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Cognitive Effort during Note Taking

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SUMMARY

Note taking is a complex activity that requires comprehension and selection of information and written production processes. Here we review the functions, abbreviation procedures, strategies, and working memory constraints of note taking with the aim of improving theoretical and practical understanding of the activity. The time urgency of selecting key points and recording them while comprehending new information at the same time places significant demands on the central executive and other components of working memory. Dual- and triple-task procedures allow the measurement of the momentary cognitive effort or executive attention allocated to note taking. Comparative data show that note taking demands more effort than reading or learning. However, it requires less effort than the creative written composition of an original text. Copyright © 2004 John Wiley & Sons, Ltd.

Note taking occurs in frequent and various everyday life situations. To make purchases, to plan future events and activities, to study for examinations, to prepare a technical talk, to design a model in an industry, and to record the minutes of work meetings are a few examples. Furthermore, the reasons why individuals take notes are highly variable. Despite the diversity of contexts and intentions, all note taking entails recording information collected from one or several sources. Such a record constitutes a stable external memory that is intended to help to plan a future activity, to learn, to think, or to create. It is important to understand this common activity for both theoretical and practical reasons. Although a large body of studies had investigated the different techniques that note takers use and their effectiveness, surprisingly few have focused on the cognitive processes underlying note taking.

For cognitive psychologists, it is important to study the mental operations that underlie note taking in addition to studying the product itself, as linguists do. A cognitive analysis is even more critical to understanding when it is recognized that note taking cannot be equated to simply copying what is heard, observed or thought. On the contrary, in a large majority of cases, note taking implies comprehension (van Dijk & Kintsch, 1983) and

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written production (Alamargot & Chanquoy, 2001) that is similar to original composition. Note takers, as readers, must comprehend information and, as learners, try to store information in long-term memory by writing it down. As writers, note takers must select the information to record and format it in ways that differ from the source material. They employ abbreviating operations, syntactical short-cuts, paraphrasing statements, and often a physical formatting of the notes that differs from the linear text of written source material (Piolat, 2001). Accordingly, the goal of a cognitive analysis is to specify the processes, knowledge, and working memory resources that note takers activate when they produce this unique kind of written product.

The present review will be organized as follows. We begin by characterizing the written products (the notes) and the reasons for their production. We then focus on the central attribute of note taking, namely, the speed with which both comprehension and production processes must be carried out. This brings forward the important role of working memory in note taking (Baddeley, 2000). Next, we describe the dual- and triple-task methods that are fruitful for measuring the cognitive effort required by note taking (Olive, Kellogg, & Piolat, 2002). We then report the findings of a series of studies that compare the cognitive effort involved in note taking versus other language activities (reading comprehension, verbal learning, and writing original texts). Finally, we examine how different contexts of note taking affect the cognitive effort involved, including variations in the kind of source material, the technique of note taking, the source medium, and the amount of information contained in the source.

THE WHAT AND WHY OF NOTE TAKING

Functions and factors regulating note taking

Notes can be defined as short condensations of a source material that are generated by writing them down while simultaneously listening, studying, or observing. Their function is to gather information distributed in a lecture, a book or in any other situation that needs to be remembered. In other words, notes are external memories whose content is more or less explicit (Hartley, 1976; Kiewra, 1989; Kiewra & Frank, 1988; Kiewra, DuBois, Christensen, Kim, & Lindberg, 1989).

The function of notes is not only to provide a record of information, however. Indeed, even if note taking is frequently used in situations where transmission of information is crucial, as in academic contexts (Armbruster, 2000; Canelos, Dwyer, Nichols, & Randall, 1984; Kiewra, 1987, 1988a, 1991; Piolat & Boch, 2004; Piolat, Roussey, & Barbier, 2003), it is also frequent in everyday life and in many professional contexts (Hartley, 2002). In these situations, manipulating and anticipating relevant information are crucial, as in judging (Houdek Middendorf & Hoff Macan, 2002), problem solving (Cary & Carlson, 1999), and decision making (Castello & Monereo, 1999), including when the work is collective (e.g. industrial design, preparation of an exhibition, etc.). In such cases, note taking could facilitate an ongoing work.

In academic contexts (secondary school and university), after several years of practice, students develop specific conceptions of the functions of note taking. These representations relate to the purposes of the notes (to record information, to concentrate, etc.), their content and structure (abbreviating procedures, structure of information, etc.) as well as to contextual factors (style of the teacher and how important information is signalled, kind of

course, etc.) that mediate note taking (Badger, White, Sutherland, & Haggis, 2001; Dunkel & Davy, 1989; Van Meter, Yokoi, & Pressley, 1994). The students' conceptions differ widely, however, as a function of the kinds of academic courses for which they take notes (Badger et al., 2001; Hadwin, Kirby, & Woodhouse, 1999).

For two decades, a few experimental studies have analysed different contextual factors that affect note taking (for a review, see Piolat et al., 2003). When taking notes from lectures, students are very attentive to a variety of signals given by the lecturer to control comprehension (fluency, changes in prosody, notes on the blackboard, explicit instructions for taking notes, etc.; see Isaacs, 1994; Titsworth, 2001). When taking notes from written documents, typographic and linguistics marks present in the text (title and headings, summarized statements, connectives, etc.) are used for selecting and structuring the information (Rickards, Fajen, Sullivan, & Gillespie, 1997; Sanchez, Lorch, & Lorch, 2001).

