewing the stimulus. Participants reported recall of specificities of iconic information as being harder during experimental prototyping compared to symbolic information. Subsequently, to reduce the memory load and perceived difficulty of Comprehension for iconic information sheets, questions were provided in advance. Similarly, from prototyping the trial durations for iconic information sheets was reduced for Comprehension, and the Review operations to appropriately adjust the perceived difficulty. Participants were randomly assigned to a presentation order group, in which the order of each task was randomised. Each task was completed twice for two similar but distinct information sheets.

Prior to undertaking the main body of the experiment each participant was asked to read a short passage of text taken from an engineering manual. The participant's gaze was recorded during this baseline activity and used to compare and relate results to existing work.

### 2.3 Equipment

The experiment has been undertaken with a Tobii TX300 eye-tracker and Tobii Studio version 3.2. The Tobii TX300 is a remote eye-tracker with an integrated 23" high definition display (1080p). Eye-movements are sampled at 300 Hz and the positional accuracy is 0.4° under ideal conditions. The 'dark pupil' response method is employed to measure eye movements.

### 2.4 Participants

Participants were recruited from the University of Bath Mechanical Engineering department with a total of 42 individuals taking part. All 42 participants completed the experiment in its entirety. Thirty-nine males and three females took part with an average age of 22.4 years (SD 2.5). Of the participants 28 had issues with their vision and 40 spoke English as a first language. Twenty-eight participants had at least a year of continuous experience in engineering industry.

### 2.5 Gaze measures

This paper is limited to reporting and discussing the results of the saccade amplitude fixation duration ratio (SF ratio) from a broader analysis of the same data set. The SF ratio is a proportionate measure of the magnitude of saccade amplitude to fixation duration and measures the time spent processing stimulus content relevant to the time spent searching for content [Holmqvist et al. 2011]. Cognitive interpretations of the saccade amplitude fixation duration ratio are based on physiological pathways in the brain. In the two-streams hypothesis of cognition, two visual systems exist: the ventral stream is responsible for object recognition and identification, the 'what' stream: and the dorsal stream is associated with spatial processing, the 'where' stream [Goodale and Milner 1992].

**Table 4. Overview of SF ratio cognitive interpretations**

| | |
|---|---|
| **Ambient processing** | Large saccade amplitudes followed by short fixation durations is characteristic of an 'ambient' style of processing linked to the dorsal stream. |
| **Focal processing** | Small saccade amplitudes followed by longer fixation durations is characteristic of a 'focal' style processing linked to the ventral stream. |

A bottom-up cognitive process is associated with an initial 'orientation' period in scene viewing that later drives more in depth scrutiny of the stimulus. It is theorised that the 'ambient' early orientation processing is linked to the dorsal "where" stream, and the later in depth scrutiny linked to the ventral "what" stream [Goldberg and Kotval 1999], [Unema et al. 2005]. Subsequently high values of the SF ratio are indicative of a more ambient style of processing whilst low values suggest a more focal style of processing (Table 4).

## 3. Results

The effect of each Information Operation on the SF ratio is estimated using regression analysis. In doing so, the relationship between Information Operations associated with symbolic and iconic information, can be compared to a baseline activity of reading and to one another. Eye-movements are affected by a wide range of factors, including some that correlate to a task (e.g. presentation order) and others that may vary between individuals (e.g. corrective eyewear). In investigating the relationship between Information Operations and eye-movements, failure to control for these factors will bias any estimates of the gaze measures. In practice, this would mean the net-effect of all gaze-affecting factors being estimated rather than an isolated Information Operation effect. Any subsequent characterisation and discrimination of Information Operations would therefore also be biased. The gaze regression functions are fitted to the sample data using Ordinary Least Squares (OLS).

