MASTER

The influence of mental maps and cognitive load on decision making effectiveness

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Award date:
2014

Eindhoven, August 2014

The influence of mental maps and cognitive load on decision making effectiveness

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in partial fulfillment of the requirements for the degree of

Master of Science
in Human-Technology Interaction

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Keywords
Cognitive offloading – Cognitive overload –Information dashboard – Information overload – Mental map – Visualization

Abstract

There is a large amount of information available nowadays and that amount is still increasing. Too much information can lead to information overload, which together with cognitive overload can lead to a decrease in information processing effectiveness (i.e., decision quality). Prior research about visualizations has been inconclusive whether or not it is beneficiary to include mental maps. Even though no empirical studies have been performed, disadvantages of mental maps have been reported, namely incompleteness and inflexibility. Therefore, this research considered visualization techniques as a possible solution for these issues. We hypothesized that a more complete mental map would lead to an increase in information processing effectiveness and that additional cognitive load would decrease information processing effectiveness. Moreover, it was expected that an increase in mental map completeness would reduce the detrimental effects of cognitive load on information processing effectiveness. In order to test these hypotheses we conducted a 5 (mental map completeness increased stepwise) X 2 (low versus high cognitive load) mixed design lab study with 100 participants. Results did not provide support for our hypotheses, although post hoc contrasts partially supported our hypothesis that a more complete mental map results in increased decision quality compared to a less complete mental map. Contrary to expectations, participants scored higher on decision quality under high cognitive load, which indicates that our manipulation was not successful. Furthermore explorative analyses revealed that incorporation of a mental map in an information display results in cognitive offloading and faster decisions of higher quality. Future research is recommended to further develop cognitive load manipulations and to adjust the research design based on our findings.

Preface

These words are the last to be written. They feel like the last chapter of my student era. A time which has brought me numerous fun moments, great opportunities, nice people met and fantastic friends gained. If life continues like this, I'm sure it will be a hell of a time! Over the last few months I had a preview of what more there is to come: work. Graduating at KPMG gave me insights in how the coming years will be, what flavors are available in the market and which ones I like. Collaborating with KPMG enriched my graduation project with practical cases, a different point of view and persons to confess my love/hate (whichever was applicable at that moment) regarding my project to. After months of hard work, it feels justified to claim: "We pulled it off!".

The word 'we' used in last sentence indicates that I didn't do it all on my own. I am thankful for the contributions and coaching received from my KPMG supervisor Roger Haenen, as well as the sounding board sessions with Dennis van de Wiel. Furthermore numerous colleagues are to be thanked for the games of table football resulting in renewed energy. For the scientific component of my graduation Jaap Ham and Chris Snijders are to be thanked for their support. Jaap has been a great mentor for the past two years, helping me with decisions in my curriculum and advising me how to deal with (the bureaucracy of) the TU/e. Chris has been a great soundboard providing me with criticism with a constructive note, which enabled me to improve my research and sharpened my ideas.

Last but definitely not least I want to thank my parents and my girlfriend Sandra. My parents are thanked for guiding me in my choices, enabling me to study and be an inspiration in terms of never giving up and working on the factors you DO have influence on. Sandra is thanked for all the understanding of me being busy, feedback, much needed relaxation and above all: unconditional support.

Without the above mentioned people, I wouldn't have been where I am today.

Enjoy reading!

Hylke van Weperen

Eindhoven, August 2014

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1. Introduction

The amount of available information in the world is increasing (Schuman, 1991). Bawden, Holtham, and Courtney (1999) state for example that a single edition of the current ‘*New York Times*’ contains more information than the average person was likely to come across in a lifetime in the seventeenth-century. Furthermore, the English language of the late twentieth century contains about 50,000 words, which is five times more than in Shakespeare’s days. Moreover, the collections of the large US research libraries doubled between 1876 and 1990. This evidence indicates that individuals are currently exposed to an increased amount of information in their daily life, which can lead up to amounts which are too big to handle for an individual (Bawden et al., 1999).