Notes: Summarized products with different formats

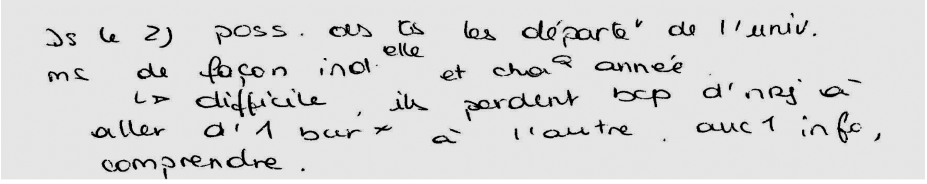
Note taking is often realized under severe time pressure. To take notes quickly, it is necessary to shorten and reduce information. Such constraints led to the invention of stenography whose graphic traces and transcribed units are simplified compared with alphabetical writings. But this technique is so scarcely mastered that note takers rarely use stenography. They generally fashion their own method of note taking during their studies or in their profession. This leads to much diversification in note-taking practices (Bretzing, Kulhavy, & Caterino, 1987; Hartley & Davies, 1978).

Analyses of the structures of notes show that the techniques used when taking notes affect three levels of language. First, *abbreviating procedures* may apply on lexical units (namely spelling; see Figure 1). For instance, end truncation (writing down '*poss.*' for '*possibility*'), conservation of the frame of consonants, and suffix contraction (writing down '*recog*^{ed}' for '*recognized*') are usual techniques of note taking (cf. Branca-Rosoff, 1998; Kiewra & Benton, 1988; Kiewra, Benton, & Levis, 1987; Lindberg-Risch & Kiewra, 1990). It is also important to notice that the same note taker can use a variety of techniques and that these techniques may be quite different from one individual to another. Moreover, the variation with which a note taker uses these techniques is astonishing. For example, the same word can be shortened in different ways within the same note-taking task or from one note-taking task to another.

Despite this variety of techniques, some are automatized sufficiently to be transferred from one language to another, as indicated by research on note taking in first and second languages (Chaudron, Loschsky, & Cook, 1994; Clerehan, 1995). For instance, as Figure 1 illustrates, when the lexical structure of two languages is comparable, suffix contraction can be used in the same way. In the two excerpts in Figure 1, the same student contracted a suffix both in French ('*ind*^{elle}' for '*individuelle*' — 'individual' in English) and in English ('*recog*^{ed}' for '*recognized*'). By contrast, because Japanese and French are two languages that are very differently structured, Japanese students have to discover and to learn new techniques when they take notes in French (Barbier, Faraco, Piolat, Roussey, & Kida, 2003).

Second, *syntax can be transformed* by shortening statements. For this purpose, note takers may adopt a telegraphic style to record the information. They may also use substitutive techniques, with mathematical ($+$, $=$), iconic (↗), Greek-alphabetic (ß) symbols for example. Such symbols (dash, arrow, star) are also ways for increasing the speed of note taking, as for example when they are used in lists (see Figure 2). They further

Note taking in French (First Language)



Note taking in English (Second Language)

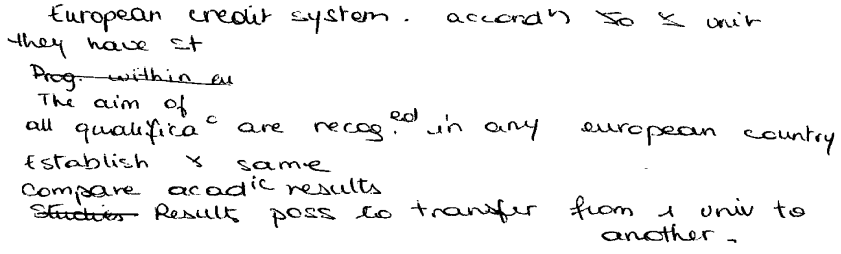


Figure 1. An example of abbreviating procedures used by the same undergraduate student in first language (French) and in second language (English)

avoid formatting the syntax of the source material that is heard or read (Branca-Rosoff, 1998; Barbier et al., 2003).

Third, the *physical formatting* of the notes may be quite different from the usual linear formatting used when producing a text (for a synthesis, see Piolat, 2001; Piolat et al., 2003). In general, the format of the notes (tabulation, inserts, etc.) exploits all the physical space of a sheet in a non-linear way (see Figures 2 and 3). The formatting of the notes written down on the paper is thus often near that of preparatory rough drafts of an essay (Kellogg, 1988; Piolat, 1998, 1999; Piolat & Roussey, 1996). They can, however, look very similar to a polished draft or a linear text (Slotte & Lonka, 2001).

Note-taking strategies use the physical space of the sheet to provide organizational cues of the information that is recorded (for a synthesis, see Kiewra et al., 1989; Piolat, 2001). When they take notes during their courses, a majority of students focus on the discourse of the teacher that they will have to restore during their examination. So, they frequently resort to a linear method of note taking that gives to their notes a traditional textual appearance (Piolat & Boch, 2004; Van Meter et al., 1994). However, in some particular educational settings (observation method for example) or in professional contexts (notes taken during a meeting) note takers can voluntary pre-select information they wish to integrate in their notes by following particular and well-defined note structures. For example, as shown in Figure 3, the note taker has used a variant of the seven-question method of note taking (Who? What? Where? When? How? Why? How many?).

