Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Int. J. Human-Computer Studies 62 (2005) 329–348
International Journal of Human-Computer Studies
www.elsevier.com/locate/ijhcs

The emergence of the contextual role of the e-book in cognitive processes through an ecological and functional analysis

Thierry Morineau*, Caroline Blanche, Laurence Tobin, Nicolas Guéguen

GRESICO Laboratory, University of Southern Brittany, Campus de Tohannic, Centre Y. Coppens, F-56000 Vannes, France

Received 23 October 2003; received in revised form 24 August 2004; accepted 12 October 2004
Communicated by C. Burns
Available online 20 December 2004

Abstract

An electronic book is a new means of presenting text, allowing downloading of documents and multiple readings on a portable computer. On the basis of an ecological and functional analysis of paper and electronic books with the Abstraction Hierarchy method, we tested the ability of a mobile e-book device to be an external memory trigger, assisting the recall of information content through its presence as a contextual index. In contrast to the classical experimental approach for research on reading and comprehension, we consider screen and paper as relevant cognitive tools per se. Specifically, we compare a book on a pocket computer and a paper book. Hypothesising that the physical reading support could serve as a contextual cue for memory, we experimented with groups of participants who could or could not see the support during recall. We measured the reading time, and the material later recalled was classified according to its cognitive nature. After recall, participants had to assess the sensory–motor properties of the reading support with the Osgood semantic differential and to note the humour level of the text. Results show that the e-book presence hinders recall of assimilated information whilst the presence of the paper support tends to facilitate it. Finally, we observed some correlation between sensory–motor assessment of the support and certain aspects of text cognitive processing: humour scoring, reading time and recall performance.

*Corresponding author. Tel.: +33 2 97 01 71 37; fax: +33 2 97 01 70 71.
E-mail address: thierry.morineau@univ-ubs.fr (T. Morineau).

1071-5819/$ - see front matter
doi:10.1016/j.ijhcs.2004.10.002

These results lead us to conclude there is a critical relation between the sensory–motor experience of the support and the cognitive processing of the text content. This relationship might explain the positive or negative contextual effect of the support on recall performance.

Keywords: Contextual cue; Episodic memory; E-book; Ecological psychology; Abstraction hierarchy; Sensory-motor evaluation

1. Introduction

The idea of the electronic book as a novel means of presenting text has developed in recent years. The concept relies on two important technologies: the internet, which facilitates downloading of documents and the portable computer, which in principle, at least, means that computers can be used anywhere. These two technologies and their combination are promising for the future, despite some current technical problems like choice of the optimum computer platform for the reading of electronic books. Attempts to make devices that are specifically dedicated to this function have failed, although some such products are on the market. But, an electronic work potentially can be read on any computer platform, and small portable computers offer interesting perspectives as the device for reading in all contexts.

At the human–machine interaction level, an important constraint seems to limit the contexts in which electronic books might be useful. This limit is the difficulty of reading from a screen. Nelson and O'Neil (2001) have shown that users of e-books read less than a chapter at a time and tend to print out parts of the book. This might indicate that the electronic book is particularly suited to those types of content that require selective reading, such as encyclopedias, technical manuals and guides (Sottong, 2001). Other authors note that e-book usage is highest in the domains of computer science, technology and engineering (e.g. Langston, 2003). But these domain-specific usages could be explained just as well by a more selective mode of reading in these fields or by characteristics of the users, who are familiar with the use of computerised devices.

In particular, education is a field where the electronic book might well be fruitfully employed. Potentially, the e-book might improve access to knowledge, particularly in distance learning. Today, many such pedagogical projects are starting up throughout the world, for example at the California State University in the United States (Langston, 2003), or in France, where the idea is being explored of an electronic school bag as a common space shared by pupil, family, teachers, other pupils and various electronic resources (Kaplan, 2002).

These huge projects driven by the availability of a technology require a global socio-technical approach to the evaluation of their use of electronic books. Nevertheless, we think that particular parameters linked to a deeper analysis of the human–machine interaction are crucial for successful implementation of this new instrument for the transmission of knowledge. A sign of this is the fact that reading from a screen seems to affect the way in which an e-book is used. As we will see in

this article, this fact is supported by some experimental work. In general, experiments show that it takes longer to read from a screen than from paper.

However, with regards to our purpose of investigating the use of the e-book in a form that can be read in daily life, experimental work concerning reading and understanding of information from paper or screen shows some methodological limits. For instance, natural use of the support involves some significant elements such as the cover of the book, its numbered pages, its ability to be flicked through. These pieces of information have been excluded in experimental research so far. The use of the screens of clone computers in the experimental room does not provide the opportunity to establish a functional environment: reading from the screen is removed from the context of the use of the computer and its contents. In the same way, the reading-from-paper part of these studies has been removed from the perceptual context (is it a newspaper article, a book or a question sheet which has been read?) and from the motor context (what has been the relation to the paper, and the ability to flick through it?). Our goal has, therefore, been to design a human–e-book interaction study based on an ecological and functional analysis of the e-book tool in order to preserve the contextual dimensions that provide meaning. We also adopted an ecological point of view in interface evaluation.

Our study is part of a larger project being undertaken by the Marsouin Research Group entitled 'e-book flicking'. This project unites computer scientists, ergonomic psychologists and researchers in cognitive and information science from several laboratories. It has as one objective the conceptual development of a new generation of e-book which is adapted to the needs of users and which benefits from the most recent advances in technology.

The organisation of this article is the following: Section 2 presents our ecological approach of paper book and electronic book. It is based on a functional analysis through the five-level hierarchy method proposed by the Ecological Interface Design framework. This analysis allowed us to elucidate three functions assessed critical for use of electronic book. Section 3 highlights some experimental issues and questions concerning these critical functions. Sections 4–6 present an experiment testing the hypotheses made about the critical functions. Section 7 discusses the results and proposes some perspectives provided by our approach. Section 8 draws general conclusions.