Imagine the following situation: you, as a knowledge worker in the twenty-first century, wake up on an ordinary day from the alarm on your phone. While having breakfast, you check your stock rates, bank balance, the news and the current traffic jams and speed controls on your route. All this information is prompted by or requested on your mobile phone. In between you are interrupted by several push notifications directing you at new emails from colleagues who already started working. On top of that, your calendar application shows you some reminders of tasks that should be completed today. In your car on your way to work several phone calls are handled, while your navigation system is rerouting due to an accident. Finally you arrive at the office, ready to start your day of work.

As the illustration above demonstrates, individuals can be surrounded by electronic devices and services which deliver us information at any given place and time during the day. During a day individuals are faced with many decisions, which are frequently based on the information received through digital channels. The outcome and effectiveness of those decisions, depends on both (perceived) quality of the information received as well as our interpretation or processing of the information (Kahn, Strong, & Wang, 2002; Nicolaou & McKnight, 2006). However, more information not necessarily means that the information is more valuable (Endsley, 2012). And also the time needed to interpret the information is often limited and decisions have to be taken under time pressure (Lu, Zhang, & Niu, 2007).

Another problem with an abundance of information is that the amount of information an individual can successfully process or store in his or her memory is limited (Miller, 1956). Thus, the amount of received information can be overwhelming and thereby exceeding human information processing limits resulting in information overload (Lewis, 1996). Information overload can lead to decreased satisfaction with decisions, less confidence in the decisions made, more confusion, loss of job satisfaction, and stress, which all contribute to a decreased decision quality (Edmunds & Morris, 2000; Lee & Lee, 2004; Lewis, 1996). However, individuals have developed ways to deal with information in order to maximize processing capacity. Chase and Simon (1973) for example, describe a process in which individuals remember chunks of digits instead of individual digits in order to be able to memorize more digits (i.e., chunking).

To counter information overload, a variety of solutions on how to deal with the increased amount of information has been proposed. Firstly, there has been the suggestion of new technologies, which should result in automatic filtering, judging or selecting the relevant information out of the huge amount of available information (Belfourd & Furner, 1997; Maes, 1994). These new technologies can consist of computer systems, which take on the role of a personal assistant, able to learn from the user how to reduce the amount of available information into a selection of merely relevant information. Secondly, using visualizations as a mean to reduce the amount of information has been suggested as a solution (Lohse, 1997). By skillfully designing visualizations, the visualizations should be able to aid the user in interpreting or working with information. Thirdly, new social etiquette has been proposed as a solution for the increasing amount of information (Bawden et al., 1999). Simple rules such as 'only forward e-mails when the receiver really needs the information', together with clever use of email subjects and other email properties, are expected to decrease the amount of information to be processed by an individual.

In the present research, we investigated the influence of visualization as a mean to reduce information overload. I argue that this is an important and promising solution, because it aims at dealing with the current amount of information instead of reducing it. Moreover, visualization is a solution that fits with the amount of displays used in our everyday life at the time of writing. Furthermore, research has investigated a phenomenon called the 'pictorial superiority effect'. In short, this effect entails that the processing of images, in terms of memory and recognition, is proven superior compared to the processing of text (Childers & Houston, 1984; Madigan, 2014; Nelson, Reed, & McEvoy, 1977; Paivio & Csapo, 1973; Standing, 1973; Standing, Conezio, & Haber, 1970).

Additionally, earlier research suggested that in current-day society besides increased amounts of information, people might be hindered in their information processing because they are interrupted very often as well (Speier, Vessey, & Valacich, 2003). These interruptions can come from various sources, such as a mobile phones, colleagues entering workspaces for a chat and incoming e-mails (Speier et al.). A multitude of interruptions does not only increase the amount of information to be processed, but also the coordination of interruptions (Szóstek & Markopoulos, 2006). Furthermore, interruptions themselves can lead to cognitive overload or increase the experienced cognitive load (Adamczyk & Bailey, 2004). In this research we included this risk, since it is an inescapable aspect of the considered (business) environment (Krediet, Zijlstra, & Roe, 1994). Furthermore, we think that clever design of visualizations can assist an individual in dealing with experienced cognitive load, for example by means of cognitive offloading (Liu & Stasko, 2010). As both information and cognitive overload are risks for a knowledge worker in daily situations, we claim it is interesting to investigate if there is a solution which reduces both risks and enhances information processing effectiveness.