Note taking and learning outcomes

Research on note taking has generally attempted to delineate the strategies and techniques that lead to notes that are relevant and effective for knowledge acquisition (Baker &

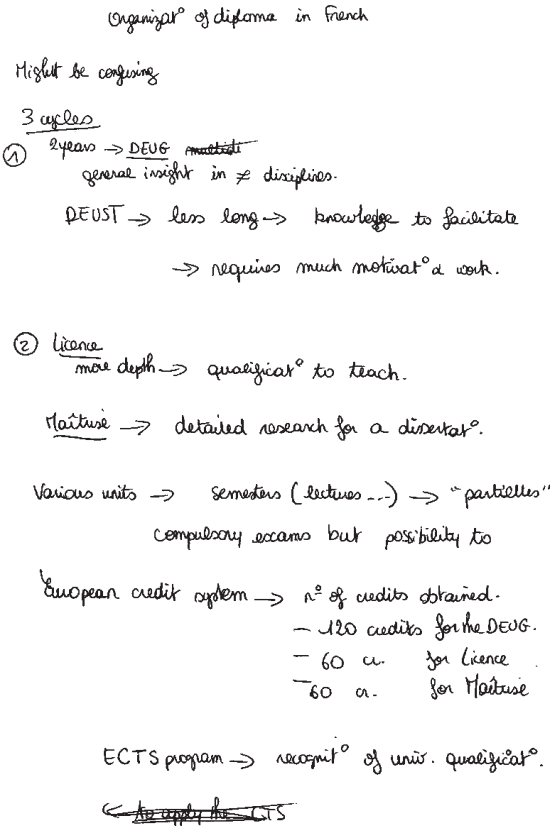


Figure 2. Use of abbreviating procedures (e.g. '*Organizat°, cr.*') and application of several list effects with indentations for physical and linguistic formatting of notes in a second language (English) by undergraduate students

Lombardi, 1985; Barnett, Di Vesta, & Rogozinski, 1981; Kiewra et al., 1991; Kiewra, DuBois, Christian, & McShane, 1988; Morgan, Lilley, & Boreham, 1988; Norton, 1981; Norton & Hartley, 1986; Nye, Crooks, Powley, & Tripp, 1984; Peck & Hannafin, 1983; Russell, Caris, Harris, & Hendricson, 1983; Slotte & Lonka, 1999; Spires, 1993). However, notetakers must endeavour to learn how to note (Stahl, King, & Henk, 1991), more especially because they often take notes with difficulty (Suristky, 1992).

The majority of the studies that investigate the effects of note-taking strategies on learning have focused on the quality of the selection and the organization of the information that is recorded (Boyle & Weishaar, 2001; Brown & Day, 1983; Dyer, Riley, & Yekovitch, 1979; Einstein, Morris, & Smith, 1985; Horton, Lovitt, & Christensen, 1991; Howe, 1974; Kiewra et al., 1987; King, 1992; Ladas, 1980; Nist & Hogrebe, 1987; Oakhill & Davies, 1991; Piolat, in press; Smith & Tompkins, 1988; Thomas, 1978; Williams & Eggert, 2002). These studies suggest that nearly all non-linear note-taking strategies (e.g. with an outline or a matrix framework) benefit learning outcomes more than does the linear recording of information, with graphs and concept maps especially fostering the selection and organization of information. As a consequence, the remembering of information is most effective with non-linear strategies (Dye, 2000; Fisher & Harris,

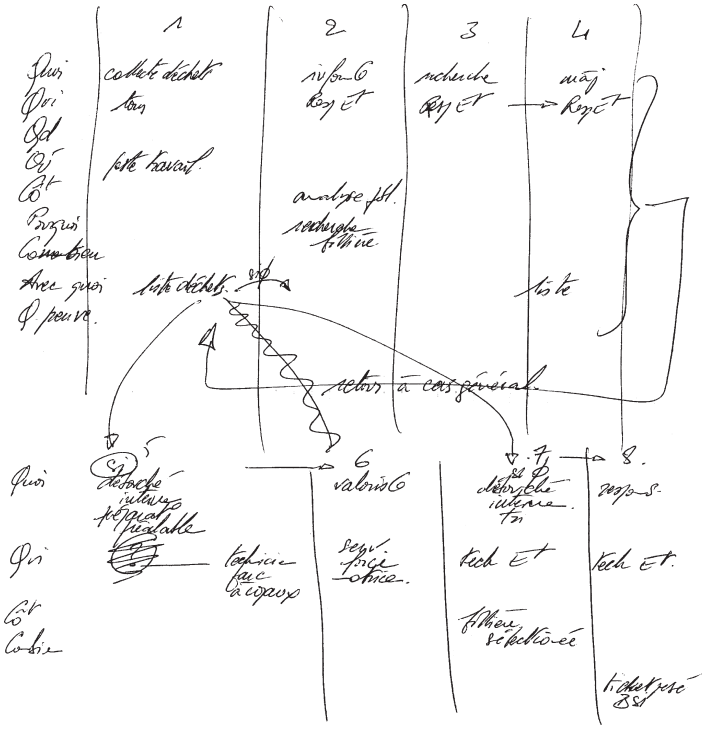


Figure 3. Notes recorded during the reading of a report in a professional context with the seven-question method by a business woman

1974; Frank, 1984; Gruneberg & Mathieson, 1997; Robinson & Kiewra, 1995; Robinson, Katayama, DuBois, & DeVaney, 1998; Slotte & Lonka, 2000; Titsworth & Kiewra, 2004).

Studies on the impact of note-taking strategies on recall and achievement in exams have shown that students not only learn when they review their notes, but also while they take their notes. The notes constitute an external memory that can be used later for studying and other tasks (Kiewra, 1985a, 1985b; Kiewra, Benton, Kim, Risch, & Christensen, 1995; Knigth & McKelvie, 1986; Laidlaw, Skok, & McLaughlin, 1993; Peters, 1972). Taking notes themselves can also increase learning by fostering retention and connections of information, as seen in the generation effect (NB: 'The generation effects refers to the finding that individuals retain materials that they have generated better than materials that have been generated by others and given to them' Foos, Mora, & Tkacz, 1994, 567). Moreover, students also memorize during note taking, particularly when they engage in deep comprehension of the source (Williams & Eggert, 2002).

