Design Activities: How to Analyze Cognitive Effort Associated to Cognitive Treatments?

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Working memory issues are important in many real-life activities. Thus, measuring cognitive effort (or mental load) has been a main research topic for years in cognitive ergonomics, though no consensual method to study this aspect has been proposed. In addition, we argue that cognitive effort has to be related to an analysis of the evolution of cognitive processes (or "time processing"). From this perspective, we present and discuss experimental procedures that have been used for years to study writing activities. In experiments reported in this paper, these procedures are used for studying design activities, in the context of computer graphics and web site design.

The objective of this paper is twofold: to present two methods that are used in cognitive psychology both to study cognitive effort and to determine "time processing," i.e., the evolution of cognitive processes while performing a specific task; and to illustrate the use of these methods in design areas which require the use of a computational tool, as it is the case in computer graphics and in web site design.

First, relationships between characteristics of design activities and working memory are evoked. Then, we present the two methods we chose to use to both measure cognitive effort and analyze time processing, and we illustrate the use of these methods in the case of two design activities.

Relationships Between Characteristics of Design Activities and Working Memory

Design problems are particularly complex, especially since they are ill *defined,* and design activities are viewed as based on an *opportunistic process.*

Design problems are considered *ill defined* because designers have, initially, only an incomplete and imprecise mental representation of the design goals (Eastman, 1969; Reitman, 1964; Simon, 1973). The designers' mental representation evolves as the problem-solving progresses. This specificity of design problems has been described as based on an iterative dialectic between problem-framing and problem-solving (Rittel & Webber, 1984; Simon, 1995). During problem-framing, designers refine their mental representation of the problem by defining new design goals and constraints, which are taken into account for elaborating elements of solutions. During problem-solving, designers elaborate solutions and evaluate them with respect to various criteria and constraints (see, for instance, Bonnardel, 1999). Indeed, design problems admit potentially a variety of solutions, which satisfy different criteria or constraints to varying degrees. These criteria and constraints can be considered as open-ended (Bonnardel, ibid.) since they depend on explicit requirements linked to the design area, on each designer's prior experiences and personal preferences, and on points of view adopted by the designer himself or herself as well as by other stakeholders involved in the design process (see for instance Chevalier, 1999).

During design problem-solving, most of the choices are made *opportunistically* (see Bisseret, Figeac-Létang, & Falzon, 1988; Bonnardel, Lanzone, & Sumner, 2003; Guindon, 1990; Hayes-Roth & Hayes-Roth, 1979; Visser,1990). Decisions can be motivated by one or two immediately preceding decisions rather than by some high-level executive program. They can be made at different levels of abstraction, and they can lead designers to throw back on previous devisions or to postpone certain choices.

Due to such functional characteristics (ill defined and opportunistic characteristics of design), designers' activities are heavily dependent on the *allocation of attentional resources in working memory*. According to Baddeley (1996, 2000), working memory is in charge of the executive functions of the cognitive system. More precisely, the "central executive" system of this working memory would supervise the activation of cognitive treatments and control their coordination.

A traditional way to characterize complex cognitive tasks is to refer to the mental load (or workload) they require (see, for instance, Sperandio, 1988). The notion of mental load is a very old one, proposed in psychology of work in the years 60's. Since then, it has been used to mainly characterize, in the case of a specific task, the cognitive difficulty encountered by individuals as well as emotional factors (such as stress due to drastic time constraints or to pairs assessments). This notion has also been used to describe an excess of motivation and involvement in the activity. Moreover, it van be distinguished from the feeling of tiredness (in general or specifically of mental tiredness): one can use important cognitive resources to perform a task without feeling tired (Leplat, 1997).

However, in our opinion, the notion of mental load can be described more precisely by distinguishing between "cognitive capacity," which refers to the maximal amount of resources that a given individual van mobilize and which depends both on individuals' working memory span and on their level of expertise in a specific area; and "cognitive effort," which refers to the amount of cognitive or attentional resources required by cognitive treatments to deal with a given task and which depends on the nature of the tools used to perform the task, the organization of work, etc.

