Reading Information Graphics: The Role of Spatial Contiguity and Dual Attentional Guidance

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SUMMARY

In a naturalistic newspaper reading study, two pairs of information graphics have been designed to study the effects of (a) the spatial contiguity principle and (b) the dual scripting principle by means of eye tracking measurements. Our data clearly show that different spatial layouts have a significant effect on readers’ eye movement behaviour. An integrated format with spatial contiguity between text and illustrations facilitates integration. Reading of information graphics is moreover significantly enhanced by a serial format, resulting from dual attentional guidance. The dual scripting principle is associated with a bottom-up guidance through the spatial layout of the presentation, suggesting a specific reading path, and with a top-down guidance through the conceptual pre-processing of the contents, facilitating information processing and semantic integration of the material. The integrated and serial formats not only attract readers’ initial attention but also sustain the readers’ interest, thereby promoting a longer and deeper processing of the complex material. The results are an important contribution to the study of the cognitive processes involved in text-picture integration and offer relevant insights about attentional guidance in printed media, computer-based instructional materials and textbook design. Copyright © 2008 John Wiley & Sons, Ltd.

Although we frequently encounter complex documents in our everyday life, there is still very little empirical evidence about how these formats are processed. Newspaper layout, for instance, contains text articles, headlines, photos, captions, tickers, drop quotes, fact boxes, maps, diagrams, tables etc. The question is how readers interact with this format, combine information from the available information sources, and create coherence.

In our naturalistic study with experimental conditions, we use eye movement measurements to investigate reading of information graphics, a complex genre used frequently in newspapers, brochures, textbooks and scientific articles. Eye movements provide ‘an unobtrusive, sensitive, real-time behavioural index of ongoing visual and cognitive processing’ (Henderson & Ferreira, 2004, p. 18), and give us insight in the allocation of attention. Eye-tracking methodology can be used to examine how readers choose entry points and reading paths, and how they integrate text and pictures. A study of authentic reading behaviour enables us to investigate in detail how the human mind works when making sense of complex informative and instructional materials.

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Reading information graphics

An information graphic usually consists of (a) a text of various complexity (key words, phrases, sentences, text paragraphs), (b) pictures on various levels of detail (abstract or naturalistic) and (c) graphical means (arrows, movement lines, zoom boxes, highlighting devices etc.). The purpose of using information graphics is to illustrate and clarify difficult issues so that the readers can more easily conceptualise and understand complex structural aspects, stages of a process, as well as effects and causes of an action. They are often used for explanations in technical contexts as well as in the Natural Sciences. Traditionally, the information graphic is formed as a unit, consisting of textual and pictorial components that are attached to or embedded in a text article with the same or similar contents. As empirical studies have shown, the information graphic has an important effect on reading behaviour since it catches readers’ attention and prolongs reading of an associated text (Holmqvist & Wartenberg, 2005).

Text-picture integration

In most complex materials, there are no explicit connections between text and illustration that would instruct the reader. When the eyes reach a certain point in the text, it is the reader who has to discover the referential links between the text and the graphics. Eye movement studies by Hegarty and Just (1993) have shown that students switch between semantically related parts of text and diagrams during several local and global inspections. Hannus and Hyöni (1999) conducted a study on the integration of illustrations and texts in biology books. They found that the high-ability pupils were significantly better at integrating the main text and graphics than the low-ability pupils as indicated by their eye movements. This is an indication that graphically unmarked connections between text and graphics may be difficult to follow for some readers. However, they have not compared different formats in their studies.

The question is then how we can make it cognitively easier for the readers to integrate information from different sources. Different design principles have been suggested, one of them being the spatial contiguity design where verbal and visual information is placed physically close to each other to facilitate processing (for details see next section; e.g. Chandler & Sweller, 1991; Cierniak et al., in press; Cierniak, Scheiter, & Gerjets, in press; Moreno & Mayer, 1999). Furthermore, attention allocation to relevant parts of a complex presentation can be directed by textual reference to the illustration, by a keyword or label, by graphical means such as arrows, pointers and speech bubbles, or colour coding (De Koning, Tabbers, Rikers, & Paas, 2007; Folker, Sichelschmidt, & Ritter, 2005; Jeung, Chandler, & Sweller, 1997; Kalyuga, Chandler, & Sweller, 1999; Mautone & Mayer, 2007). Finally, as we will show in the following, a coherent, conceptually pre-processed spatial format can guide the readers and contribute to easier processing of the materials.