All the studies mentioned above focus on the integration of information in long-term memory, but fail to explore the role of working memory in note taking. Hartley and Davies (1978) had considered that attentional capacity of note takers decreased as a function of several factors such as the importance given to the course and to the information delivered. Kiewra (1988b, 1989) mentioned the role of working memory in note taking, indicating that quantity and quality of notes might be quite different according to the 'working memory skill' of note takers. Scerbo, Warm, Dember, and Grasha (1992) analysed the nature of the information that was noted and concluded that the attentional capacity of note takers decreases throughout a course or lecture. Some other authors have considered

that the role of working memory when note taking is a means to decrease cognitive load during reading (Yeung, Jin, & Sweller, 1997) or in problem solving (Cary & Carlson, 2001; Cohn, Cohn, & Bradley, 1995). The notes, as an external memory, thus support retention in working memory of intermediate information or solutions that will be used for comprehension or for elaborating a final solution. Researchers have neglected to study the critical relation between working memory and note taking, given that taking notes involves juggling comprehension and production processes under, at times, severe time pressure.

MEASURING COGNITIVE EFFORT OF NOTE TAKING

Note taking: A high resource-consuming activity

Note takers have to deal with several problems related to the flow of information, particularly when taking notes from lectures. When writing notes, the note taker is constrained by the rate of speech of the lecturer: writing speed is about 0.2 to 0.3 words per second whereas speaking speed is about 2 to 3 words per second (Foulin, 1995; A. Piolat, unpublished phD thesis, 1982). In other words, note takers must maintain an active representation of what they are hearing in order to get sufficient time to exploit and to transcribe a portion, while being faced with a continuous updating of the message content as it is spoken.

Even with written documents, note takers must also deal with a temporal pressure, because their transcription remains slower than their reading. They cannot delay or slow their writing time too much in order to still be able to maintain in working memory the intermediate representations that result from comprehension. The temporal management of information is, therefore, a special difficulty in note taking. Note takers must coordinate the attention and storage demands of both comprehension and written production. They are thus constrained by the limited resources of the central executive and storage components of working memory (Baddeley, 1996).

Working memory, as defined by Baddeley (2000), plays a crucial role in all cognitive activities that require the temporary storage and manipulation of information, whether the individual accomplishing these activities is just learning or is highly skilled. Working memory is engaged in comprehension (Daneman & Merikle, 1996) and in writing (Kellogg, 1996; Levy & Ransdell, 2002; Olive, 2004). These two activities are also elicited in note taking.

Although taking notes implies activating automatized processes specifically related to comprehension (e.g. accessing the mental lexicon) and to writing (e.g. letter formation), it also implies a set of anticipating and control mental operations (i.e. executive functions) that are resource demanding. Multiple cognitive processes must be coordinated in rapid succession for note taking to be successful. Such coordination involves the central executive component of working memory (Baddeley, 1996, 2000). In note taking, these controlled operations are for a large part conscious and are subject to a metacognitive control (Castello & Monereo, 1999; Piolat & Bloch, 2004). In others words, note takers may deliberately regulate their activity to simultaneously comprehend, evaluate, sort, and write down the information that must be recorded.

To circumvent the limited capacity of working memory, note takers may choose between two main strategies, with this choice being susceptible to change while taking

notes (Piolat, 2001; Piolat et al., 2003). They may reduce their activity either to comprehension (listening or reading and noting the less possible) or to transcription (without processing the content of what is heard or read in order to be able to transcribe the maximum of information). In the later case, the on-line verbatim transcription of speech poses a serious psychomotor problem that note takers solve by giving up the transcription of letters, words, part of sentences, even of whole sentences, by using abbreviating procedures. Nevertheless, the use of such procedures is not always effective for resolving the variation of rate between fast oral production and slow writing.

Even if, for some note takers, the abbreviating procedures do not require working memory resources, the selection of information cannot be performed in an automatic way, even when note takers have at their disposal procedures that markedly shorten their notes, as for example, with concept maps (Piolat, 2001; Piolat & Boch, 2004). Thus, these activities of comprehension and production of notes are, in large measure, deliberate operations that require central executive resources.

The cognitive effort (Kahneman, 1973; Kellogg, 1987, 1988, 1994) that note taking engages should vary according to different situational parameters such as the nature of the information that is noted, the domain-knowledge of the note taker about the lecture or the reading, etc. The assessment of the amount of cognitive resources that is required by a complex cognitive activity may be carried out by several techniques according to the nature of the task that is investigated. For our part, we elected the dual-task paradigm and the triple-task techniques.

Measuring cognitive effort with the dual-task paradigm

Cognitive effort refers to the fraction of limited attentional resources that are momentarily allocated to a process (Kahneman, 1973; Tyler, Hertel, McCallum, & Ellis, 1979). Among the experimental methods that are available, the dual-task technique has often been used for evaluating the cognitive effort engaged in higher-order cognitive tasks, such as comprehension or text production. In these tasks, participants are asked to perform concurrently a primary task and a secondary probe task. For example, while composing a text or taking notes, participants must react as fast as possible to tones (by pressing a mouse button or by saying 'stop' to a microphone linked to a vocal key) that are periodically distributed in a random interval (in general between 15 and 45 s). The central executive of working memory must coordinate the concurrent tasks, focus attention when each tone is detected, and select a motor response as instructed. Reaction time (RT) in this dual-task situation is compared with a control condition when the probe is responded to as a single task. The degree of interference in RT (IRT) caused by the primary task provides a measure of the amount of cognitive effort devoted to composition or note taking. So, if the composition of two texts whose content is quite different engages a comparable degree of cognitive effort, the IRT should not differ. Conversely, if one task engages more cognitive effort than another, then this should be revealed in their respective IRTs. In sum, the longer the IRT, the more the primary task places demands on the central resources of working memory.