### 3.1 Trends and data description

The distribution, and trend over time, of the SF ratio are estimated so as to highlight potential issues with the data, such as outliers. The distribution of the outcome measure is estimated using the Epanechnikov kernel function (as implemented in Stata 13.1). Time trends of the SF ratio are estimated using a locally weighted Lowess regression. Lowess smoothing of scatter plots is advantageous in that it produces a moving average of the data without the prior need to make assumptions about it's overall shape. The default bandwidth used by Stata is 0.8, meaning that 80% of the data points are used to smooth each data point [Stata 2015].
The SF ratio for symbolic information interaction is between 15% and 35% lower than the SF ratios for iconic information interaction (statistically significant at $p<0.05$) (Table 5).
The standard deviation for between persons is an order of magnitude lower than for within person for symbolic and iconic information interaction (Table 5). This suggests that the nature of the SF ratio "randomness" is generalizable between people. If a model of an individual participant's behaviour can be sufficiently fitted, which is not a trivial task, then the model should be applicable to other individuals too.

**Table 5. Summary statistics of SF ratio for symbolic and iconic information sheets**

| | Mean | | SD | | Within person SD | | Between person SD | |
|---|---|---|---|---|---|---|---|---|
| **Information Operation** | **Symbolic** | **Iconic** | **Symbolic** | **Iconic** | **Symbolic** | **Iconic** | **Symbolic** | **Iconic** |
| Reading | 0.0099 | - | 0.0142 | - | 0.0141 | - | 0.0018 | - |
| Familiarisation | 0.0205 | 0.0274 | 0.0259 | 0.0315 | 0.0257 | 0.0313 | 0.0027 | 0.0039 |
| Finding | 0.0189 | 0.0217 | 0.0221 | 0.0246 | 0.0220 | 0.0244 | 0.0028 | 0.0040 |
| Comprehension | 0.0182 | 0.0244 | 0.0247 | 0.0276 | 0.0246 | 0.0274 | 0.0025 | 0.0032 |
| Review critique | 0.02 | 0.0275 | 0.0270 | 0.0329 | 0.0268 | 0.0327 | 0.0030 | 0.0038 |
| Review selection | 0.0188 | 0.0276 | 0.0260 | 0.0332 | 0.0259 | 0.0330 | 0.0026 | 0.0037 |

It is well documented that large saccades are frequently followed by short fixations, and small saccades are often followed by long fixations [Holmqvist et al. 2011].

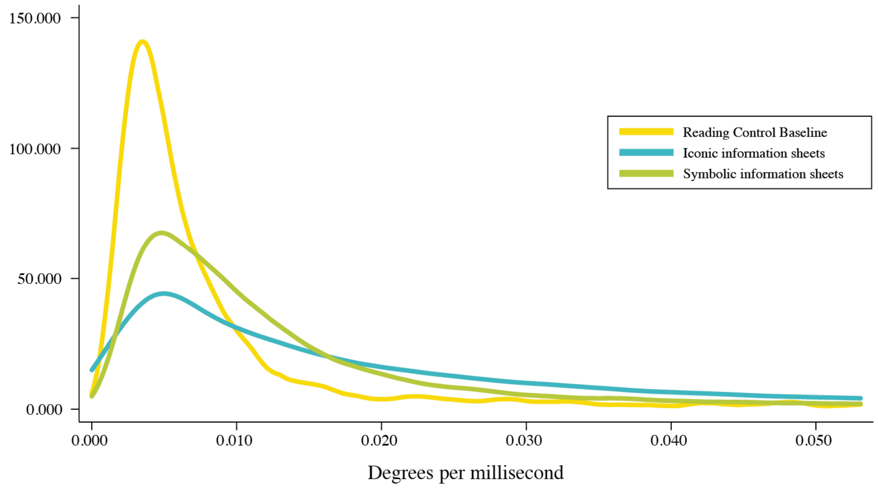


**Figure 2. SF ratio kernel density estimates – symbolic and iconic information**

Symbolic and iconic information interaction overlap to a degree in their distributions of SF ratio but exhibit a lesser clustering around small ratio values compared to reading (display limited to 90$^{th}$ percentile for clarity – Figure 2). This is because during reading the consistent word spacing and convention for reading from left to right leads to a high number of short saccades followed by relatively consistent duration fixations. Symbolic and iconic information interaction exhibit a greater variation in SF ratio values indicating they are different to reading.