In this paper, since our objective is to relate designers' cognitive treatments to cognitive effort, the crucial problem is to measure the allocation of attentional resources during design problem-solving.

Characterizing Cognitive Effort and Time Processing During Complex Cognitive Tasks

Description of experimental procedures

One successful way to see the heavy demands on the central executive system during complex cognitive tasks has been to measure cognitive effort through secondary task reaction time, which corresponds to the classical "additional task" (or "dual task") procedure (see, for instance, Baddeley & Andrade, 2000; Baddeley & Hitch, 1974; Kahneman, 1973; Levy & Ransdell, 2002; Posner, 1978). It has been especially the case for various complex tasks, such as playing chess (Britton & Tesser, 1982), reading simple and complex texts (Britton, Glynn, Meyer, & Penland, 1982), and incidental and intentional learning (Kellogg, 1983).

In order to associate cognitive effort with the nature of cognitive treatments, Kellogg (1987a&b, 1996) designed a new experimental procedure, called the "triple task," which he used mainly to study writing activities. This procedure was later adapted by Levy and Ransdell (1994, 1995). In both procedures, while performing the main task (e.g., writing a text), participants have to respond as rapidly as possible to auditory probes distributed on a variable interval schedule. The idea underlying these experimental procedures is that the residual capacity (i.e., capacity which is not used to perform the main task) can be used to perform another task. Variations on the additional task reveal the amount of attentional resources allocated to the main task (see, for instance, Kellogg, 1987a&b; Piolat, Kellogg, & Farioli, 2001): high reaction time (RT) to auditory probes - with regard to baseline reaction time (measured when the secondary task is performed alone) - reveals that important cognitive resources are being used for the cognitive treatment performed at the time of the auditory probe.

In addition, participants perform either a concurrent "directed retrospection" (in Kellogg's procedure) or a simultaneous verbalization (in Levy and Ransdell's procedure), in order to relate reaction times to cognitive processes. Directed retrospection used in Kellogg's procedure consists in categorizing thoughts, which occurred at the time of each probe, according to labels corresponding to specific writing processes.

To summarize, participants are involved in a triple task by performing the main task (e.g., writing a text), reacting to probes, and indicating the cognitive process which has been interrupted, either by pointing out labels (Kellogg,1987a) or through simultaneous verbalization (Levy & Ransdell, 1994).

These experimental procedures may seem demanding for participants, so experimental studies were conducted in order to analyze the "reactivity" of these techniques, i.e., whether they influence the process of the activity and the final product.

Impact on participants' activities

Methodological concerns were expressed about the dual task technique (see, for instance, Fisk, Derrick, & Schneider, 1986-87). Therefore, numerous experiments have been conducted to analyze the impact of the proposed additional tasks (reacting to probes and reflecting on cognitive processes) on participants' activities and products (see, Kellogg, 1987b; Levy & Ransdell, 1995; Piolat et al., 2001; Piolat, Roussey, Olive, & Farioli, 1996). These experiments are based, for instance, on comparisons between "natural" writing conditions (i.e., without any specific technique) and "unusual" conditions (e.g., the main task associated with only the reactinn time task or with two additional tasks). Various features were tested and different results were obtained on behalf of these procedures (for a review, see Olive, Kellogg, & Piolat, 2002; Piolat & Olive, 2000).

Two major ones can be described here:

- There is no deterioration of the quality of the final products. Participants can allocate enough attentional resources to preserve their objectives and they can define "commitments" in managing their attentional resources, which allow them both to produce a text with the same quality as in natural conditions and to perform the additional tasks (Kellogg, 1987a&b; Levy & Ransdell, 1995; Pélissier & Piolat, 1999).
- Though the interruptions may slow down the task (especially when the probes are particularly frequent), the mobilization of the writing processes and the management of the task as a whole are not modified by the interruptions (Levy & Ransdell, 1995; Piolat et al., 1996).