Using this kind of secondary task, Kellogg (1986, 120; 1994, 17) compared the cognitive effort of adults engaged in intentional and incidental learning of nonsense syllables (Kellogg, 1986), text composition (Kellogg, 1994), reading comprehension (Britton, Glynn, Meyer, & Penland, 1982), and game playing in chess (Britton & Tesser, 1982). As shown on Figure 4, undergraduates composing short texts in the laboratory

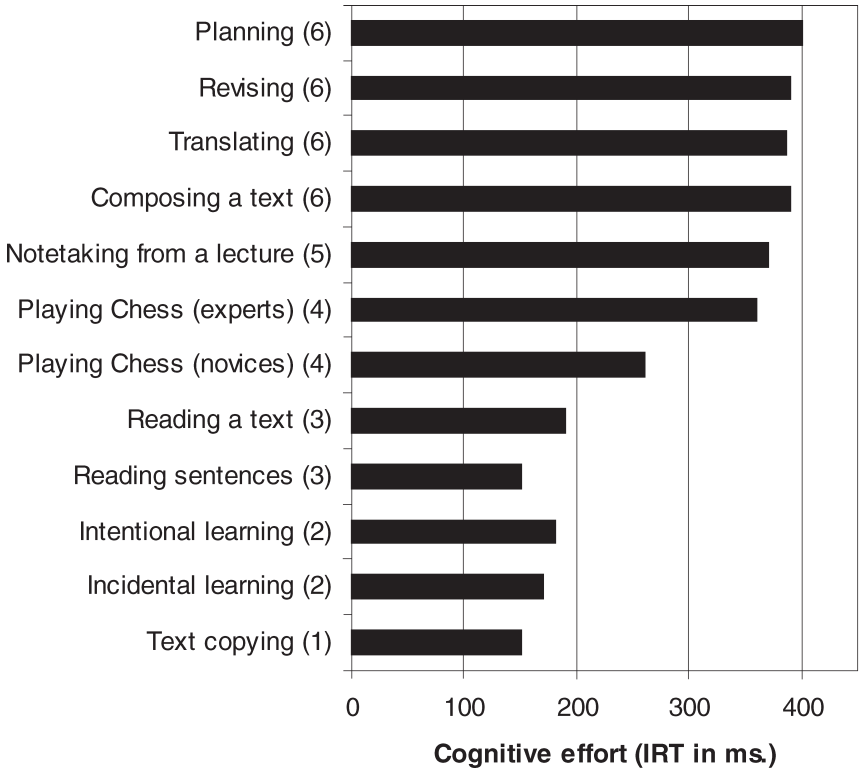


Figure 4. Cognitive effort (in milliseconds) in different processing information tasks [(1) Olive & Piolat, 2002; (2) Kellogg, 1986; (3) Britton et al., 1982; (4) Britton & Tesser, 1982; (5) Piolat, in press, and (6) Piolat et al., 1996]. NB: the values of standard errors are not available

expend a high degree of cognitive effort, matched only by chess experts as they select a move in the middle stages of a match. What is common to these two tasks is that they both involve retrieval of large amounts of knowledge, conceptual planning, and the development of solutions to the problems posed in each situation. In such activities, the engagement of the individual in the task is critical and the cognitive effort allocated is more substantial than when these operations are not needed, such as in reading, rote learning or text copying (Olive & Kellogg, 2002). Although texts with complex sentences demanded more effort than those with simple sentence structures, it is of interest that reading syntactically complex texts, is still less demanding than writing.

Thus, it appears that the manipulation of information retrieved from long-term memory and management of these processes in working memory (either in text composition or when making a skilled move during a chess game) are highly demanding on the central executive. In the remaining review, similar comparisons are made across different tasks. It is recognized that these comparisons lead to inferences that must be tested in a single experiment using statistical procedures. Even so, the comparisons suggest interesting research questions that can be tested in future experiments.

Measuring cognitive effort with the triple task

The chronometric approach of mental functioning just discussed can be further extended by analysing the cognitive effort associated with specific processes involved in note taking

or writing. This involves asking for an immediate directed introspection after each tone's detection. The participant categorizes his or her thoughts at the moment the tone occurred. For example, in studying text composition, the participants indicated whether their thoughts reflected planning ideas, translating ideas into text by generating sentences, or reviewing ideas or text (Kellogg, 1987; Levy & Ransdell, 1995). With the triple task, then, participants perform: (1) the primary task under investigation, (2) the secondary probe task described above, and (3) a verbalization task that asks participants to label the process that was interrupted by the probe. For this last task, participants have first been trained to identify the cognitive processes activated at the moment based on immediate recollection of their conscious thoughts at the time of the probe. In most of the writing studies, the three major writing processes (i.e. planning, translating and reviewing) have been the focus of the researcher and writers are thus trained to identify these processes. Obviously, different processes can be the targets of the investigation.

The time course of the triple task is as follows: while writers compose their text, just after having reacted as fast as possible to the auditory probes, they designate the process interrupted by the probe, and then the task continues with several cycles of reaction to the probes followed by directed introspection. Two variables are then analysed. First, the verbalization data provide information about the processing time of the writing processes and how this processing time changes throughout a writing session. The percentage of times spent on a writing process constitutes an index of its processing time. Second, the RTs to the probes allow one to study the allocation of cognitive resources to these processes. Each RT to a probe is associated with an immediate, directed introspection response and the latency of these RTs (in terms of a difference with a baseline RT) estimates the cognitive effort given to the reported writing process. This method, then, sheds light on how writers succeed or fail in managing the demands of writing by tracking the time and effort devoted to specific processes.