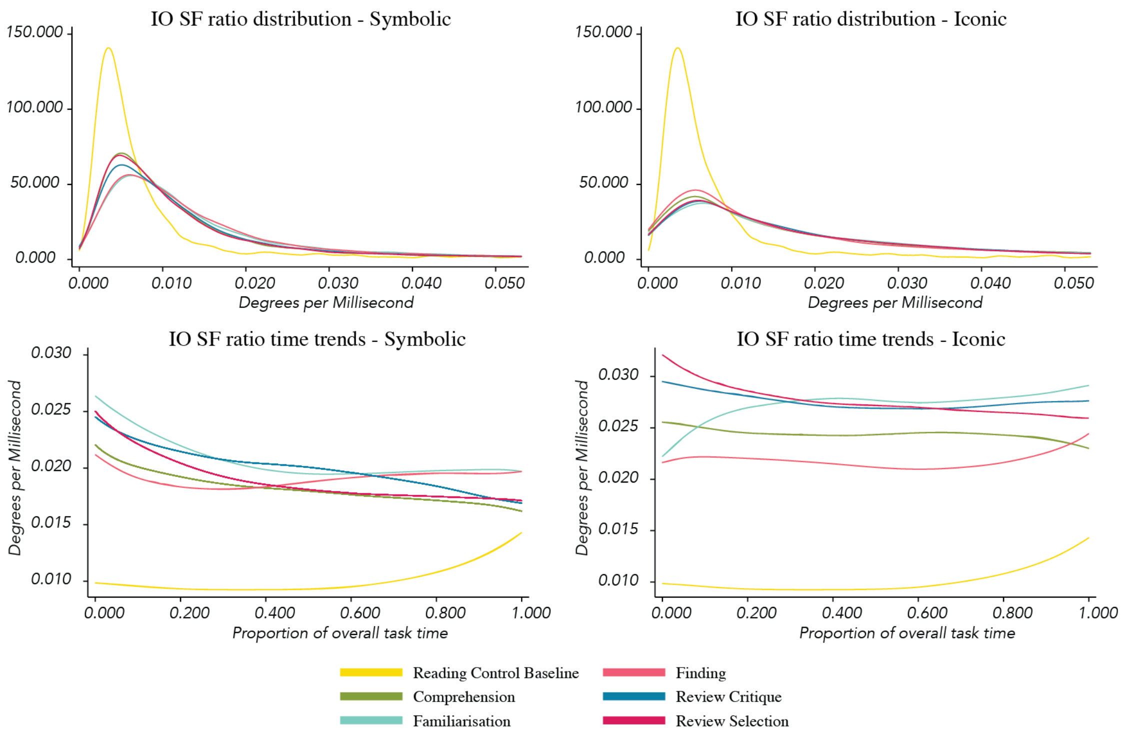


**Figure 3. Comparison of SF ratio between information operations**

Overall distributions of SF ratios for individual Information Operations are clearly distinguishable from the baseline activity of reading but are less so from each other (Figure 3). Time trends for symbolic and iconic information interaction differ from one another for IOs and are similar to those exhibited by saccade amplitude.

### 3.2 Regression model

The conditional expectation function for the SF ratio for a given participant, time, and information sheet is given in Equation 1. The corresponding coefficients for each explanatory variable for the SF Ratio are estimated using OLS linear regression. The model is fitted separately for symbolic and iconic information interaction data sets and is formulated based on the data exploration in the previous section and known gaze determinants.

$$Y_{i,t,s} = \beta_1 i + \beta_2 T_{i,t,s} + \beta_3 t + \beta_4 t^2 + \beta_5 T \cdot t + \beta_6 T \cdot t^2 + \beta_7 R \cdot t + \beta_8 R \cdot t^2 + \varepsilon_{i,t,s} \quad (1)$$

Where, $Y_{i,t,s}$ is the SF ratio, for a given participant, time, and information sheet, $i$ is the participant, $t$ is the percentage time elapsed, $T$ is the Information Operation task, $s$ is the information sheet, $R$ is the repeat of an Information Operation task, $\varepsilon_{i,t,s}$ is the error, for a given participant, time, and information sheet.