Earlier research has been inconclusive whether or not visualizations including a mental map have a negative or positive effect on the effective use of information. Whereas on the one hand mental maps should lead to “superior performance” (Norman & Hutchins Jr, 1988) and “applications without it will be severely limited” (Hollan, Hutchins, & Weitzman, 1984), on the other hand mental maps are claimed to be a poor basis for interface design (Nardi & Zarmer, 1991), incomplete (Kuo, 1998; Reisberg, 1987) and inflexible (Reisberg, 1987). The implications of the supposed shortcomings of mental maps on decision making effectiveness remain unclear and have not been tested empirically.

Therefore, the current research investigated the supposed shortcoming due to incompleteness and focuses on the relation between the incompleteness (level to which a mental map is structured) of a mental map (in a visualization) and its effects on decision making effectiveness. That is, we compared the quality of people's decisions when they are hindered in their information processing by a secondary task (high cognitive load condition) to when they are not hindered in their information processing (low cognitive load condition).

In general, numerous visualization techniques exist and can be used for different purposes or goals (Viegas, Wattenberg, Van Ham, Kriss, & McKeon, 2007). However, current research will focus on the following functions of visualizations: supporting mental maps, external anchoring, information foraging and cognitive offloading (Liu & Stasko, 2010; Lu et al., 2007). As stated before, cognitive load in the form of interruptions is included, since it is an inescapable aspect of the business environment and a factor which effects decision making effectiveness. This research aims at decreasing both experienced cognitive load and information overload by means of clever visualizations. Altogether this leads to the following research question:

"What are the effects of cognitive load and completeness of a mental map on decision making effectiveness?"

In-depth knowledge of the relation between completeness of a mental map and effective decision making will help us answer the question under which conditions it is beneficiary to use mental maps in information displays. Answering this question is relevant because it can be expected that the amount of available information will grow and aids to help users cope with that information growth will be desirable in the (near) future. Moreover, given the detrimental effects for decision quality of cognitive load as a result of interruptions in business environments, it seems relevant to investigate possible solutions which could help a user cope with the experienced cognitive load. By means of cognitive offloading, visualizations seem to be a plausible candidate in order to reduce the detrimental effects of this risk.

1.1 Subquestions

In order to answer the research question, we defined the following subquestions. First of all, the research question entails two factors which raise separate subquestions. That is, the effect of mental map completeness on decision making effectiveness and the effect of experienced cognitive load on decision making effectiveness. Prior research demonstrated that mental maps can be incomplete, meaning that objects or links are missing when the mental map is compared to reality (Kuo, 1998). Therefore, the current research will empirically investigate the effects of completeness on decision making effectiveness. Furthermore, earlier research (Gillie & Broadbent, 1989) demonstrated that interruptions can cause experienced cognitive load to increase in business environments. The current research investigated the effects of this additional cognitive load on decision making effectiveness.

Secondly and most importantly, the current research will investigate whether at higher levels of completeness of a mental map, adding cognitive load has less detrimental effects on decision making effectiveness. Therefore, our additional (sub-) questions are:

- What is the effect of the completeness of a mental map on decision making effectiveness?

- What is the effect of experienced cognitive load on decision making effectiveness?
- What is the effect of the completeness of a mental map and experienced cognitive load on decision making effectiveness?

By answering these questions, we will gain knowledge about under which conditions the use of mental maps in information displays can support decision making effectiveness. Furthermore, we will learn about the effects of external interruptions on decision making effectiveness and the potential of mental maps to mitigate this additional cognitive load and its effects.

2. Theory and background

The various concepts used in this research will be defined in this section. In addition, some background material will be covered for the following concepts: information overload, interruptions and experienced cognitive load, visualizations, information dashboards and mental maps. Finally, we will present a definition of decision making effectiveness.