2. An ecological approach to the e-book

2.1. Theoretical perspectives

At present several currents of thought in psychology are focusing on potential links between cognition and the environment experienced through a cycle of 'perception–action'. Thus the 'situated cognition' theory envisages cognitive mechanisms as strongly interacting with the context (Clancey, 2002; Suchman, 1987), whereas 'embodied cognition' highlights the critical role of the interaction in cognitive mechanisms and the physical bodily placement of the individual in an

environment (Gibbs, 2003; Varela 1988). To give a further example, the ecological explanation underlines that an individual's mechanisms for adaptation to the environment are crucial elements in understanding his/her behaviour (Barker, 1968; Gibson, 1979; Von Uexküll, 1956). All these theoretical strands share a vision of the individual as located physically and cognitively in an environment that provides constraints and resources. This constitutes an ecological vision of Humans in the broad sense of the term (Hirose, 2002; Morineau and Parenthoën, 2003). In the area of human–machine interaction, the ecological approach has been particularly elaborated through the Ecological Interface Design framework (Vicente and Rasmussen, 1990). This framework provided a practical methodology for the design of user interfaces. The purpose is to take into account the needs of the user by means of the display of information directly relevant in the domain of her/his action (Vicente, 1999). Here, we used this framework to make a functional picture of an already existing artefact: the paper book. This functional depiction, when compared with the functional domain of the electronic book, has served to highlight some critical functions for this latter artefact.

2.2. *Ecological and functional analysis of book and e-book*

We compared a functional description of the classical book with that of a particular type of e-book whose support is a pocket computer loaded with software for displaying electronic texts that have been downloaded from the web. This functional comparison was motivated by the definition of an abstraction hierarchy (AH) and a refinement hierarchy (RH) relevant to each support (Rasmussen, 1986). To expand on this now well-known method in cognitive engineering, it is a matter of dividing the domain under study into sub-systems in order to establish a hierarchy of refinement. Then on the basis of this hierarchy, the entire set of functions of the systems and sub-systems are described and categorised under a hierarchical form of general and physical functions implemented by the hardware constituting the system (AH).

More precisely, our method of analysis was as follows: firstly, we brainstormed on the functions concerning the book. Our brainstorming group was composed of one expert in book science and linguistics, another one in social and cognitive psychology and two in cognitive ergonomics. In a second stage, the points elicited from this meeting were organised hierarchically in order to formalise the five classical levels of AH articulated with the sub-systems of the book. Table 1 sums up the purposes, laws, functions and objects composing the AH for each subsystem concerned. Note that we divide the book into two sub-systems: the semantic content and the physical book. This functional analysis could be expanded and made deeper, but this level of formalisation was considered sufficient for our current goal (see Blanche, 2003 for more details).

Finally, this domain description of the classical paper book was compared with the e-book function of the portable computer that we have chosen. We studied a specific pocket computer which has a 'read e-book' function on it as well as other functions such as a diary, editors, spreadsheets, etc.

Table 1
AH and RH of the book

	Book content	Physical book
General purposes	Acquiring knowledge, logic, reading and writing skills	*Contextual recall of information* (*F.II*)
	Reinforcing one's beliefs	
	Emotional experience	Recall of emotions
	Extracting information	Exhibiting
	Gaining control over the world	Storing
	Sharing a meaningful experience with someone else	Physical trade of the book's content
Abstract functions	*Allowing cognitive processes for encoding and retrieval of information* (*F.I*)	*Allowing sensory–motor experience* (*F.III*)
	Allowing psycho-linguistics laws for form recognition, and paradigmatic and syntagmatic axis processing	Possible use of conventional or individual criteria for classification
	Allowing logical laws processing and conventional laws of text reading, and the information structuring processes and information access	Possible use for ostentation
		Possible value or identity given to the object
		Allowing socio-economical exchange
Generic functions	Access to the semantic, logical, and emotional contents	Materialising the message
	Selecting information	Giving, duplicating, selling or buying, securing the object
	Indexing information	
Physical functions	Title, summary, index, references…	Binding, first page, cover, dust jacket, table of contents…
Physical forms	Text, graphics, image	Colour, size, pages, texture, paper, noise when flicked through…

In the three functions assessed as critical (*F.I, F.II, F.III*).

With regards to the functional analysis of the classical book, our question was what are the functions that might be critical in the case of our portable e-book. The main answer on which we focused was that the classical book is a unitary object where the content cannot be distinguished from the material part. This physical association between content and support is split up for the e-book. Its computer nature allows different virtual contents for one material support. It is a system allowing an actual functional and structural decomposition during human–machine interaction.

In Table 1, the critical functions highlighted by our functional analysis are given in italic and entitled F.I, F.II, and F.III. With its unitary identity, the classical book

strongly incorporates the function of encoding and retrieval of information involved in the content cognitive processing (F.I) and the support function of contextual recall of information (F.II), through a sensory–motor experience of the physical support (F.III). The paper book can be a physical representation of a body of knowledge whose nature is evoked by the perception of the book and its cover. For example, seeing a book in a library is an index which gives a representation of the knowledge contained within the book. In this sense, the book constitutes an external memory inserted in a context (Hutchins, 1995). Just as a knot in a handkerchief provides an index for the retrieval of information, the physical presence of the book gives an indication of the field of knowledge which it contains. This concords with a current theory of comprehension which sees comprehension as founded on the basis of the link between a semantic element and an affordance coming from the environment (Glenberg and Robertson, 2000). In the case of the e-book, we can question the consistency of this functional and structural relation, since multiple contents can be apprehended via the same support device. We can ask whether the electronic book is able to serve in the same way as the paper book as a contextual index for the retrieval of encoded information. But before testing this, let us discuss issues on these topics raised by previous experimental work.