The SF ratio is approximated as a normal distribution by taking the data in natural logs. This deals with the skewness evident in the SF ratio (Figures 2 and 3). During processing to produce the SF ratio saccade amplitudes recorded as zero degrees are discarded, so that all resulting SF ratios are greater than zero. Outliers have been removed by trimming the data set to the 99$^{th}$ percentile. For the SF ratio a median for the whole data set of 0.01°ms$^{-1}$ is observed, with a 95$^{th}$ percentile of 0.08°ms$^{-1}$, and a 99$^{th}$ percentile of 0.13°ms$^{-1}$, this is deemed a necessary step.

Information Operation task is interacted with first and second order time terms in the SF ratio regression model. Doing so isolates the differences in the change and rate of change, of the SF ratio for each Information Operation. The magnitude and the rate of change of the magnitude of the SF ratio is likely to change with time according to which Information Operation is being performed. For example, Familiarisation is likely to be characterised by high values of the SF ratio throughout the trial as a person continues to make large amplitude movements followed by short fixations. This would be exhibited as a high first order coefficient (β3). A first and second order time term in the SF ratio regression model is included to isolate this effect of repeating a stimuli task on a similar information sheet (repeat variable). It is anticipated that recognising elements of repeated information sheets will affect behaviour. Inclusion of the repeat variables within the regression model will estimate the size of this effect on the SF ratio. Individual participant time trends, specific information sheet, and presentation order variables are not included in the model as in line with the base measures of the SF ratio. Error terms are calculated for individual participants looking at each information sheet making their estimation conservative.

### 3.3 Regression results

All standard errors are displayed in square brackets, with asterisks indicating the following significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Regressor coefficients are interpretable as being the approximate percentage difference to the SF ratio for the baseline activity of reading (with the exception of Time and Time$^2$ which are the baseline SF ratio coefficients). In Table 6 it is observed that for symbolic information the SF ratio rises over the trial duration for the baseline activity of reading (Time and Time$^2$) and the effect of viewing a repeated information sheet on the SF ratio is small for first and second order time effects (Repeat#Time and Repeat#Time$^2$).

**Table 6. Symbolic and iconic information regression coefficients common to all IOs**

| Time | | Time$^2$ | | Repeat#Time | | Repeat#Time$^2$ | | Constant | |
|---|---|---|---|---|---|---|---|---|---|
| Symb. | Icon. | Symb. | Icon. | Symb. | Icon. | Symb. | Icon. | Symb. | Icon. |
| -1.048<br>***<br>[0.145] | -1.060<br>***<br>[0.143] | 1.303<br>***<br>[0.143] | 0.542<br>**<br>[0.266] | 0.0202<br><br>[0.0783] | 0.105<br><br>[0.111] | -0.0276<br><br>[0.103] | -0.131<br><br>[0.144] | -5.071<br>***<br>[0.0491] | -5.044<br>***<br>[0.0519] |

For symbolic information interaction the effect of IOs on the SF ratio is large compared to the baseline activity of reading (Task, Table 7). All Information Operations affect the SF ratio significantly. Over time all Information Operations have a higher SF ratio that falls at a greater rate compared to the baseline of reading (Time#Task and Time#Task$^2$, Table 7). First order time effects are not significant for Familiarisation. The effect of viewing a repeated information sheet over time on the SF ratio is greater for iconic information than for symbolic (Repeat#Time and Repeat#Time$^2$, Table 6).

**Table 7. Symbolic and iconic information regression coefficients for each IO**

| | **Task** | | **Task#Time** | | **Task#Time$^2$** | |
|---|---|---|---|---|---|---|
| **Information Operation** | **Symb.** | **Icon.** | **Symb.** | **Icon.** | **Symb.** | **Icon.** |
| Familiarisation | 0.814*** [0.0534] | 0.808*** [0.0502] | 0.140 [0.252] | 1.004*** [0.266] | -0.582** [0.240] | -1.231*** [0.277] |
| Finding | 0.630*** [0.0498] | 0.782*** [0.0671] | 0.761*** [0.255] | 0.327 [0.312] | -1.025*** [0.258] | -0.705** [0.301] |
| Comprehension | 0.567*** [0.0372] | 0.816*** [0.0500] | 0.651*** [0.198] | 0.542** [0.266] | -1.054*** [0.205] | -0.895*** [0.265] |
| Review critique | 0.633*** [0.0367] | 0.911*** [0.0438] | 0.681*** [0.185] | 0.602** [0.234] | -1.127*** [0.186] | -0.986*** [0.249] |
| Review selection | 0.595*** [0.0385] | 0.967*** [0.0401] | 0.469** [0.184] | 0.392* [0.215] | -0.851*** [0.183] | -0.868*** [0.215] |