Illustrations in Professional Areas

Our objective is now to show that these two experimental procedures can be efficiently used to analyze certain professional activities. Towards this end, we are going to briefly present two studies conducted in professional design areas: the first one to illustrate the use of Kellogg's procedure and the second one to illustrate the use of Levy & Ransdell's procedure.

Our choice of professional areas has been motivated by the fact that, in today's workforce, many individuals are involved in design activities. Depending on the design area, these individuals can be situated on a continuum, with on one side, skilled professionals' - as it is the case, for instance, in architectural design or in computer graphics - and, on the other side, novice designers or lay-designers - as it can be the case for web site design. Indeed, the design of a web site is not only performed by specialists in new technologies: everyone can now design his or her own site, Towards personal or professional aims. In addition, the design activities are more and more realized using computational tools and design support environments (which aim explicitly at supporting certain aspects of design activities). Thus, there are very pragmatic reasons to bring elements of answer to different types of questions:

- How do designers perform tasks using such computational tools and do these tools facilitate their activities?
- Are these tasks cognitively expensive or associated to cognitive difficulties?

Numerous research efforts in computer science and artificial intelligence have been focused on creating various types of design support environments (see, for instance, Fischer, 1994; Fischer, Lemke, Mastaglio, & Morch, 1991; Nakakoji, 1993; Trousse, 1996, 1998). Several studies have also been conducted in cognitive psychology and cognitive ergonomics to determine the influence of computational tools on the designers' activities (see, for instance, Bonnardel & Sumner, 1996; Chen, 2001; Lebahar, 1986, 1996; Whitefield, 1986). These studies are frequently based on observations associated with comments from the designers on their activities. Very interesting results have been obtained, but we still need to know more about both cognitive effort required by such tasks and the evolution of cognitive treatments performed by designers. Towards this end, we conducted studies in two areas in which designers develop products that satisfy certain requirements, but are also innovative: computer graphics (Bonnardel & Gaden, 2000) and web site design (Bonnardel et al., 2003). To illustrate the use of the two experimental procedures, we chose to conduct two studies with either professional designers or lay-designers. Each of the two procedures can be used whatever the participants' level of expertise. However, professional designers are more representative of computer graphics activities, whereas the design of web sites can be performed by any designer. These observations motivated our choice of participants for each of the studies. The objective is indeed to show the interest of the two procedures, but not to compare the impact of the designers' level of expertise on the tasks they perform.

Experiment 1: Cognitive Effort and Treatments During Computer Graphics

Different aspects observed in design situations without computational tools are important in the dynamic of the design activity. For instance, due to the ill-defined characteristic of design problems, designers develop a schematic (or global) reflection at the beginning, which becomes progressively more precise and concrete as the problem-solving progresses (see, for instance, Adelson & Soloway, 1988; Simon, 1973). In addition, designers try to retain flexibility, so that when a problem is re-examined from a new viewpoint, decisions taken previously can be modified (Simon, 1995). Towards this end, designers may postpone decisions as late as possible to keep the space of solutions large (see Lebahar, 1983).

The use of a computational tool may profoundly modify such aspects of design activities. Especially, it may compel designers to make early decisions about detailed (or local) features of the object to be designed (see, for instance, Lebahar, 1986). However, we do not know what is the proportion of global and local treatments in design activities developed while using a computational system. In addition, what type(s) of treatments is or are the most resources demanding? To answer such questions, the triple task based on directed retrospection appeared both efficient and easy to propose to professional designers. However, it is required to perform a pre-study in order to define relevant categories for the directed retrospection.

Method

Participants

Four professional designers specialized in computer graphics participated in the experiment. They were ail working in the same offset printing office, and they ail had a similar level of expertise in graphical design activities as well as in the use of the Illustrator software.

Pre-experimentai phase

Since we wished te, use Kellogg's procedure, it appeared necessary to first conduct task and activity analyses in an offset printing office, in order to define cognitive treatments involved in computer graphics. Towards this end, we conducted interviews and observations in real time with designers who were using the Illustrator software. Among the different softwares used by computer graphics artists, we decided to select Illustrator, since this software provides designers with a white page and, thus, does not limit them in the early design stages.