3. Experimental issues on critical functions emerging from AH/RH book analysis

3.1. Encoding and retrieval of information read from the screen (function F.I)

From the 1980s onwards, a number of experiments have shown that reading time off a screen is longer than from paper by some 20–30% (Dillon, 1992). However, the causes were not really investigated. In a series of experiments, Gould (1987) varied parameters such as the font size and the orientation and brightness of the screen and found no factor on its own was sufficient to explain the extra reading time from the screen. In addition, some studies did not show significant differences in reading times (Askwall, 1985; Muter and Maurutto, 1991).

Work on this question has recently been taken up from a cognitivist perspective. Mayes et al. (2001) thus propose an explanation in terms of the mental workload because reading from a screen might require more concentration than from paper. In a first experiment they asked their participants to read a text from screen or paper within a time limit of 25 min. After reading, the participants had to reply to a comprehension test and to a questionnaire that gave a subjective indication of the workload felt by the participants during reading. The results showed reading from paper was significantly faster and that there was an inverse correlation between comprehension and the workload experienced: the more the participants had understood the text, the less the mental workload had seemed. The authors explain the slower reading from the screen as a strategy by the participants to insure that the content was assimilated well. In a second experiment, the authors studied the workload more objectively by adding a second task to that of reading. Participants had to memorize a list of letters before reading the text and afterwards recall them in

correct order. This time the results showed no significant difference in reading time between paper and screen. All that was noted was that the level of comprehension was a little lower when the participants had an additional task to perform.

In a reply to the article by Mayes et al. and basing themselves on the work by Tulving (1983), Noyes and Garland (2003) noted that the evaluation of the level of understanding is founded on the use of two recall processes: (i) episodic recall, which constitutes a recall of events which the participant has experienced (i.e. memories), and (ii) semantic recall, characterised by the recall of elements of knowledge assimilated by the individual (i.e. things that have been learned). The apparent comprehension of a document may therefore be no more than the recall of what has been read, or it may reflect assimilation of the underlying concepts. It is thus necessary to evaluate the respective roles of episodic and semantic recall.

In their experiments, Noyes and Garland (2003) asked participants to read from screen or paper. The conditions of brightness and contrast were subjectively adjusted to be fairly similar for both supports. The fonts, layout, etc. of the two texts were also similar. The principal items recorded were the reading time and the responses to a questionnaire that tested both episodic and semantic recall. The results indicate no significant reading-time difference between paper and screen. In contrast, semantic recall was less for material read from screen, while episodic recall was similar for both supports. The authors explain this result as due to some effect that is characteristic of a screen and which might interfere with cognitive processing in both long-term and working memory. However, they emphasise that deeper analysis is needed to understand the mechanisms in play.

3.2. *Recall of information and contextual effect (F.II)*

The episodic mechanism in the retrieval of information can be made evident through the effects of context on recall performance. Numerous studies have shown that the quality of information retrieval is sensitive to the context in which it occurs. It has thus been shown on several occasions that the recall of memorized information is poorer when the participant changes situation after the encoding phase rather than staying in the same surroundings for recall (for a review, see Smith et al., 1978). This effect of surrounding-dependence has been demonstrated in numerous contexts: learning in one room and then another (Smith and Guthrie, 1921, cited by Farnsworth, 1934); learning by students in a classroom then recall in an examination room (Metzger et al., 1979; Farnsworth, 1934); or even, in a more astonishing situation, learning and recall of words on a beach and/or under water (Godden and Baddeley, 1975).

The classical explanation for this effect of dependence on surroundings comes from the implicit association which the participant is presumed to make between the encoded target information and contextual indices present in the immediate surroundings. This cognitive association between a piece of information and the context in which it occurs could have the function of aiding subsequent recognition of objects in certain scenes and constrain the range of possible occurrences expected in a given context (Chun, 2000). The effect of context-dependence might thus be a

function of episodic memory whose task is the memorisation of information within the schema of events that have occurred in a given context.

In their experiment, Noyes and Garland (2003) showed that reading from a screen made the recall of semantic aspects of information relatively poorer than for episodic aspects compared to a control situation where reading was off paper. Nevertheless, these results derived from subjective questionnaires. The effect of context dependence could be a factor that allows for a more objective manipulation of the episodic dimension in the retrieval of information from a screen. It seems to us important to consider the ecological role which the reading support may have on the reader, that is to say as an element that is part of a context of use. However, we are unaware of any experimental result assessing the role of a single object as a contextual cue in information retrieval.

3.3. *Potential effect of the sensory–motor experience (F.III)*

Interaction with the physical support of the e-book during encoding is very different than with a classical paper book, but we know of no experimental work on this matter. The Pocket PC provides a metallic and plastic interface that is rigid and which is clearly different from that of a book and from contact with paper. Certain sensory–motor properties are absent such as the supple feel and distinctive smell of paper. Flicking through the e-book is done by touching an icon on the screen with a stylus or finger, and is poorer from a tactile point of view than flicking through paper pages. From an ecological point of view, the encoding of information from an e-book generates a set of affordances—that is to say sensory–motor experiences—that directly guide actions which are more like those presented by a traditional computer than by a paper book (Gibson, 1979).

As we can see, studies to date have been limited to cognitivist interpretations in terms of the mental workload or to interpretations of a purely psycho-physical nature (i.e. lighting level and contrast). These are descriptive models of phenomena which in no way explain the differences obtained that lie at the heart of the experimental results. In our opinion, in order to understand experimental results which have highlighted relations between parameters such as the support and the level of comprehension, we require an experimental approach which links what is in one part perceptive, or more generally sensory–motor, and in another part cognitive.