The SF ratios for iconic Information Operations are larger than for symbolic, compared to the baseline activity of reading (Task, Table 7). Time trends for iconic Information Operations indicate a higher SF ratio that is falling over time at a greater rate compared to the baseline activity of reading (Task#Time and Task#Time$^2$, Table 7)

## 4. Discussion

Marginal effects for the SF ratio show that Comprehension is distinct from Familiarisation and Finding for symbolic interaction (Figure 4). For iconic information interaction overall marginal effects indicate that Finding is distinguishable from all of the other operations. The baseline activity of reading is clearly different to the Information Operation with a substantially lower SF ratio for symbolic and iconic information interaction. To aid interpretation marginal effects are transformed from log to absolute levels in Table 8.

**Table 8. Marginal effects (overall and over time) transformed from log to levels for SF ratio**

| | **Overall mean (degrees per ms)** | | **dYdt mean (degrees per ms per % time)** | |
|---|---|---|---|---|
| **IO** | **Symbolic** | **Iconic** | **Symbolic** | **Iconic** |
| Reading (baseline) | 0.009 | - | 2.0 | - |
| Familiarisation | 0.019 | 0.027 | 1.3 | 1.8 |
| Finding | 0.019 | 0.022 | 1.5 | 1.5 |
| Comprehension | 0.016 | 0.024 | 1.3 | 1.6 |
| Review critique | 0.017 | 0.026 | 1.3 | 1.5 |

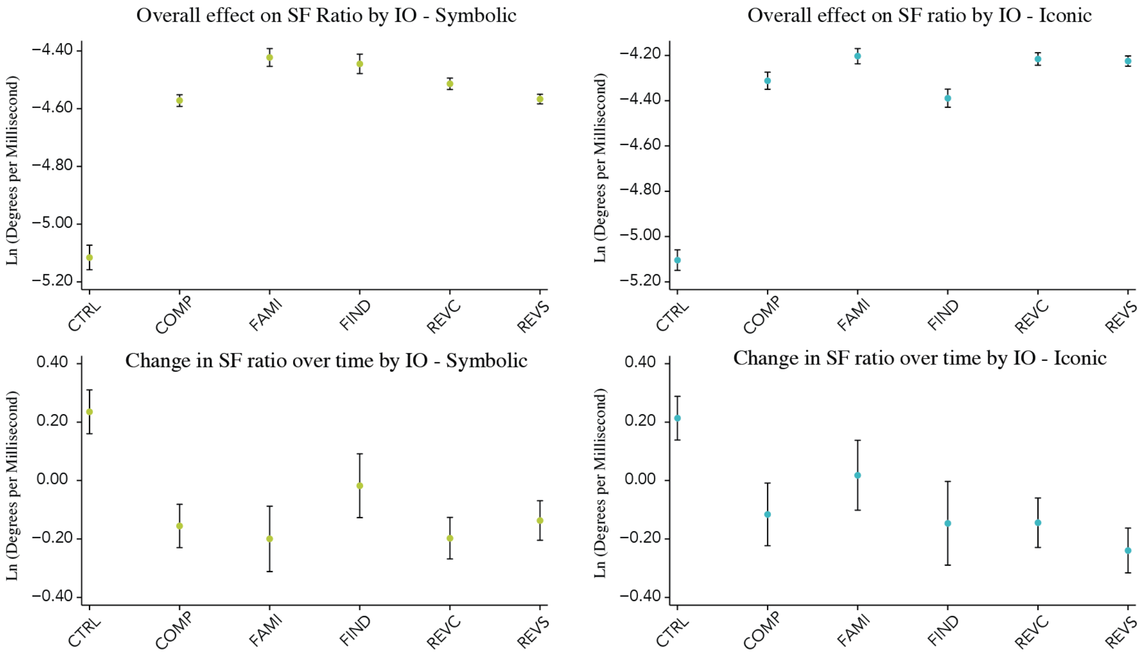


**Figure 4. Marginal effects (overall and over time) in natural logs for SF ratio. The centre point indicates the estimated mean, with bars indicating 95% confidence intervals for the mean**