The triple task uses directed introspection as opposed to the undirected introspection obtained in think aloud protocols (Ericsson & Simon, 1980). Verbal protocols provide a much richer record of the cognitive processes engaged in by the writer. However, thinking out loud as one writes is particularly challenging given the heavy demands of the primary task on working memory. When generating sentences, the think aloud protocol requires speaking a sentence at the same time that it is written and the protocol is often nothing more than a verbalization of the written sentence. Undirected verbalization is quite informative with respect to planning and reviewing, but the continuous verbalization requirement is more intrusive than training writers to identify one of three or four categories (Olive et al., 2002; Piolat & Olive, 2000). A brief, categorical response minimizes the disruption of the primary task and at the same time allows one to estimate processing time and cognitive effort. Further, it allows participants to report nonverbal processes, such as visual imagery in planning, without the cost of recoding into words as required in a think aloud protocol (Piolat, Olive, Roussey, Thunin, & Ziegler, 1999). The use of directed introspection has proven extremely valuable in other research areas, such as the categories of 'remember' *versus* 'know' in studies of episodic memory (Gardiner & Richardson-Klavehn, 2000).

The triple task may appear complex and disruptive of the primary task. Several experiments have been carried out to test the impact of the probe task and directed introspection on the primary task (Kellogg, 1987; Pélissier & Piolat, 1999; Piolat, Kellogg, & Farioli, 2001; Piolat, Roussey, Olive, & Farioli, 1996). The findings of these experiments show that the functioning and performance of the participants to the primary task

are neither degraded nor altered. Moreover, processing time and cognitive effort of the writing processes do not necessarily co-vary; for instance, although translating processes are activated more often than planning and revising, the cognitive cost of translating is usually smallest. The triple–task method is a powerful technique that highlights key features of the strategies writers use when composing a text.

In sum, with such tools of mental chronometry and according to the goals of the study, researchers can elect to focus on only the holistic cognitive effort engaged by a particular task (e.g. by comparing note taking from a lecture or from a written document). For this purpose, the dual-task technique with a secondary probe task suffices. The researcher might, however, want to track the time course and cognitive effort of the cognitive processes that underlie an activity. The triple-task technique offers a way to do so that is un-intrusive and informative.

COGNITIVE EFFORT IN DIFFERENT SITUATIONS OF NOTE TAKING

Several complex cognitive processes involved in language processing activities are simultaneously activated when taking notes (comprehension, writing, and learning). To assess their respective cost, in terms of cognitive effort, findings from various studies are compared in this section. Results are not presented in the following sections in a canonical way for the following reasons. Firstly, our goal is to offer a synopsis of the different studies that have evaluated cognitive effort during note taking and the detailed statistics of each study are not presented here. Secondly, putting all these studies together is meant only to present an overview of a large sample of results in order to suggest hypotheses, as was done in Kellogg's (1986) review of writing tools. Our main goal is to attempt to predict in which way working memory is engaged depending on the writing activity (e.g. writing versus note taking) and on the different contexts (e.g. note taking from a document *versus* from a website).

Comparing note taking with comprehension, learning and writing

Taking notes implies comprehending either a written document or a lecture and recording information by writing it down. So, we first compare noting from a lecture, reading a text (to assess the cognitive effort of comprehension), and writing by longhand. Figure 4 shows the results of four areas of enquiry in which cognitive effort was measured.

In a difficult intentional learning task, participants learned (psychology undergraduate students) a list of nonsense syllables (Kellogg, 1986). In the reading study (Britton et al., 1982), participants read a brief text. The note-taking situation asked participants (psychology undergraduate students) to take notes from a 12-min lecture on literature before filling a questionnaire (Piolat, in press; Roussey & Piolat, 2003). In the last study, participants (psychology undergraduate students) composed an approximately one-page long argumentative text (Piolat et al., 1996). As Figure 4 shows, the cognitive effort engaged by note taking is greater than learning and comprehending (reading in Figure 4). This indicates that taking notes demands more of the central executive than either learning or comprehending alone, and supports the assumption that both of these activities are engaged in note taking.

In another experiment that used the triple-task technique (Gérouit, Piolat, Roussey, & Barbier, 2001), note takers had to categorize their activity after each reaction to a tone

according to whether they were reading a booklet or recording information by writing it down. Despite the reading task being highly effortful, judging from the large IRT observed (590 ms), the note-taking task (661 ms) was still reliably more demanding. As this finding shows, the writing activity of note taking seems to be more costly than that of comprehension. Thus, taking notes consumes at least as many resources as composing a text. Noting and writing both involve comprehension processes because both writers and note takers build a conceptual mental representation of what they are composing—for the former, and of what they are hearing—for the latter. But they also activate other processes to format their notes with the various physical and linguistic formatting procedures they have at their disposal. Applying these procedures is more effortful than comprehending (see reading in Figure 4). This finding is compatible with data from a comparison between creative and non- creative activities (see next section, and text copying in Figure 4).

Comparing note taking with the processes involved in text composition

The analysis of the processes involved in note taking indicates that note taking is closer to text composition than to graphic transcription (Piolat et al., 2003). This interpretation is supported by data from the comparison between cognitive effort associated to note taking, copying, and the three major cognitive processes (planning, translating and revising; Piolat, in press; Roussey & Piolat, 2003) with data from an experiment that assessed cognitive effort of the three major writing processes (Piolat et al., 1996) and with data from an experiment in which the cognitive effort of copying was assessed (Olive & Piolat, 2002). In this last experiment, participants (psychology undergraduate students) had to copy a text that they had just composed in one of the conditions.

As Figure 4 illustrates, note taking is not only transcribing (cf. copying). The cognitive effort devoted to note taking is indeed reliably higher than the effort devoted to copying. In other words, taking notes is not a simple graphic transcription of the information that is carried out in the lecture or in the reading. Indeed, in addition to operations of comprehension, when taking notes, note takers also select information, reformulate the contents (abbreviations, telegraphic style, linguistic formatting of the notes), operations which all require an effort that is greater than that required for a simple sequential transcription. Finally, the low cognitive effort of copying (i.e. handwriting) also suggests that gaining access to meaning, sorting and selecting information can be elicited simultaneously with writing (more precisely, with translating and the associated motor execution of handwriting).