Results of these analyses allowed us to point out certain specificities of the activities of computer graphics artists:

- They are focused on two main characteristics of the products they have to design: the shape and the color of these objects.
- The graphcal activities they realize on the computational tool are spontaneously interrupted in order to assess what they are creating.
- These different cognitive treatments are performed at different levels of abstraction; thus, we decided to distinguish global treatments and local treatments.

Consequently, the labels we chose to propose to participants during the directed retrospection are the followingz: global or local shape of the object to design, global or local colors of the object, global or local evaluation.

Experimentai task

The experiment was computer-driven with the Scriptkell software (Piolat, Olive, Roussey, Thunin, & Ziegler, 1999), which records and analyzes the different variables of Kellogg's procedure (number of reactions, frequency of category choices, mean reaction times...).

The participants' experimental task consisted in the these following sub-tasks:

- to design a logo for a photography office; this design problem was representative of the usual tasks these computer graphics artists have to perform while using the Illustrator software, but this specific task had never been asked in the company;
- in the same time, the designers were interrupted by auditory probes, presented within 40 to 70 second intervals (the interval is never constant in order to avoid expectations from the participants in the study), and had to react to them by pressing a push button;
- to indicate the cognitive treatment they were performing while interrupted by the probe, by choosing among labels corresponding to the cognitive treatments defined during the previous analyses.

Procedure

The experimental situation began by explanations from the experimentar. Then, the designers had to perform two training tasks (during about half an hour) corresponding to the two additional tasks:

- They were trained to react to auditory probes, independently of any other task, which also allowed us to measure each participant's baseline reaction time (RT).
- They were trained to categorize samples of thoughts to the proposed labels.

After these training tasks, the designers had to perform the experimentai task, i.e., to design the logo, in one-hour duration. In addition, they had to perform simultaneously the two additional tasks previously described (reacting to auditory probes and performing the directed retrospection).

Main Results

Cognitive treatments

To characterize the evolution of the design activity (time processing), we divided the total time of the designers' experimental task into three parts (or "thirds"), which allowed us to have three views of the cognitive treatments they performed. In the following results, we group together different categories used in the directed retrospection task, in order to distinguish only between local and global treatments (for complementary results, see Bonnardel & Gaden, 2000).

We observe that (see Figure 1) the designers performed more local treatments than global treatments (in mean 60.5% of the designations correspond to local treatments vs 39.4% for the global treatments), and the local treatments decrease as the design problem-solving progresses, whereas the global treatments increase.

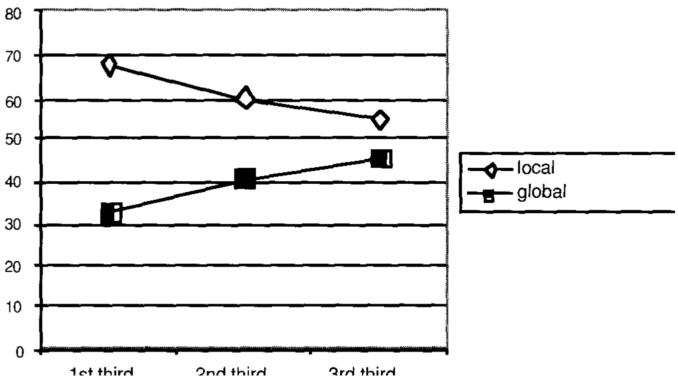

Figure 1: Percentages of designation of global and local treatments according to the evolution of the design activity (thirds).

Cognitive effort

The participants' baseline RTs measured during the training were subtracted from RTs measured during the experimental task, providing "RT interference scores." Such scores allow the determination of the participants' cognitive effort.

On Figure 2, global treatments appear to be associated to shorter reactinn times than local treatments, whatever the treatments are about (i.e., shape, color, or evaluation).