2.1 Information overload

Information overload has been investigated in a range of scientific disciplines, varying from medicines, business studies to social, computer or information sciences (Edmunds & Morris, 2000). Each discipline used own definitions and terms to refer to the phenomenon of information overload (e.g., infoglut, information fatigue syndrome, data smog). For example, research of Hwang and Lin (1999) represented information load as an inverted U shape in which there is under load, an optimum and information overload, see figure 2.1. Not enough information results in suboptimal decisions as does too much information. In between there is an optimum in which the amount of information results in the highest value for decision quality (i.e., information processing).

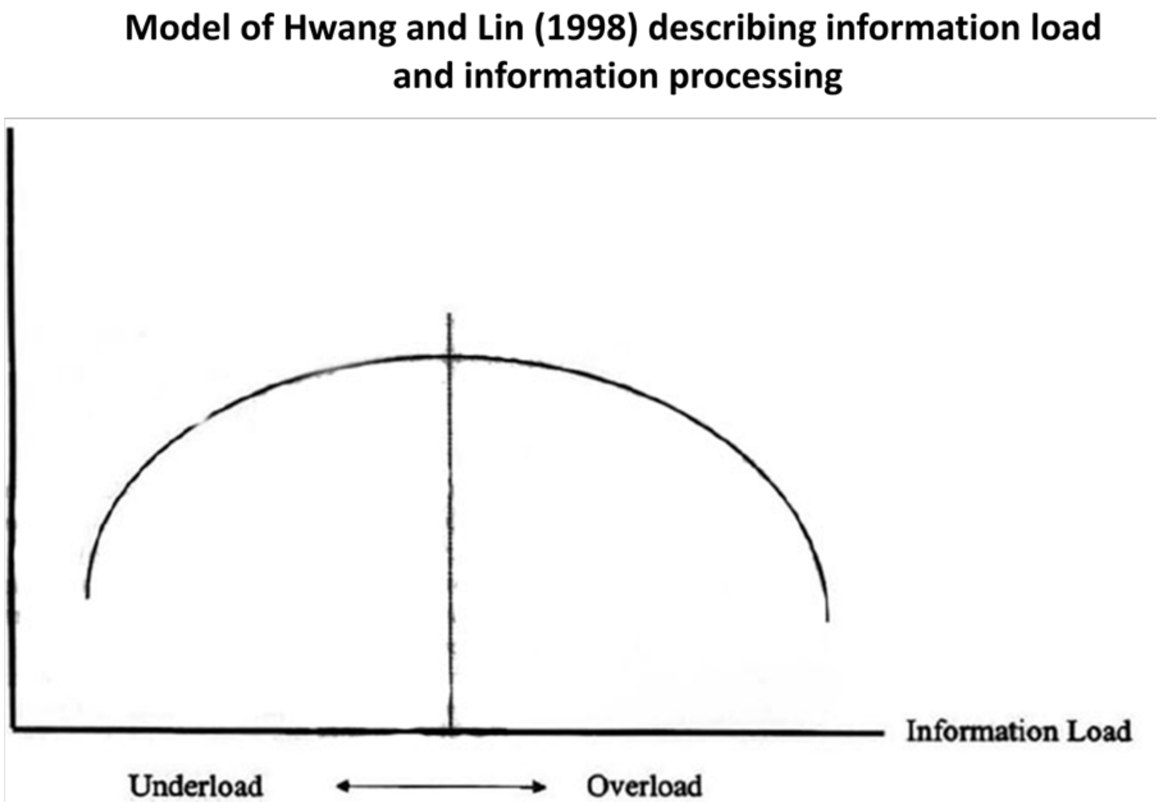

Figure 2.1: The relation between information load and information processing according to the model developed by Hwang and Lin (1999).

Others described the phenomenon as something occurring at the limits of human processing capacity in which additional information is acting like noise or hindering performance (Butcher, 1998; Feather, 2000; Klapp, 1986). This study will adhere to the definition of Klapp (1986), as the thought of additional information hampering performance is best aligned with the current research. Klapp (1986) describes information overload as: "A large amount and high rate of information act like noise when they reach overload: a rate too high for the receiver to process efficiently without distraction, stress, increasing errors and other costs making information poorer."