4. Aims of the experiment

This experiment aims to define two lines for our research. The first is ergonomic and explores the capacity of the e-book to fulfil some critical functions offered by the classical book. The second line is to bring new results to bear on the questions that are of current debate in psychology concerning the effect of the support on reading and understanding of information. On this issue we think that the ecological and functional approach that is implied by our ergonomic viewpoint may enrich our

understanding of previous experimental results by suggesting a new interpretative framework.

Thus the analysis of the functions of the e-book compared to those of the classical book allow us to frame the following hypotheses:

(i) We expect that reading from the e-book will specifically affect the semantic mechanisms of understanding. Thus, in agreement with the results of Noyes and Garland (2003), we expect reduced recall performance following encoding from the e-book will be concentrated on information which has undergone significant semantic processing (assimilation). We should also have a significant difference in the evaluation of the level of understanding of text according to whether it has been read on an e-book or on a traditional one (function F.I). We assessed the understanding of the text through a humour score. Indeed, this indicator seems to correspond to an evaluation that takes account of the process of comprehension of content (Attardo, 1997; Coulson and Kutas, 2001).

(ii) Given that an e-book is a generic computer tool able to perform different computer functions but also able to store several e-texts, we expect that the PC Pocket will be a bad candidate for being a contextual cue helping the retrieval of information, unlike the case of a paper book (function F.II).

(iii) Taking account of a relation which our ecological approach suggests between the symbolic context of the text and the emission of sensory–motor messages by its physical support, we expect that the level of understanding of a text should be correlated with the sensory–motor information coming from its physical support (function F.III).

5. Method

5.1. Design

This experiment was designed to assess the effect of two main variables on the cognitive processing of information: the type of support used (paper or e-book) and the potential effect of presence versus absence of the support during recall as a contextual cue. The modalities of the first variable were represented by two separate groups of participants, each using one type of support (“between-subject”). The latter variable was tested by each participant during two trials (“within-subject”).

We made measurements concerning the different aspects of the critical functions highlighted by our functional analysis. The encoding of the content was measured by the reading time. The retrieval of information was assessed by the number of concepts recalled as a function of their cognitive status (see Section 5.5. for more details). The comprehension of the content was evaluated by a humour scoring and the sensory–motor experience by scales inspired from the works of Osgood in semantics (Osgood et al., 1957).

Several aspects of the experimental situation were controlled. A first phase for getting familiar with the support consisted in showing the PC Pocket and its relevant

functions to the group of participants. Then, the participants read an extract from a book on paper or electronic support as the function of the experimental condition and with the requirement of subsequently making a written summary from memory. This pre-phase before experimental trials was necessary to control the potential presence of several book contents on the same support in the "e-book" condition. During reading, the lighting and contrast conditions were subjectively controlled by the experimenters so that they were equivalent for the two supports. During the experimental trials of reading, the order of the modalities for the contextual effect of presence or absence of support and the selection of which text was read were both counterbalanced. The number of words and ideas and the number of questions asked were adjusted to be similar for both texts (464 versus 473 words; 58 versus 69 ideas; 12 versus 11 questions).

5.2. Participants

Forty participants split randomly into two groups participated in this experiment. They were not paid, but received a chocolate bar afterwards in thanks for their participation. Thirty participants were students and ten were staff members of the University of Southern Brittany. The mean age was 25 years (standard deviation = 6.6 years). Twenty-three participants were male and 17 female. Seventeen participants had a corrected eyesight problem.

5.3. Materials

The support studied in this research was a Pocket PC, COMPAQ iPAQ H3900, currently on sale in France. This little micro-computer (height 134 mm, width 84–77 mm, depth 15.9 mm, mass 184 g) has the following functions: text processing, spreadsheet, diary, and internet connection. It allows the user to read an e-book through specially-designed software. The user can download electronic versions of books and install them on the Pocket PC. The screen is a thin film transistor (TFT) transflective colour one with 240×320 pixels and back-illumination. Its brightness is controlled automatically via a photo-sensor. Interaction with the computer can occur via a button, or directly on the screen using a stylus, or by touch.

The first text given for reading concerned a socio-technical matter: the Internet (Godeluck, 2002). In the experimental phase during which the measures were made, the two text extracts came from a work that was available both electronically and on paper in which the author asked young children a number of questions (Euvrard, 2001). A sample of the text is presented in Appendix A. The texts were presented similarly in paper and electronic versions. The paper version was a little booklet of the same size as the PC Pocket with pagination, recto presentation only, and size of characters, line spacing and breaks that were identical to the electronic version.

5.4. Procedure

The experiment was performed in two phases. After presentation of the support for the group of participants concerned, the participants read an extract from the book concerning the topic of the Internet and made a summary from memory.

In the second phase, the two groups of participants were asked to read two different extracts from interviews of young children which were presented either on paper or on the Pocket PC. After each reading of an extract, the participants had to recall the content of the answers that the children had made to the adult's questions. These questions were given to the participants on a piece of paper immediately before this recall. The instructions given before the reading of the extracts were the following: "*Now I am going to ask you to read carefully an extract from another book. Afterwards I shall only ask you questions relevant to this text. You must respond to them in the most accurate way possible. You must read the text only once.*" When the questionnaire was given out, the following instructions accompanied it : "*Have you finished? Here is the questionnaire. Reply to the questions in order. Reply just as you would if you were the child.*" Each participant read two extracts, with and without the presence of the support during the recall.