Discussion

The first result (about time processing) *clearly demonstrates* that the use of a computational tool

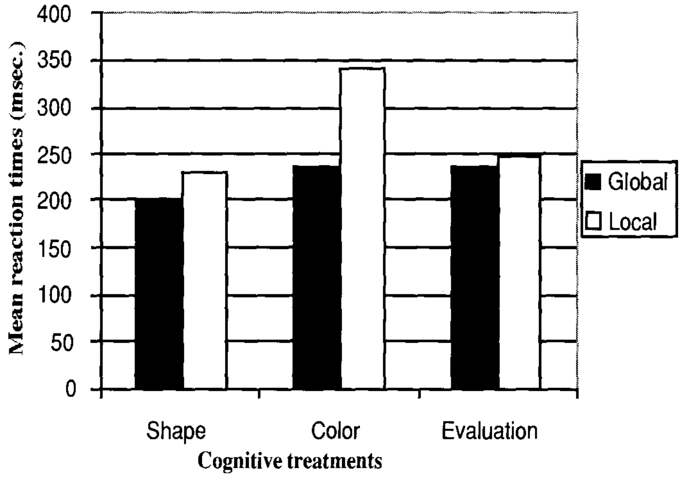

Figure 2: Mean reaction times according to the cognitive treatments performed by designers.

compels designers to make majoritary decisions about local or detailed features of the object to design in order to graphically represent it on the computer. A risk resulting of such an approach is that certain decisions may be made too early in the design problem-solving (e.g., when certain information elements are still lacking), which will make modifications more difficult (or even impossible) to perform.

Moreover, we observed an evolution of the local and global treatments, which reveals a change in the approach designers mainly adopt (see Bonnardel & Gaden, 2000). The important local treatments at the beginning of the problem-solving correspond to a focus on defining and graphically representing the object to be designed; whereas the increase of global treatments (and decrease of local treatments), which occurs later in the design activity, allows the designers to step back in order to more completely review their product.

The second result (about cognitive effort) shows that the treatment of local or detailed features of the object requires the most important attentional resources. It can be due to the nature of decision-making, which may involve conflictual local choices requiring moreover the manipulation of complex functions of the software.

Such data and complementary experiments (e.g., comparison between designing with and without a computational tool) could allow a better understanding of designers' difficulties, especially due to incompatibilities between the "natural" progressive refinement of their mental representation and the use of a computational tool.

Experiment 2: Cognitive Effort and Opportunistic Actions During Web Site Design

The World Wide Web (Web) enables not only specialists in new technologies but also individuals from all walks of life to design and "self-publish" their own sites. In fact, many web sites are designed and created by "lay-designers," i.e., people with little or no formal training in either web site design specifically or its attendant skills (e.g., database design, graphic design, user interface design). Since little is known about cognitive 'treatments of lay-designers, an experiment was conducted in order to characterize both opportunistic actions such designers perform and their cognitive effort (see Bonnardel et al., 2003).

In addition, we wished to determine whether it is better to provide lay-designers with a detailed schedule of conditions in order to guide (to a certain extent) their activities, or, on the contrary, with only information about the general purpose of the web site in order to let them free to design what they wish. Therefore, two experimental conditions were defined, one in which participants were provided with a well defined schedule of conditions (WSC) and another one in which they were provided with an ill' defined schedule of conditions (ISC).

Method

Participants

Ten lay-designers participated in this experimental study. All of them were in the same study program at the university (masters in cognitive psychology), and they just attended the same training course on web site design (with the same teacher and at the same time).

Experimental task

The participants were asked to design a small, three-page web site to present a painting gallery ("main task"), and they were provided with either the WSC or the ISC. They had one hour to create the site, using the Netscape Composer authoring tool'. This duration seemed sufficient given the limited size and complexity of the site. The design task was inspired by a real task observed during earlier interviews and observations conducted in a small web site design company.