2.2 Interruptions and experienced cognitive load

The foundations of the construct of cognitive load were laid by the research of Miller (1956), who was interested in the limits of human's capacity to process information. Later in time, while investigating problem solving and learning, Sweller (1988) constructed Cognitive Load Theory (CLT). This theory basically stated that during problem solving, cognitive overload had detrimental effects on learning. Current research is still based on refined versions of Sweller's Cognitive Load Theory.

Different researchers have developed and used different scales for measuring experienced cognitive load. For example, Paas and Van Merriënboer (1993) introduced a scale using both standardized performance scores measurements of mental workload. More recently, Paas, Tuovinen, Tabbers, and Van Gerven (2003) suggested performing a secondary task as an alternative way to measure experienced cognitive load. The current research contained both these methods in order to have multiple measurements on the perceived cognitive load. In this research we used interruptions to manipulate cognitive load.

Interruptions can be a source of cognitive load, because, besides the content, it distracts from the task at hand and might cause detrimental after-effects (Gillie & Broadbent, 1989). Possible consequences of interruptions are a higher memory load and loss of information, which both can result in errors (Laxmisan et al., 2007). In practice, there is a wide variation of interruptions and corresponding definitions. This research will adhere to the definition of Coraggio (1990), as it is specified in the context of knowledge work and therefore very comparable to today's business environment. Interruptions are defined as: *"An interruption is an externally-generated, randomly occurring, discrete* *event that breaks continuity of cognitive focus on a primary task."* (Coraggio, 1990, p. 19).

In the current research, phone calls have been chosen to add cognitive load, as it is one of the most common interrupters on the work floor according to Krediet et al. (1994). Earlier research of Xia and Sudharshan (2002) has used phone calls as interruptions during tasks as well. It is possible to decrease the detrimental effects of interruptions, as demonstrated before by Cutrell, Czerwinski, and Horvitz (2001). By use of certain visual cues, they were able to limit the loss of information as a result of interruptions.

There exists an interplay between interruptions and information overload. That is, interruptions during complex decision tasks seems to lead to information overload, whereas this effect is smaller during simple decision tasks (Speier, Valacich, & Vessey, 1999; Xia & Sudharshan, 2002).

2.3 Visualization

Visualizations have been used by mankind for a long time. In earlier days individuals would use drawings to convey thoughts to another if language was not an option. Visualizations can serve many functions, and for example have been applied for instructional and teaching purposes (Baldwin & Kuljis, 2001). The following functionalities are defined by Liu and Stasko (2010) and Lu et al. (2007) and are (partly) applicable for this research: supporting mental maps or mental models, information foraging, cognitive offloading and external anchoring.

A nice example of external anchoring through visualizations can be found in the works of Speier et al. (2003), where they investigated the effects of interruptions on both spatial and symbolic representations. One of their findings concludes that graphical (e.g., symbolic) representations can help in order to mitigate detrimental effects of interruptions. Presumably this is the result of cognitive offloading and external anchoring. Due to using a visualization for certain tasks, the information normally stored in working memory can be presented in an external visualization and thus reducing the workload on the working memory. As the working memory is burdened less with information, cognitive load decreases and memory capacities can be used for other goals (Liu & Stasko, 2010). When experienced cognitive load increase above the processing capacity of the individual this will lead to detrimental effects on the task performance (Huang, Eades, & Hong, 2009).

2.4 Information dashboards

Information dashboards can be considered a specific type of visualization. These dashboards are mostly developed and used in business environments. Previous research has focused on creating decision support systems in general or for management specifically (e.g., executive support systems). These systems and corresponding research generally focuses on supporting the user in making decisions efficient and increasing the effectiveness of those decisions (Shim et al., 2002).

Especially at managerial level information is accumulated and present in enormous amounts, executive support systems can support individuals in dealing with all these input (Kuo, 1998). Besides technological artifacts which are suited for supporting decisions, Kuo (1998) also mentions the natural mechanisms such as mental maps which can be used to make more effective decisions.

In order to gather information about the number of items on information dashboards out of the practice, we reached out to KPMG. This company has been fabricating numerous dashboard for the past years and was willing to share this information. The stimuli used in the current research are partly based on their input and examples of information dashboards.