At the end of the experiment, the Osgood semantic differential test was administered to evaluate the participants' sensory–motor evaluation of the support. The participants had the following instructions: "*Now, independent of the text that you have read, I am going to ask you to characterise the sensations which you had during your contact with the book or the Pocket PC, by means of this questionnaire. Tick the boxes which correspond to your sentiment for each adjective.*" Then we asked the participants to evaluate the level of humour in the two text extracts by giving them a mark between 0 ('not at all funny') and 10 ('extremely funny').

5.5. Encoding of the information remembered

Following trial experiments with two participants, we designed a categorisation of the contents recalled according to the nature of the recall, so as to be able to enrich our analysis of the rate of recall of items by an evaluation of the level of semantic processing implicated in the recall. Four categories were defined a priori: (1) *Similarity*: the concept recalled is lexically identical to that presented in the original text. (2) *Assimilation*: the concept recalled is not present as such in the text but the recall is a lexical reformulation of it. (3) *Transformation*: the concept recalled has been semantically modified compared to the original sense. (4) *Addition*: the concept recalled was not present in the original text. The categorisation of the information recalled was performed independently by two experimenters who then conferred to resolve discrepant cases. In Appendix A we present the categorisations for one sample concept.

6. Results

As a preliminary, we checked the similarity of the two text extracts by comparing the mean reading time required for each. For the first extract we found a mean reading time of 187 s (standard deviation = 58) and for the second extract a mean of 171 s (s.d. = 51). The difference is not significant ($t(77) = 1.27$; $p = 0.21$), which is an element which allows us to say that the texts are comparable.

Next, the Kolmogorov–Smirnov test for the normality of a distribution was applied to the different variables measured (reading time, type of recall, semantic differential, level of humour). When the distribution differed significantly from a normal one ($p < 0.05$), a non parametric test was applied (the Kruskall–Wallis or the Spearman RHO test).

As Table 2 shows, the reading time as a function of support is slightly longer on average for the e-book (+13%); nevertheless the difference is not statistically significant ($F(1, 38) = 1.77$; $p = 0.19$).

Concerning recall performance, there is no major significant effect of the support type on either the number of items recalled or—and in particular—on the recalled item's category (similarity, assimilation, transformation or addition). Table 3 shows notably that the mean values for assimilations, transformations and additions are small. In particular, the standard deviations are bigger than the means for transformations and additions. But, the average recall of similarities corresponding formally to correct responses is high in the e-book and paper book conditions (about 25–27 items with standard-deviations about 8–9 items).

In the same way no major significant effect was found relating the variable 'recall with or without presence of the support' to the number of items remembered, either globally or by category (similarity, assimilation, transformation or addition). Nevertheless, we do see a significant interaction between the two variables 'type of support' and 'presence versus absence of the support as an index for the recall', for the recall category 'assimilation' ($F(1, 38) = 5.4$; $p = 0.025$). The number of

Table 2
Reading time in seconds according to the support

	Minimum	Maximum	Mean (s.d.)
E-book	107	342	190 (60)
Paper book	92	276	168 (47)

Table 3
Mean recall performance as a function of the category of item recalled and type of support

	Similarity	Assimilation	Transformation	Addition
E-book	27.2 (7.9)	2.5 (1.74)	1.23 (1.31)	1.18 (1.26)
Paper Book	25.28 (9.4)	2.28 (1.43)	1.15 (1.31)	1.33 (1.86)

assimilations recalled in the presence of the paper book is higher than in its absence. But, we observe the inverse effect in the case of the e-book. Its presence interferes with recall of concepts assimilated, that is to say the concepts reformulated by the participants during the recall (Fig. 1).

We note that the effect of the presence or absence of the support is particularly relevant for the e-book. Whilst the e-book presence interferes strongly with assimilation recalled, the benefit observed with the presence of the paper book during recall is small.

Concerning the appreciation of humour as a function of the support, we find no significant difference. The scores are very similar in the two cases. In the case 'e-book' the text extracts obtained a mean score of 6.2 out of 10 (s.d. = 2.2) while for the case 'paper book' the mean score was 6.6 (s.d. = 1.5).

Finally concerning the relation between the participants' sensory–motor evaluation of the support (Osgood semantic differential) and the cognitive variables (reading time, type of recall, humour level), we note a group of significant correlations. In the first case, certain objective criteria for sensory–motor evaluation of the supports allow us to say that the participants have evaluated the physical supports well and have not been influenced by the sensations felt while reading the text. Thus the e-book support is considered as more rounded ($t(37) = -2.95$; $p = 0.01$), heavier ($t(28) = -3.02$; $p = 0.01$), and tighter ($t(36) = 2.36$; $p = 0.02$) than the paper book, and these are objective facts. Nevertheless, on average the participants considered the e-book support to be larger, and this is incorrect ($t(28) = -2.81$; $p = 0.01$).

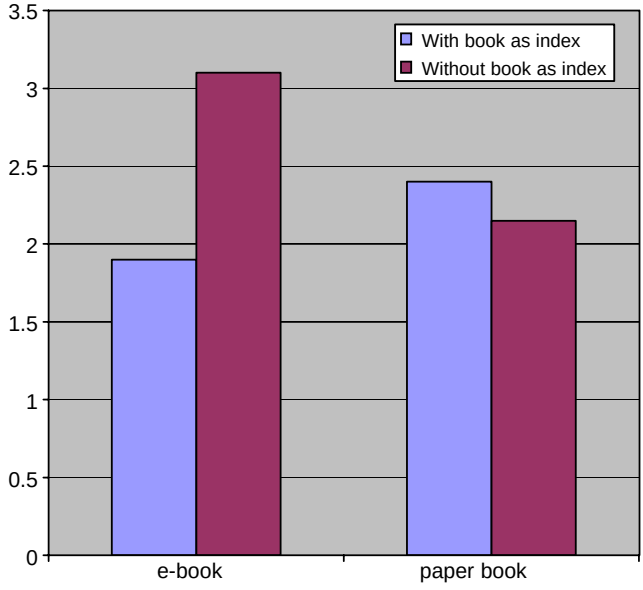

Fig. 1. Mean number of assimilation recalled as a function of the type of support used during reading and the presence/absence of support during the recall stage (book as index).