Attentional guidance and cognitive load

According to the cognitive theory of multimedia learning (Mayer, 2001, 2005) and cognitive load theory (Chandler & Sweller, 1991; Sweller, Van Merriënboer, & Paas, 1998), instructional materials should be designed to prime the integration of pictorial and verbal representations into a coherent mental representation. Cognitive load theory (Sweller et al., 1998) provides guidelines for instructional design with the aim to encourage
learner activities and optimise performance. The cognitive load is either determined by the
nature of the material being learned and the expertise of the learner (intrinsic cognitive
load) or by the instructional design, organisation and presentation of information
(extraneous and germane cognitive load). According to this theory, presentation of
information should reduce extraneous working memory load that does not contribute to
schema construction and encourage germane load which does. The cognitive theory of
multimedia learning (Mayer, 2001, 2005) specifies which cognitive processes learners are
actively engaged in when constructing a coherent mental representation of their
experiences and formulates principles for reducing cognitive processing demands
associated with extraneous load. The nature of mental representations is described in
Schnitz & Bannert’s (2003) model of text and picture integration. Other theoretical
accounts have considered coherence of complex presentations to be central for reading and
comprehension. It has been focused on in the rhetoric tradition, and attempts have been
done to apply it to illustrated documents (Bateman, 2008). The structure of complex
multimodal documents and the process of meaning-making have been discussed in the
(socio) semiotic tradition (Kress & van Leeuwen, 1996; cf. also Holsanova, Rahm, &
Holmqvist, 2006). However, few empirical studies of authentic reading behaviour have
been conducted in order to reveal these ongoing cognitive processes. Van Gog, Kester,
Nieveltstein, Giesbers, and Paas (in press) stress the importance of using eye-tracking and
other process-tracing techniques to uncover exactly how and why well-known cognitive
load theory effects occur.

Two principles from multimedia learning theories are relevant for the current study. The
first one is the spatial contiguity principle stating that ‘people learn more deeply from a
multimedia message when corresponding words and pictures are presented near rather than
far from each other on the page or screen’ (Mayer, 2005, p. 183; cf. also Chandler &
Sweller, 1991; Moreno & Mayer, 1999; Sweller & Chandler, 1994; Sweller et al., 1998).
When readers interact with complex messages, they have to read the text and scan the
illustration, process both to derive meaning, search for referents and mentally integrate the
contents. This process can be cognitively demanding if the two sources of information
are placed far from each other (so called split-attention format, Sweller et al., 1998). The
theory suggests that extraneous cognitive load can be reduced and schema construction
facilitated by physically integrating the two sources of information.

The second one is the signalling principle stating that ‘people learn more deeply
from a multimedia message when cues are added that highlight the organisation of the
essential material’ (Mayer, 2005, p. 183). Several signalling techniques can be used to
guide the learner’s attention such as providing headings, lists of the main steps and a
spoken emphasis on key words. In the present paper, we will apply a dual attentional
guidance through form and content of the material that we call the dual scripting principle.
The dual scripting principle states: People will read a complex message more deeply when
attentional guidance is provided both through the spatial layout (supporting optimal
navigation) and through a conceptual organisation of the contents (supporting optimal
semantic integration). In our approach, we do not only highlight relevant parts of the
message but also re-structure the message in order to assist the reader. On the level of
message surface, attentional guidance is provided by a suggested reading path. On the level
of the message content, the material is rhetorically organised and conceptually pre-
processed (from known information, over expert information to practical information). We
suggest that the dual scripting principle is an extension of the signalling principle in
multimedia learning.
In what follows, we present an eye-tracking study on reading information graphics. We address the issue of minimising extraneous cognitive load by testing two principles of attentional guidance: (a) spatial contiguity principle in graphic 1 (separated vs. integrated format) and (b) dual scripting principle in graphic 2 (radial vs. serial format). The first aim of the study is to test whether a complex text-graphic integration will be supported by a format with spatial contiguity between text and illustrations. The second aim of the study is to test whether a complex information graphic will facilitate reading when organised and presented in a coherent and sequential way, with dual attentional guidance.