2.5 Mental maps

Coping with large amounts of information is part of life nowadays, with all kinds of different sources and corresponding information. One of the natural mechanisms to deal with information is the concept of a mental map. A mental map is basically a simplification of reality. It can contain all kinds of information, such as, abstract concepts and their underlying relations or a simplified spatial overview of a route from A to B. The latter can be seen as the foundation of the concept of a mental map used in science today, as first investigated by Lynch (1960). In daily life, mental maps have the following benefits: they reduce the information needed to process, it can be a solid foundation when reasoning or can be used to simplify complex situations or concepts (Kolkman, Kok, & Van der Veen, 2005).

Over time, mental maps have often been topic of research which resulted in many different definitions and discussion regarding those definitions (Doyle & Ford, 1998; Tversky, 1993). For example, in the context of learning, mental mapping (e.g., cognitive maps) have been studied previously (Sterman, 1994). Doyle and Ford (1998) have meta-reviewed literature covering mental maps in search of a general definition of the concept of a mental map. This research will adhere to the definition given in their work: *"A mental model of a dynamic system is a relatively enduring and accessible, but limited, internal conceptual representation of an external system whose* <u>*structure*</u> *maintains the* <u>*perceived structure*</u> *of that system"* (Doyle & Ford, 1998, p. 17). The current research will focus on the ‘structure’-aspect of their definitions in creating and manipulating stimuli. The reason for this being that this factor is within our control and easy to manipulate in the context of visualizations.

Eearlier research has not been able to determine whether or not it is benificial to include mental maps in information diplays (e.g., dashboards). Both arguments in favor or against the use of mental maps can be found in the literature. Research in favor of using mental maps in dashboards argue that clever ‘mapping’ of information promises ‘superior performance’ (Norman & Hutchins Jr, 1988). Or the other way around, the lack of mental models in dashboarding will lead to severely limited applications (Hollan et al., 1984). Others claimed that mental maps are incomplete (Kuo, 1998; Reisberg, 1987) and not flexible (Reisberg, 1987). Furthermore, according to Nardi and Zarmer (1991) mental models form a poor basis for interface design.

Despite these contracdicting claims, neither side has conducted empirical research or has created unrefuteable claims based on hard evidence. For example, in the research of Reisberg (1987) persons were asked to imagine animals or words and report specific details (e.g., How many stripes does the tiger have? Can you spell the word backwards?). Based on the failing of participants on these types of tasks, Reisberg reported that mental maps are not flexible and often incomplete. These outcomes might be the result of perceived pressure to answer questions and are not really comparable with tasks and abstract reasoning in the context of information dashboards. Therefore, this research claims that prior research does not fully answers the question whether or not to include mental maps in dashboards. Besides, the relation between the counterarguments of including mental maps (e.g., inflexibility and incompleteness) and performance has not been studied so far. Research on the influences of these factors on performance can generate knowledge about in which conditions or with which prerequisites, the use of mental maps can be benificiary.

2.6 Decision making effectiveness

As stated before by Shim et al. (2002) decisions should be effective. For decisions to be effective, they should be correct. In order to make correct decisions, it is desirable for the amount of information load and cognitive load to be within human capacities (Shim et al., 2002). As these variables are all present in the context of information dashboards, we have defined decision making effectiveness as the ability to make the optimal decision under influences of perceived information overload, and perceived cognitive load.

3. Hypotheses

Subquestion 1: What is the effect the completeness of a mental map on decision making effectiveness?

It is expected that participants who are presented with a complete mental map will perform best in terms of decision making effectiveness, and that participants with the least complete mental map will perform worst. The conditions in between will have intermediate results such that more completeness leads to more effective decision making. This is expected as a result of increased available mental capacity for decision making as a result of cognitive offloading (Liu & Stasko, 2010). More specific, the expectation is that participants with a complete mental map score highest on decision quality, experience the least information overload and the least cognitive load.This results in the following hypothesis:

H1: It is expected that an increase in the completeness of a mental map will result in an improvement in decision quality.

Subquestion 2: What is the effect of experienced cognitive load on decision making effectiveness?