In addition to this main task, the participants had to perform two additional tasks, in accordance with the procedure proposed by Levy and Ransdell (1994): thinking aloud (simultaneous verbalization), and reacting to auditory probes (presented within 40 to 70 second intervals, as it was the case in the previous study).

Procedure

Prior to the experimental task, participants were trained to perform independently the two additional tasks: thinking aloud while designing a boat using paper and pencil, and reacting as quickly as possible to auditory probes. Such motor reaction times allowed us to calculate each participant's baseline reaction time (RT).

Participants performed the training and experimental tasks individually. Half of the participants were provided with the ISC and the other half with the WSC. Participants' verbalizations were recorded on a tape-recorder and the Scriptkell computer program (Piolat et al., 1999) was used to both deliver auditory signals and record RTs.

Main Results

The analysis was conducted on different types of data, especially verbal protocols, in order to characterize opportunistic activities, and reaction times, in order to characterize lay-designers' cognitive efforts.

Different types of actions performed by lay-designers and reflecting opportunistic activities were analyzed, but we will focus only on reviewing and postponing of actions or decisions. Under the category "reviewing" we group both "giving up previous decisions" and "going back over previous actions":

- giving up previous decisions was identified by comparing the decisions the designers *planned* to perform (i.e., which were verbally expressed) and the actions they *effectively* performed;
- going back over an action was identified each time an action was performed in order to modify the effect of a previous action (e.g., one designer commenting on the page he had developed noted that "these colors are not great and I am going to change the title").

Postponing of actions or decisions appeared explicitly in the designers' comments (e.g., "I will put the finishing touches on it later").

The verbal protocols were separately analyzed by two judges and a large majority of agreement was obtained (in the rare cases where the analyses differed, consensus was reached after short discussions). Each reviewing and postponing of actions or decisions was counted and we calculated mean numbers as well as frequencies.

Reviewing and postponing of actions or decisions

The level of precision of the schedule of conditions appears to exert a significant effect on reviewing and postponing of actions or decisions. As shown in Figure 3, lay-designers provided with the ISC reviewed and postponed significantly more design decisions than designers with the WSC (respectively, in mean, 17.37 vs. 8.8).

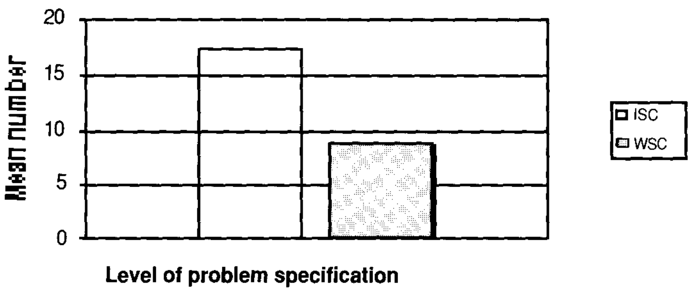

Figure 3: Mean number of reviewing and postponing of actions or decisions, according to the level of problem specification.

Concerning the *evolution of opportunistic actions* throughout the design process, the reviewing and postponing of actions or decisions appear to diverge according to the level of problem specification (see Figure 4):
- for lay-designers with the WSC, reviewing and postponing of decisions are relatively frequent in the first phase of their activity (.44), but these actions decrease considerably in the second phase (.27) and remain stable in the third phase (.29);
- for lay-designers with the ISC, reviewing and postponing of decisions appear relatively less frequently in the first phase of their activity (.25), but increase in the second phase (.36) and remain relatively frequent in the third phase (.38).