METHOD

Participants
Thirty-one participants (18 females, 13 males; age $M = 26.61$ years, $SD = 7.13$), native Swedish speakers with normal or corrected-to-normal vision, were recruited from the readership of Norrköpings Tidningar, a Swedish daily newspaper.

Apparatus
Eye movement data were collected by the head-mounted SMI iViewX eye-tracker. The eye tracker is based on the pupil/corneal reflex method with a sampling rate of 50 Hz. The spatial accuracy is better than 0.5 degrees. The eye camera and the scene camera are mounted in a bicycle helmet. Head position is tracked with the help of a light weight Polhelmus headtracking system mounted at the top of the helmet. The system allows free motion of the head and body within a volume of more than one cubic metre. Each recording resulted in coordinate data files and gaze-overlaid video data.

Materials
We printed two versions of the same authentic-looking newspaper consisting of 15 spreads with built-in experimental conditions. Both versions contained two information graphics that were subject to experimental manipulation. For graphic 1, we varied serial vs. radial format and for graphic 2, we varied separated vs. integrated format. The two interventions described here were each on a single spread with all other information being identical on that spread. The information graphic 1 concerned a dramatic diving accident where a diver has died because of a frozen vault in his mouthpiece. The graphic has been designed in two alternative formats to study the effect spatial contiguity principle. We started from a traditional separated graphic where the main text and the explanatory graphic box are physically far from each other (Figure 1). We then created an integrated format by placing the semantically relevant parts of the information graphic physically close to those parts of the main text where the reference had to be made or where an explanation was needed (Figure 2). The two contrasting versions of the information graphic contained the same text, the same illustrations, but had a different overall layout. We hypothesised that a shorter distance between the text and illustration would support the readers in their search for relevant information: The integration of text and graphics would be much easier to make, a split of attention would be avoided, and a deeper semantic processing of the material promoted. Thus, we expected that reading of the integrated format would result in
a better integration of the different informational sources than reading of the separated format.

The information graphic 2 concerned the medical issue of catching a cold. This graphic has been designed in two alternative formats to test the dual scripting principle. We started from a radial format (Figure 3) and created a serial format (Figure 4). The radial format follows the centre–periphery-principle. It consists of a dominant naturalistic picture in the central part of the graphic and a number of smaller components such as lists of items, renderings with annotations, sequences of depictions and zooming boxes, all placed in the periphery. The radial format allows the reader to choose between many possible entry
points and reading paths. The readers can make their own connections between the components since there is no explicit guidance in the format.

The remodelled, serial version of the information graphic has a sequential format with dual attentional guidance. First, we provided a bottom-up guidance through the spatial layout of the presentation by suggesting a specific reading path. Second, we provided a top-down guidance through the conceptual organisation of the contents, facilitating information processing and semantic integration. The different components of the information graphic were grouped into macro-topics in a logical sequence: from introductory information (Why you catch a cold), everyday background knowledge (The usual ways of catching a cold), expert knowledge (What happens in the body) to practical information (How you can soothe the symptoms). By enhancing the temporal, spatial semantic and logical arrangement of components, we created an overall coherent
presentation that supports the message. We hypothesised that such a format that is spatially and conceptually organised and ‘pre-processed’ would guide the readers’ navigation and prolong reading. We expected that the readers of the serial layout would navigate in the suggested way, spend more time reading and integrate text and pictures to a larger extent than in the radial layout.