The comparison between note taking and the three writing processes (planning, translating and revising) first shows that planning the content of a text is the most effortful process (Kellogg, 1994). Retrieving and organizing ideas during a text composition are still more effortful than selecting the information that will be recorded. Searching a new and ‘creative’ solution (i.e. the text written down) requires more resources than taking notes, even if the notes often present content characteristics different from what has been heard or read.

Comparing note taking from different sources and with different techniques

Note taking is used in very different situations that impose different information processing demands. Note takers frequently extract information from a written document

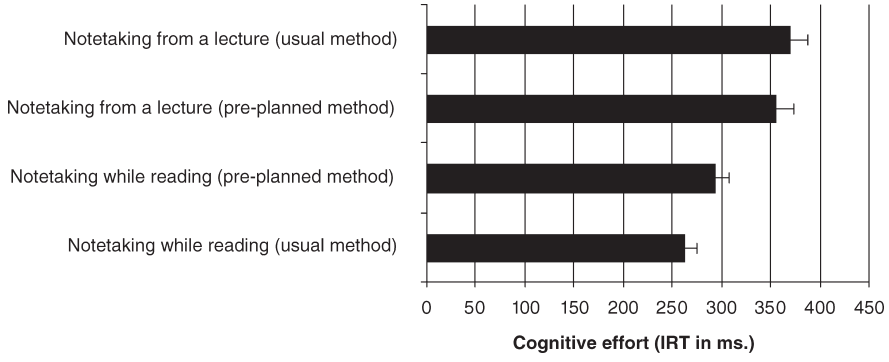


Figure 5. Mean cognitive effort (in milliseconds, and standard errors) when taking notes from a lecture or while reading and with two methods (usual *versus* pre-planned; Piolat, in press; Roussey & Piolat, 2003)

(an article, a book) to learn its content, or in order to use this information later. By contrast with note taking from a lecture, the pace at which note takers have to comprehend and select information from a document is slower when they read. They can, therefore, activate successively and not concurrently some of the operation needed to record the information via handwriting. Techniques also vary substantially, with almost all note takers using a personalized method for taking notes on a blank sheet. Some of them use pre-planned methods that reduce the urgency in taking notes. The sheets are marked with a plan, such as an outline, that guides the selection and recording of information from readings or lectures.

Piolat (in press) has compared these different situations of note taking by psychology undergraduate students (Roussey & Piolat, 2003). More precisely, she compared note taking when listening to a lecture on literature with note taking while reading a transcript of it, and she contrasted these two contexts with two methods: taking notes with one's own usual method or with a pre-planned method (Figure 5).

Not surprisingly, taking notes from reading requires less cognitive effort than from a lecture. When listening, more operations are concurrently engaged and, thus, taking notes from a lecture places more demands on working memory resources. In Piolat's experiment (in press), the note-taking method did not affect the amount of working memory resources note takers engaged in the task. One possible interpretation is that the different methods that can be used for taking notes only affect the temporal management of the different activities that underlie note taking rather than their cognitive effort. This finding needs to be replicated, however.

Comparing note taking from different mediums with different amounts of information

Both the amount of information and its support can affect the cognitive effort of note takers. The written documents that constitute the source of the note-taking activity can be of various lengths (from a few pages to a book). Information can, moreover, be presented on paper (books) or on a computer screen or notepad (hypertexts). In Figure 6 the findings from two studies are presented. In one study, students took notes from a two-page written document of 1680 words. Psychology undergraduate students were instructed that they

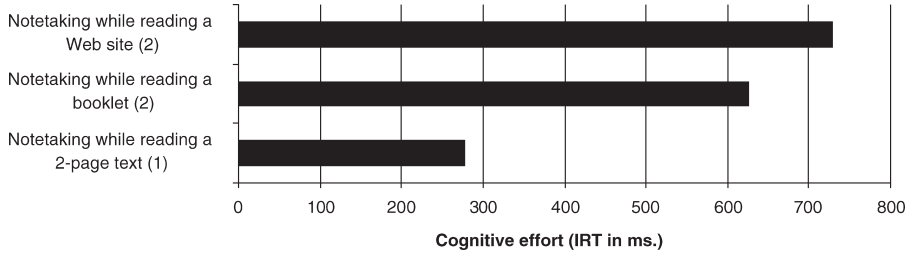


Figure 6. Mean cognitive effort (in milliseconds) according to the size of the written source (two pages *versus* 30 pages) and the medium (paper *versus* hypertext) [(1) Piolat, in press; Roussey & Piolat, 2003; (2) Gérouit et al., 2001]. NB: the values of standard errors are not available

had to take notes because they had then to complete a questionnaire (Piolat, in press; Roussey & Piolat, 2003). In the other experiment, psychology undergraduate students explored a large document (around 30 pages) on pollution that results from shipwrecks and on specificities of maritime transport. Their task was to write an argumentation defending the sea transport of dangerous products. Information was presented either in a booklet or through a hypertext document (namely, a website; for a discussion of the differences between the two types of documents, see Gérouit et al., 2001).

As this comparison indicates (see Figure 6), taking notes from a short text is less effortful than from a long document. In addition to activating text comprehension processes, when taking notes from a large document, note takers also must generate a large mental representation of the text (namely, a more complex mental model). Furthermore, to perform the task well, they develop strategies for scanning the whole text that are very different from the strategies developed for reading short texts. With short text, the note takers generally adopt linear scanning strategies, while they do not for longer texts.