Discriminating different forms of information interaction is challenging using eye movements as they are highly idiosyncratic and prone to significant variation. Combining saccade amplitude and fixation duration into a single ratio measure improves the ability to discriminate the Information Operations based on the explanatory power of the regression model. The SF ratio values of R-squared are improved by approximately double compared to comparable regression models for the base measures of fixation duration and saccade amplitude (not reported in this paper) (Table 9).

**Table 9. Summary of regression models for SF ratio and corresponding regression models for the base measures of fixation duration and saccade amplitude (split by symbolic and iconic)**

| | Fixation duration | | Saccade amplitude | | SF ratio | |
|---|---|---|---|---|---|---|
| **Regression model measure** | **Symb.** | **Icon.** | **Symb.** | **Icon.** | **Symb.** | **Icon.** |
| Observations | 108,911 | 62,686 | 104,452 | 60,358 | 98,419 | 56,537 |
| R-squared | 3.3% | 3.6% | 3.1% | 6.5% | 4.5% | 7.5% |
| Root mean squared error | 0.424 | 0.47 | 0.851 | 0.924 | 0.953 | 1.075 |
| Number of clusters | 411 | 376 | 411 | 376 | 411 | 376 |

Regression post-estimation specification tests (Ramsey reset) return significant values for symbolic and iconic information interaction indicating missing regression terms in the model (Equation 1). The significant values combined with the low R-squared values suggest that the issue is as a result of the idiosyncrasy of the underlying measures (saccade amplitude and fixation duration) of the SF ratio.

**Table 10. Ramsey reset results for missing terms in the SF ratio regression model**

| Outcome measure | Information type | F statistic Ramsey reset | P value |
|---|---|---|---|
| Ln SF ratio | Symbolic | 2.77 | 0.04** |
| Ln SF ratio | Iconic | 3.18 | 0.02** |

Absolute values of the SF ratio that constitute ambient or focal processing are dependent on the stimuli scene. In the experiment the conditional mean of the SF ratio for reading is 0.009 degrees per

millisecond. At the opposite end of the scale Familiarisation during iconic information interaction has a conditional mean SF ratio three times higher of 0.027 deg/ms. Assuming that the control baseline task of reading is at the focal end of the spectrum, Familiarisation is accordingly at the opposite end.
The requirement to read text makes symbolic information interaction inherently more aligned with focal processing. Iconic information interaction, which is not constrained by word and line spacing conventions, requires greater spatial processing and is more closely aligned to ambient processing.

## 5. Conclusions

Forty-two undergraduate engineers participated in an experiment where their eye movements were recorded as they undertook a series of tasks designed to promote five Information Operation – Finding, Familiarisation, Comprehension, Review critique and Review selection. Characterisation of eye movements with respect to the five IOs is made against a baseline activity of reading, a well understood and widely reported behaviour in the literature. The interpretation of analysed SF ratio values reveals a complex interrelation between the Information Operations. A more focal style of processing is suggested by low SF ratio values whilst higher values suggest a more ambient style of processing. Within the spectrum the relative alignment of symbolic and iconic Information Operations to ambient and focal processing is not always identical. For example, Finding relative to other symbolic operations is more ambient, but for iconic information interaction it is relatively the most focal. In contrast, Familiarisation is the most closely aligned to ambient processing for both symbolic and iconic information interaction. Eye movements are highly idiosyncratic and the degree of variation observed in the results is substantial. Corresponding R-squared values for the regression model (goodness of fit) are relatively low with large confidence intervals for estimated conditional means. However, more sophisticated signal-processing techniques and further data processing could be used to improve the model's power.

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