Procedure

On arrival, participants were randomly assigned to one of two groups ($n = 16$ vs. $n = 15$) and seated 70 cm in front of a table. The newspaper was attached to the table in the middle of the spread, but was covered with a white sheet of paper. Before the experiment, each participant was calibrated. Thirteen calibration points were placed on the covering sheet of paper. Before reading, the participants were presented with a realistic scenario: ‘Imagine

Figure 3. Example of the radial graphic with prototypical scanpath of one reader

Figure 4. Example of the serial graphic with prototypical scanpath of one reader
that you are sitting at Norrköping central station waiting for your train and you find this newspaper. You have 20 minutes until your train leaves. Read the newspaper as you would do in such a situation.’ After the instruction, the covering sheet was taken away. The participants were free to read anything they wish from the paper in any order they wish. Participants could move freely, turn pages at their own pace and go forward or backward in the newspaper as they desired (Figure 5).

Data analysis
For all participants and both types of graphics, we compared three important measures of on-line reader behaviour: reading order, reading time and text–graphic integration. The order in which separate parts of the graphics are read was presumed to reflect navigation and information seeking; the time spent on the information graphic (in seconds or in percentage of the total time spent on that newspaper spread) was presumed to reflect cognitive interest in the material; the proportion of integrative saccades was presumed to reflect semantic integration of text and illustration. Integrative saccades are transitions between semantically related pieces of verbal and pictorial information, indicating the process of readers’ construction of referential connections between text and illustration (Figure 6).

Figure 5. The experimental set-up

Figure 6. Integrative saccades between related pieces of verbal and pictorial information
RESULTS

Graphic 1 (integrated vs. separated)

Figures 1 and 2 show scanpaths of two typical readers. When the graphic is separated from the text, the reader chooses to read the information graphic rather than the text immediately after the headline. When the graphic is integrated with the main text, it is processed locally together with the text. This pattern reoccurs for almost all readers.

Text–graphic integration

The mean proportion of integrative saccades is 8.2% in the integrated format (SD = 0.8) and 2.3% in the separated format (SD = 0.03). The difference is significant (t(28) = 2.81, p < .01, one-tailed). We can also note that the distribution of integrative saccades in the two types of graphics differs. In the integrated graphic, the number of integrative saccades is proportional to the total number of saccades the individual reader has made (the highest number being 28), whereas in the separated graphic, the number of integrative saccades stays relatively constant for all readers, independent of how many saccades they have made (the highest number being five but the most usual number—for more than half of the readers—is one integrative saccade).

In short, the separated format gives few integrative saccades between semantically related pieces of information in the main text and in the illustration. Readers do not switch between text and graphics. Instead, they treat them separately as two different units. In integrated graphics, however, we find an even reading flow as readers proceed in the suggested order. The illustrations are scanned and studied in direct connection to the article text, resulting in many integrative saccades.

Graphic 2 (radial vs. serial)

Reading order

Data clearly show that there is no common preferred reading path in the radial graphic and the order in which the readers choose to read the different parts varies. In the serial graphics, on the contrary, the readers follow the suggested reading path in an almost linear order (Figures 3 and 4). The correlation of the actual reading order to the designed reading order in the serial format is $r = 0.95$ ($p < .001$), whereas, the correlation of the actual reading order to the designed reading order in the radial format is $r = 0.49$ ($p < .05$). However, it should be noted that in the case of the radial graphic, there is no designed reading order from the beginning. What we are comparing here is the actual reading order in the radial graphic with the designed reading order in the serial graphics that we assume is the (logically and semantically) ‘natural’ one. Hence, users in the radial condition were able to identify and follow this logical order, but this happened less reliably compared to the serial layout.

Reading time

The serial graphic is read more than twice as much as the radial graphic—in spite of the fact that the content and the position in the newspaper were exactly the same. The proportion of total spread time spent on the serial layout was 30.3% (SD = 8.23) compared to 18.1% on the radial layout (SD = 6.41), which corresponds to a significant difference between the layouts ($t(9) = 4.90, p < .001$, one-tailed). Measured in absolute time, readers

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spent on average 22.3 seconds on the serial graphic (SD = 8.67) compared to 8.9 seconds on the radial graphic (SD = 4.49). This difference is significant as well ($t(9) = 3.28$, $p < .01$, one-tailed).