Searching and sampling part of a text in order to find information to be recorded are more effortful with a hypertext than with a paper document. Using computer technology to manage information through the click of a mouse can actually increase cognitive effort, judging from these results. It may be that the use of these technologies is less practised than reading and handwriting. Similar results were obtained by Kellogg and Mueller (1993), however, who found that writing by longhand was less effortful than using a word processor even for skilled typists.

Note taking and linguistic skill

Note takers' linguistic skill, and in particular their mastery of a language, is another factor that might affect cognitive effort. Barbier and Piolat (M.-L. Barbier & A. Piolat, paper presented at the Sig Writing Conference, Geneva, 2004) examined the notes produced by undergraduate French students in their third year of English (as a foreign language). These students were instructed to take notes from an 8-min lecture (an 840-word text was recorded and then played) and they had then to summarize the text. They took notes first in French (first language) from a lecture about enrollment in French universities and second in English (second language) from a lecture about the general organization of studies in French universities (test order was counterbalanced: half of the students passed L1 and then L2, the other half L2 then L1).

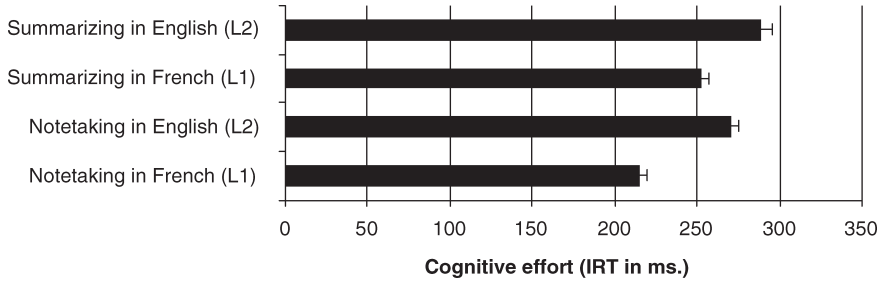


Figure 7. Mean cognitive effort (in milliseconds, and standard errors) by undergraduate students when taking notes or when summarizing a lecture after having taken the notes in first language (French) and second language (English) (Barbier & Piolat, in press)

Producing a text (in our case summarizing it, see Figure 7) requires more executive attention than taking notes in both languages. This finding supports the results reported in Figure 4. Not surprisingly, both note taking and text composition in a second language demands much more effort than in a first language.

Level of skill in a specific activity (as for example linguistic skill or domain knowledge, cf. Olive, Piolat, & Roussey, 1997) does not explain all the observed inter-individual differences. For instance, Piolat (in press) and Roussey and Piolat (2003) have shown that working memory capacity—assessed with the French adaptation of a reading span test (Desmette, Hupet, Schelstraete, & Van der Linden, 1995)—favours the adoption of different strategies of note taking and affects the cognitive effort that is engaged by note takers.

CONCLUSION

We have argued that the time urgency of note taking imposes significant demands on the limited resources of working memory. The problems encountered by the note taker can be understood in terms of the major cognitive effort required in specific contexts or situations. Note taking is a complex activity that involves interweaving both comprehension and production processes. As with reading, writing and other complex activities, working memory is a critical cognitive component and individual differences in performance can be traced to how well the demands on working memory are managed. The findings reviewed here show that the dual-task paradigm (and its variants) provides a relevant window on the mental functioning of note takers. The effects of different situational factors on the engagement of central executive of working memory can be fruitfully studied.

It is important in future work to use the triple-task method to identify and investigate more precisely all the information processing operations engaged in note taking. Identifying when and how many times comprehension, selection and production processes are activated, as well as how these processes are orchestrated constitutes an important challenge to understanding the functional characteristics of note taking. Our objective here was to delimit the basic process of note taking in a manner paralleling the written composition of original texts to lay the foundation for decomposing the task and its mental components further (Hayes & Flower, 1980; Kellogg, 1994).

It also remains for future research to relate cognitive effort (that most often results from strategic adaptation) with behavioural outcomes, such as the quality of the notes taken or the performance or the time required to complete the task. However, in contrast to texts written for public consumption, notes are generally a private product intended to be meaningful only to the note taker. It may be more difficult to adopt criteria of quality that are agreed upon as valid for note taking in comparison to written texts.

However, because processing time (or frequency) of the processes involved in note taking can also be assessed with the triple-task method, the effect of the different methods (or formats) and strategies (for instance focusing essentially on comprehension on recording of information) of note taking can be investigated. Moreover, inter-individual characteristics of note takers, already visible in the notes, may be discovered. Perhaps there are individual 'writing signatures' for note taking similar to those observed already in full texts' compositions (Levy & Ransdell, 1995; van Waes & Schellen, 2003).

In text composition, writers have to find a balance between the quality of the text they want to reach and the cognitive cost of the activity (Kellogg, 1994; Olive & Piolat, 2003). In particular, this balance is sensitive to the level of expertise (domain knowledge, linguistic skill). By analogy with text composition, evidence for such a trade-off between procedures in note taking, namely the nature of the produced notes, and the requirements in cognitive resources should appear a promising way for a better understanding of note taking and of its learning outcomes.

The observations reviewed here indicate that, from a cognitive perspective, note taking cannot be conceived of as only a simple abbreviated transcription of information that is heard or read. Rather, on the contrary, it is an activity that strongly depends on the central executive functions of working memory to manage comprehension, selection, and production processes concurrently. Indeed, the severe time pressure of note taking requires that information is both quickly comprehended and recorded in written form. It is a unique kind of written activity that cumulates both the inherent difficulties of comprehending a message and of producing a new written product. Yet, it differs in many of its characteristics from the usual linear and conventionally presented written texts.

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