Table 4
Correlations between cognitive variables and sensory–motor variables (semantic differential scale)

Variable 1	Variable 2	Correlation coefficient	*p*-value
Reading time	Heavy–light	−0.27	0.02
Reading time	Active–passive	0.23	0.04
Reading time	Slow–fast	−0.27	0.05
Humour	Large–small	0.27	0.016
Humour	Cold–hot	0.27	0.015
Humour	Sad–happy	0.36	0.001
Humour	Heavy–light	0.27	0.016
Humour	Bright–dark	−0.27	0.014
Similarity	Large–small	−0.29	0.01
Similarity	Unpleasant–pleasant	0.23	0.04
Addition	Transformation	0.46	<0.01
Addition	Unpleasant–pleasant	−0.23	0.05
Addition	Rounded–angular	0.27	0.01
Assimilation	Cold–hot	0.24	0.03
Transformation	Sad–happy	0.24	0.03

Table 4 gives an overview of the correlations found between the cognitive variables and the sensory–motor evaluation of the support. As far as the reading time is concerned, we find that this is correlated with an ensemble of subjective impressions concerning the support. The longer the reading time, the more the participants evaluated the support a posteriori as heavy, passive and slow. These sensations go in the sense of a slow impression which mirrors the participants' slow reading.

In the same way, a higher level of perceived humour is correlated with the physical support being described as small, hot, happy, light and clear. Finally, the types of recall of the information contained in the text are correlated with impressions concerning the support. Indeed, when a participant produces a large number of similarities and thus correctly performs the recall task, he or she characterises the support as rather pleasant, and vice versa. In contrast, additions during recall, that is to say erroneous information, generate a negative sensation concerning the interface, which is judged unpleasant and angular. The reader will note that the production of additions is correlated with the production of semantic transformation during recall. These constitute two types of erroneous response.

7. Discussion

This section discusses the different results with regards to the three critical functions emerging from our functional analysis and returns to the use of the AH/RH functional analysis and the perspectives that it offers in this experiment and that it opens for future studies.

7.1. Encoding and retrieval of information (function F.I)

The results obtained during our experiments indicate that there is no significant difference between the reading times as a function of the type of support. This result is consistent with the data of Noyes and Garland (2003). The higher mean time for the electronic book is not significant. The maximum reading time was 5.7 min, which is short compared to the texts typically employed in experiments of this sort. For example, in the experiment of Mayes et al. (2001), 25 min were required. Nevertheless, one can question the value of results obtained with long texts. Empirical observations concerning the use of electronic documents indicate clearly that participants tend to print them out if they require too long to read. Thus the differences obtained between the classical book and the e-book perhaps only reflect classical visual fatigue for reading from a screen. We can also evoke the possible involvement of the level of complexity of the text in the performance of recall. In our experiment, the correct recall of concepts (similarities) is relatively high and can be explained by the simplicity of the text. It is not a conceptual or technical text, unlike the material usually found in classical experiments. The ease of semantic processing could reduce the visual effort engaged during reading and consequently the potential effect of the screen on reading. Another explanation could reside in the type of screen used. We used a LCD-TFT screen, whereas the majority of experimental studies have used CRT screens. Nevertheless, recent work has shown no difference in the perceptual processing involved with the two types of screen (Wang et al., in press).

Concerning those factors which are properly cognitive, the recall task indicated to us that the support has no significant effect. The participants who had read the text in electronic form were able to recall the content as such (similarities), or reinterpreted according to their schemas of knowledge (assimilations) and were no more prone to making erroneous responses (semantic transformations or addition of concepts). The retrieval of information does not therefore seem affected by the fact that the encoding occurred from an e-book. Similarly, the semantic niceties inherent in humour were appreciated just as well when read from an electronic support as from paper. In contrast to our hypothesis, we can conclude that the electronic book provides satisfactory realisation of the function "Allowing cognitive processes for encoding and retrieval of information" in our AH/RH analysis of the functional domain of the book.

7.2. Contextual recall of information (F.II)

Behind the lack of effect of the type of support or its presence versus absence during recall, the analysis of variance shows an interaction between the type of support and the effect of its presence or absence during recall on the number of assimilations produced. As we have hypothesised, because of its generic form the e-book seems to be a bad candidate for being a contextual index for the retrieval of information. It perturbs the capacity to recall information as a reformulation (assimilation). Thus the multifunctional character inherent to a computer support means that it has no status as a device that materialises a piece of knowledge, or to

put it another way, no status of external memory (Havelange et al., 2002; Hutchins, 1995). This result would mean that the function F.II of the material support of the book consisting in allowing recall information is not satisfied by the e-book. However, the two-by-two comparison of the variance shows that the benefit coming this time from the presence of the paper book in assimilation recall is quite small. Also, it modulates the weight of this function of contextual cue provided by the paper support and predicted by our functional analysis. However, we must emphasise that the paper book used in this experiment was very rudimentary. It was only a booklet without an actual cover and composed of a set of leaves bound with two staples. The presence of a true book as support should be tested in future experiments, with the prediction of a better effect as a contextual cue on memory performance. Finally, it is still to be determined why this effect is found exclusively in the number of assimilations produced and not for example on the number of similarities. Noyes and Garland (2003) found in their experiments that semantic processing was perturbed during reading from a screen, which reflects in particular what we have called the assimilations.