**Text–graphic integration**

Integrative saccades were almost twice as common in the serial format compared to the radial format. The number of integrative saccades, measured as a percentage of all saccades in the information graphic, was 14.1% in the serial version (SD = 0.03) compared to 7.9% in the radial version (SD = 0.05), which is a significant difference ($t(9) = 2.56$, $p < .05$, one-tailed).

**DISCUSSION**

Our data show that a difference in the spatial layout has a significant effect on readers’ behaviour. For graphic 1, in the *separated* format, readers do not switch between the text and the illustrations; rather, they treat them as two independent units, and almost no integration occurs. In contrast, the *integrated* format with shorter physical distance between text and graphics facilitates integration. It makes it easier for the reader to find the correspondences between referents in the text and in the illustration, and to mentally integrate information from the two different sources. Our results confirm the *spatial contiguity principle*. In the separated format, readers probably interpret the two sources of information as self-contained. Accordingly, they choose one of them (the information graphic) and ignore the other one (the text). This is in line with Chandler and Sweller’s (1991) *redundancy effect* and with Sweller et al.’s (1998) claim that it is easier to ignore nonintegrated than integrated material.

For graphic 2, the *radial* layout, which allows for a variety of different reading orders, leads to initial reader interest followed by short reading times indicating a later disinterest in the content. Since the readers have several decisions to make—to choose the entry point, to decide about the reading path, to find relevant pieces of information, to create a connection between them and to integrated them mentally—the material might be judged as difficult to grasp and not worth deeper processing. This further suggests that the freedom of choosing entry points and reading paths is not an optimal strategy for attracting readers to stay with a complex material and get a deeper understanding of its contents.

The *serial* layout that is spatially structured and conceptually pre-processed enhances reading and text–picture integration. Due to dual attentional guidance, the format supports navigation and semantic processing of the contents. This not only leads to catching the readers’ attention but also to sustaining their interest in the material. We take this as a strong indication that readers prefer to be guided through complex information graphics and suggest the *dual scripting principle* as an extension of the signalling principle.

One important question is whether longer reading of the material also results in better understanding. There is a strong support for the spatial contiguity principle showing that groups studying integrated formats perform much better than groups studying separated formats (Mayer, 2005). In our study on readers’ comprehension of information graphic, a regression analysis showed that reading time, reading order and the number of fixations correlate significantly with comprehension. Surprisingly, the number of integrative saccades did not. It seems that a few well-placed and well-timed movements between relevant parts of text and graphics are more important than making as many saccades as
possible. We have to bear in mind that frequent switches between text and graphics can be caused by different cognitive processes. They can reflect either a successful integration of the material or difficulties integrating the information. Therefore, apart from the oscillation frequency, it is important to study the qualitative aspects of text-picture integration.

A combination of eye tracking with other methodologies such as concurrent or retrospective verbal protocols (Holsanova, 2008; Van Gog, Paas, & Van Merriënboer, 2005) might elucidate these covert mental processes.

The presented study provides a contribution to the exact tracing of the readers’ interaction with complex material in the framework of cognitive load theory. Results from our naturalistic study of newspaper reading with experimental conditions contribute to the examination of the cognitive processes involved in text–picture integration, and offer relevant insights for applications in printed media, computer-based instructional materials and textbook design. There is a growing body of research on text–picture integration and eye tracking in different genres: advertisements (Radach, Lemmer, Vorstius, Heller, & Radach, 2003; Rayner, Miller, & Rotello, in press; Rayner, Rotello, Steward, Keir, & Duffy, 2001), cartoons (Carroll, Young, & Guertin, 1992), newspapers and netpapers (Holmberg et al., 2006; Holmqvist, Holsanova, Barthelson, & Lundqvist, 2003), as well as textbooks and instruction materials (Folker et al., 2005; Hannus & Hyönä, 1999; Hegarty & Just, 1993). We suggest that future research should focus more extensively on the guidance of attention allocation (where to look and when), on instructional aspects of learning with visualisations (Scheiter, Wiebe, & Holsanova, in press) and on the role of integrative saccades.

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