Cognitive effort

The level of precision of the schedule of conditions also exerts a significant effect on the designers' RT

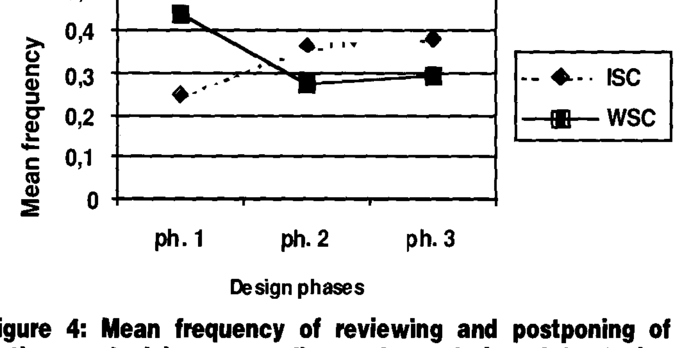

Figure 4: Mean frequency of reviewing and postponing of actions or decisions, according to the evolution of the design problem-solving (thirds) and to the level of problem specification.

interference scores. The designers provided with the WSC have higher RT interference scores than those provided with the ISC (respectively, 372 ms vs 186 ms). This indicates that the cognitive effort of lay-designers with the WSC is higher than the one of lay-designers with the ISC.

The analysis of *the evolution of lay-designers' RT interference scores* across the three design stages (or thirds) of problem-solving (see Figure 5) shows that:
- in accordance with the previous result, RT interference scores of lay-designers with the WSC remain, during all the design problem-solving, higher than the ones of lay-designers with the ISC;
- RT interference scores of lay-designers provided with the WSC decrease, whereas the ones of lay-designers provided with the ISC increase.

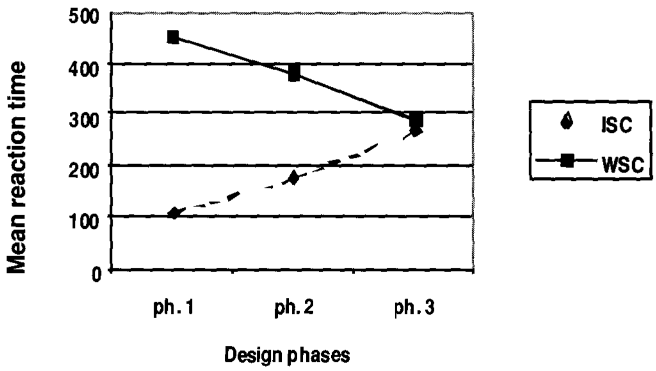

Figure 5: Mean RT interference scores of lay-designers, according to the evolution of the design problem-solving (thirds) and to the level of problem specification.

Discussion

The lay-designers who participated in this study appear to depend heavily on requirements specified in the schedule of conditions. Such a dependence can be observed at different levels.

Lay-designers provided with the ISC have more difficulties to plan their activity, as shown by their higher frequency of reviewing and postponing of decisions, than the designers provided with the WSC.

Lay-designers' cognitive effort is lower when they are provided with the ISC than with the WSC. This result is in accordance with the idea that opportunistic activities would alleviate designers' cognitive effort (see Visser, 1994), but it is also in accordance with the hypothesis that designers' cognitive effort is related to the amount of information they have to deal with. Since other observations showed difficulties encountered by lay-designers (see Bonnardel et al., 2003), the last hypothesis seems more plausible. Lay-designers' cognitive effort would be heavily dependent on the number of information elements they have to deal with: the more lay-designers deal with requirements and constraints, the more they mobilize attentional resources to treat them.

The evolution of cognitive effort throughout the design activity can be interpreted in the same perspective. As soon as they are provided with the WSC, lay-designers in this group can directly consider the requirements presented in the schedule of conditions (especially prescribed constraints), which would explain their relatively high cognitive effort in the first phase. Lay-designers with the ISC, being provided with only a few information elements have to deal with a very small number of data, which would explain their relatively low cognitive effort in the first phase. Then, becoming conscious of the need to define supplementary requirements, they would infer more and more new constraints, which would lead to an increase in their cognitive efforts in the second and third phases. Such inferred information elements would allow these designers to complete their mental representation (possibly relatively late in the design problem-solving) and to take into account similar aspects to those considered by lay-designers with the WSC. Indeed, though their processes appeared to differ during the design problem-solving, lay-designers' final productions were very similar (see Bonnardel et al., 2003).

Conclusion

After this small presentation of experiments and results, the benefits of the experimental procedures we described can be analyzed.