7.3. *Sensory–motor experience (F.III)*

Our last hypothesis concerned a strong relation between the cognitive activity during reading and the sensory–motor interaction with the physical support. This general prediction has received some confirmation through a group of correlations obtained between the reading time, the evaluation of humour and the types of recall on the one hand, and the evaluation of the support via the Osgood semantic differential on the other. We observe that the evaluations of the support's sensorial qualities are mirrored by the reading times. The time required to read the text is correlated with affordances that reflect the same characteristics of speed: slow/fast, heavy/light, active/passive. This might signify that the participants have a certain consciousness of their mean reading speed and project it onto their opinion of the support. In the same way, the evaluation of the funniness of the text is reflected in the evaluation of the support, notably through the scale sad/happy. A priori, one might think that this is an artefact in the sense that the explicit or implicit evaluation of the text (the time required to read it, the level of humour attributed to it) has contaminated the evaluation of the support. We note that objective evaluations of the support are coherent with the characteristics of the support, which indicates that the participants have characterised the support accurately. On the other hand, we note that the evaluation of funniness in the text was done after evaluation of the support.

In this manner, we observe a general activation of the sensory–motor experience in the "conceptual handle" of the semantic content of the book or the e-book (F.III). These results lead us to think that there is a strong link between the affordances brought by the physical support and the symbolic information contained within it. The sensory–motor affordances associated with the contents of the book would thus activate the index function of knowledge assimilated from the presence of the support as a contextual indicator. From a methodological point of

view, this result shows the relevance of Osgood scales for the evaluation of affordance encoding.

7.4. AH/RH functional analysis and perspectives offered

Originally, the Abstraction and Refinement Hierarchies were proposed for analysis of a work domain with the purpose of designing artefact like user interfaces (Rasmussen, 1986 ; Vicente, 1999). This methodological tool was also used in the context of the evaluation of users' strategies navigating through some ecological interfaces (Burns, 2000). In our case, we have attempted to evaluate the degree of isomorphism between a classical tool and its functional domain (paper book) and an innovative tool (electronic book) using modern technologies coming from computer science (Internet and small portable computer). Whilst research on ecological interface design generally focuses on the use of AH, the application of the method to books underlines the importance of the decomposition in subsystems through the RH. The simple dissociation between a book's content and its material support allowed us to point out the unitary nature of the book as a concrete object for the user. In contrast, the electronic book can be envisaged as an actual system, where the e-text, the software and the generic hardware constitute a set of interacting components. On the basis of this observation, we highlighted some functions in the AH particularly involved in the relationship between the text and its physical support and tested their functioning through a first experiment.

Interestingly, the application of this method based on an ecological perspective in cognitive engineering, pointed out the necessity to consider an ecological role for the e-book in its usage. As an external memory storing knowledge, the classical book seems to present a set of sensory–motor affordances through its material support. Our experiment gives some first results supporting this view. Further research is needed to assess the amplitude of this role, and its duration (can the book be a contextual cue for memory after a long time such as a day, a week? How far can the affordances of the support be correlated with the text?). But to rise to this status of external memory, we think that the electronic book would have to integrate some affordances, in order to give an e-text a permanent and unitary identity and which can be associated with the affordances perceived from the physical interface. This would obviously lead to an ergonomics scrutiny of the interface.

But, note that our HA/HR analysis of the book could also give other insights about critical functions assumed by the book and e-books. For instance, the abstract functions of "possible use for ostentation" is fundamentally redefined in the context of electronic book. Indeed, how can you display your pleasure to have a great book of a great author when this document is stored in electronic format in a Personal Digital Agenda? In this case, the function of "ostentation" deviates toward the characteristics of your small computer, which you can be more or less proud to show to anyone. This problem should lead to further experimental work and ergonomic evaluation.

8. Conclusion

The classical work in psychology and ergonomics concerning reading from a screen tried to explain the variations in reading time and in comprehension mechanisms through an experimental paradigm that discussed the supports in a generic fashion such as a screen or a sheet of paper. However, our approach in this paper has been ecological. We have established a functional framework where the support has been a specific one, viz. a classical book or a specific e-book capable of a defined range of functions. Functional analysis of the classical and electronic books has allowed us to explore the capacity of the e-book to transmit knowledge by encoding and appropriate retrieval of the information. The results obtained show that the function of encoding knowledge is comparable to that which occurs with a paper book, thus permitting a similar level of comprehension of the information (humour of the text, quantity of data recalled from memory). Nevertheless, because the electronic book is functionally closer to a computer than a traditional book (because of the support's inherently multi-functional nature) it does not provide the external indicators to memory that the classical book does, in that it does not serve as an unambiguous index to indicate a field of knowledge on the basis of its particular physical form.

The sensory–motor evaluation of supports has allowed us to show the strong relationship that exists between the sensory–motor representation of the user and his/her treatment of the information content of the paper book or e-book. In our opinion, these correlations between the subjective appreciation of the physical support and the cognitive activity devoted to its content explain why the support can serve as a contextual indicator for the retrieval of the information which it contains. These results need to be explored more deeply because assimilation processes are critical mechanisms in learning.

Acknowledgments

We thank Christine Chauvin and Jean-Pierre Gaillard for pertinent ideas, and William Tobin for his help. This research received financial support from the Marsouin Research Group.

Appendix A. Sample of the text extracts used in the experiment and categorization of the concepts remembered by the participants

(*In bold italic, the question asked by the adult in the text and later presented to the experimental subjects during the recall phase of the experiment*.)

Are the adults irritating?

"*Yes*, … *Sometimes my brother hardly does anything and me neither. We do something which is only micro-naughty and they make a big song and dance about it*"… .