Due to the complexity and creativity inherent in design activities, designers intentionally make numerous treatments, which are demanding because not automatic for the main part of them. In order to better understand these different aspects of the cognitive functioning of designers, three types of data were analyzed in the studies we presented.

Most of the designers' cognitive treatments not being automatic, these treatments can be identified through directed retrospection or simultaneous verbalization. Therefore, the two procedures we presented appeared useful for identifying certain *cognitive treatments* involved in design activities (global vs. local treatments, reviewing and postponing of decisions in the studies we presented).

A way to analyze the role of working memory in the cognitive functioning of designers is to track down how attentional resources are allocated to different treatments. Both procedures allowed us to concretely measure reaction times and, on this basis, determine *cognitive effort* required by the considered treatments.

Moreover, it appeared possible to characterize *the evolution of the considered treatments* throughout the design problem-solving, which is crucial for understanding the dynamic of design activities and, on this basis, developing a reflection about efficient ways to support designers' activities.

The use of one or the other of the two procedures is dependent on both the objectives of the study and on pragmatic constraints of the real-life situations to be analyzed (e.g., the availability of professional designers, the possibility or not to *a priori* define the cognitive treatments which will be analyzed). On the experimenter's point of view, differences can be observed in the time and effort required to plan the experiments, run them, and analyze the gathered data.

Concerning the preparation of the experiment, Kellogg's procedure requires a preliminary analysis of the participants' tasks and activities, in order to determine relevant labels for the directed retrospection. In Levy & Ransdell's procedure, the participants are free to express their own thoughts without having to relate them to predefined categories.

Concerning the running of the experiments, the participants' training before being engaged in the experiment itself is more important in Kellogg's procedure than in Levy and Ransdell's one, since participants have to be used to the directed retrospection task, in order to perform it correctly.

Concerning the verbal data analysis, Kellogg's procedure allows the easiest and quickest analysis. This benefit is substantial since the duration of design activities is particularly important, the retranscription of verbalizations takes a lot of time, and numerous features of the participants' activities can be considered.

Whatever the experimental procedures, they appear efficient for identifying and analyzing crucial cognitive treatments, and measuring the attentional resources these treatments require and, on this basis, taking into account the role of working memory in design activities.

From a more general point of view, we can point out the fact that the two procedures we described are flexible: they can be specifically *adjusted* in order to meet various objectives. The nature and the extent of the cognitive treatments that are analyzed are chosen by the analyst (e.g., a cognitive ergonomist or researcher), through the choice of labels for the directed retrospection or the choice of categories for the verbal protocol analysis. In addition, the measure of reaction times occurs about each minute, which also allows various choices in the analysis of cognitive effort. In the two studies we presented in this paper, the evolution of cognitive effort and cognitive treatments was analyzed with regard to three temporal phases (or thirds), but other temporal phases could be defined according to the objectives of the studies. Thus, the focus of the analyses can be on punctual and brief treatments as well as on more long and complex treatments.

In our studies, the focus was specifically on cognitive effort and cognitive treatments. However, it sounds possible to conceive the use of such procedures in order to analyze emotional factors which may interact with cognitive treatments. For instance, such factors could be related to the participants' stress (e.g., induced by drastic time constraints for performing the work at hand) or tiredness (e.g., due to a particularly important duration of the work at hand). Towards this end, new factors could be introduced, either in laboratory or in natural conditions, and they would affect both time reactions and time processing.

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Footnotes:

' We can point out the fact that when the objective is to analyze real-life professional situations, the number of participants in such analyses is obviously limited.

A label "other" (which could be used to refer to any other thoughts) was also proposed to participants, but it appeared to be infrequently used, so it was not further analyzed.

For these participants, the overall design process is still ill defined especially because they still have to complete and refine their mental representation during design.

' The use of this authoring tool appears well-suited to lay-designers, since its graphical WYSIWYG (what-you-see-is-what-you-get) interface supports the rapid creation of basic web sites without requiring extensive knowledge of HTML.

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