The concepts underlying the sentence:

1. Sometimes my brother hardly does anything
2. And me neither
3. *We do something which is only micro-naughty*
4. And they make a big song and dance about it

Recall types for concept No. 3:
Similarity: for something micro-naughty;
Assimilation: we do not do very much;
Transformation: we do something really naughty;
Addition: my brother and I argue.

References

Askwall, S., 1985. Computer supported reading vs. reading text on paper: a comparison of two reading situations. International Journal of Man–Machine Studies 22, 425–439.

Attardo, S., 1997. The semantic foundations of cognitive theories of humor. Humor: International Journal of Humor Research 10, 395–420.

Barker, R.G., 1968. Ecological Psychology. Standford University Press, Standford.

Blanche, C., 2003. Conception d'une nouvelle génération de livre électronique: une approche écologique en psychologie ergonomique. Mémoire de Recherche, Master Psychologie du Travail et Ergonomie, Université de Rennes II.

Burns, C.M., 2000. Navigational strategies with ecological displays. International Journal of Human–Computer Studies 52, 111–129.

Chun, M.M., 2000. Contextual cueing of visual attention. Trends in Cognitive Sciences 4, 170–178.

Clancey, W.J., 2002. Simulating activities: relating motives, deliberation, and attentive coordination. Cognitive Systems Research 3, 471–499.

Coulson, S., Kutas, M., 2001. Getting it: human event-related brain responses to jokes in good and poor comprehenders. Neuroscience Letters 316, 71–74.

Dillon, A., 1992. Reading from paper versus screens: a critical review of the empirical literature. Ergonomics 35, 1297–1326.

Euvrard, M., 2001. Je dis des gros mots dans ma tête. Editions C.Y., Paris.

Farnsworth, P.R., 1934. Examinations in familiar and unfamiliar surroundings. Journal of Social Psychology, 128–129.

Gibbs, R., 2003. Embodied experience and linguistic meaning. Brain and Language 84, 1–15.

Gibson, J.J., 1979. The Ecological Approach to Visual Perception. Lawrence Erlbaum Associates, London.

Glenberg, A.M., Robertson, D.A., 2000. Symbol grounding and meaning: a comparison of high-dimensional and embodied theories of meaning. Journal of Memory and Language 43, 379–401.

Godden, D.R., Baddeley, A.D., 1975. Context-dependent memory in two natural environments: on land and underwater. British Journal of Psychology 66, 325–331.

Godeluck, S., 2002. La géopolitique d'Internet. Editions La Découverte, Paris.

Gould, J.D., 1987. Reading is slower from CRT displays than from paper: attempts to isolate a single-variable explanation. Human Factors 29, 269–299.

Havelange, V., Lenay, C., Stewart, J., 2002. Les représentations: mémoire externe et objets techniques. Intellectica 35, 115–129.

Hirose, N., 2002. An ecological approach to embodiment and cognition. Cognitive Systems Research 3, 289–299.

Hutchins, E., 1995. How a cockpit remembers its speeds. Cognitive Science 19, 265–288.

Kaplan, D., 2002. Electroniques, virtuels, numériques: l'élève, le prof et leur cartable dans l'école de demain. Rapport de synthèse, Fondation internet nouvelle génération, Paris. from http://www.fing.org/index.php?rubrique=ecartable.

Langston, M., 2003. The California State University E-book pilot project: implications for cooperative collection development. Library Collections, Acquisitions, & Technical Services 27, 19–32.

Mayes, D.K., Sims, V.K., Koonce, J.M., 2001. Comprehension and workload differences for VDT and paper-based reading. International Journal of Industrial Ergonomics 28, 367–378.

Metzger, R.L., Boschee, P.F., Haugen, T., Schnobrich, B.L., 1979. The classroom as learning context. Journal of Educational Psychology 71, 440–442.

Morineau, T., Parenthoën, M., 2003. Une présentation de l'approche écologique en psychologie ergonomique. Psychologie Française 48, 77–88.

Muter, P., Maurutto, P., 1991. Reading and skimming from computer screens and books: the paperless office revisited? Behaviour and Information Technology 10, 329–358.

Nelson, L., O'Neil, F., 2001. Electronic monographs in the academic library: an implementation story. LASIE 32, 13–20.

Noyes, J.M., Garland, K.J., 2003. VDT versus paper-based text: reply to Mayes, Sims and Koonce. International Journal of Industrial Ergonomics 31, 411–423.

Osgood, C.E., Suci, G.J., Tannenbaum, P.H., 1957. The Measurement of Meaning. University of Illinois Press, Urbana.

Rasmussen, J., 1986. Information Processing and Human–Machine Interaction. Elsevier, Amsterdam.

Smith, S., Glenberg, A., Bjork, R.A., 1978. Environmental context and human memory. Memory and Cognition 6, 342–353.

Sottong, S., 2001. E-book technology: waiting for the "false pretender". Information Technology and Libraries 20, 72–80.

Suchman, L.A., 1987. Plans and Situated Actions: the Problem of Human–Machine Communication. Cambridge University Press, New York.

Tulving, E., 1983. Elements of Episodic Memory. Clarendon Press, Oxford.

Varela, F.J., 1988. Invitation Aux Sciences Cognitives. Editions du Seuil, Paris.

Vicente, K.J., 1999. Cognitive Work Analysis, Toward Safe, Productive, and Healthy Computer-based Work. Lawrence Erlbaum Associates, Hove.

Vicente, K.J., Rasmussen, J., 1990. The ecology of human–machine systems II: mediating "direct perception" in complex work domains. Ecological Psychology 2, 207–249.

Von Uexküll, J., 1956. Mondes animaux et monde humain. Denoël, Paris.

Wang, A.-H., Fang, J.-J., Chen, C.-H. Effects of VDT leading-display design on visual performance of users in handling static and dynamic display information dual-tasks. International Journal of Industrial Ergonomics, in press.