Participants who are exposed to the additional installed cognitive load are expected to process information less effectively, because this way a decreased amount of mental capacity is available for decision making (as it is now occupied by the additional cognitive load). More specific, the expectation is that participants with a minimum of additional cognitive load score higher on decision quality, and perceive less cognitive load. This is expected as a result of previous research, indicating that cognitive overload has detrimental effects on decision making (Laxmisan et al., 2007; Xia & Sudharshan, 2002). This results in the following hypothesis:

H2: It is expected that an increase in experienced cognitive load will result in a decrease of decision quality.

Sub question 3: What is the effect of the completeness of a mental map and cognitive load on decision making effectiveness?

It is expected that presenting a display with a complete mental map to participants will decrease the detrimental effects of interruptions on decision making effectiveness. This is expected because inclusion of a mental map will increase mental capacity available for decision making as a result of cognitive offloading (Liu & Stasko, 2010). The more incomplete the mental map is, the lesser cognitive offloading will occur which will result in decreased decision making effectiveness compared to a complete mental map. On top of that, the expectation is that a complete mental map will reduce the recovery time after interruptions the most, as they offer more structure to the participants in order to resume their original task, resulting in more effective decision time (Cutrell et al., 2001). Participants facing less complete mental maps will therefore experience more detrimental effects from the additional cognitive load. This results in the following hypothesis:

H3: It is expected that increased completeness of a mental map will reduce the detrimental effects of cognitive load on decision quality. The third hypothesis is visualized in figure 3.1.

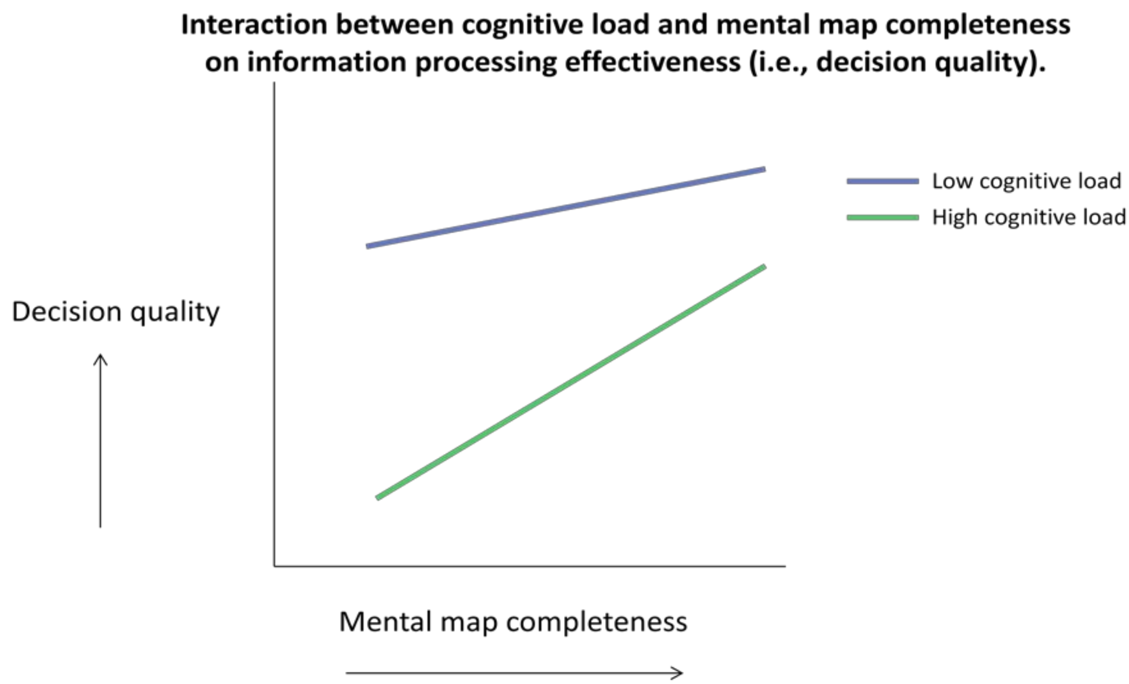

Figure 3.1: A graphical representation of the third hypothesis: increased completeness of a mental map will reduce the detrimental effects of cognitive load on decision quality.

Figure 3.2 shows a schematic overview of the hypotheses of the current research.

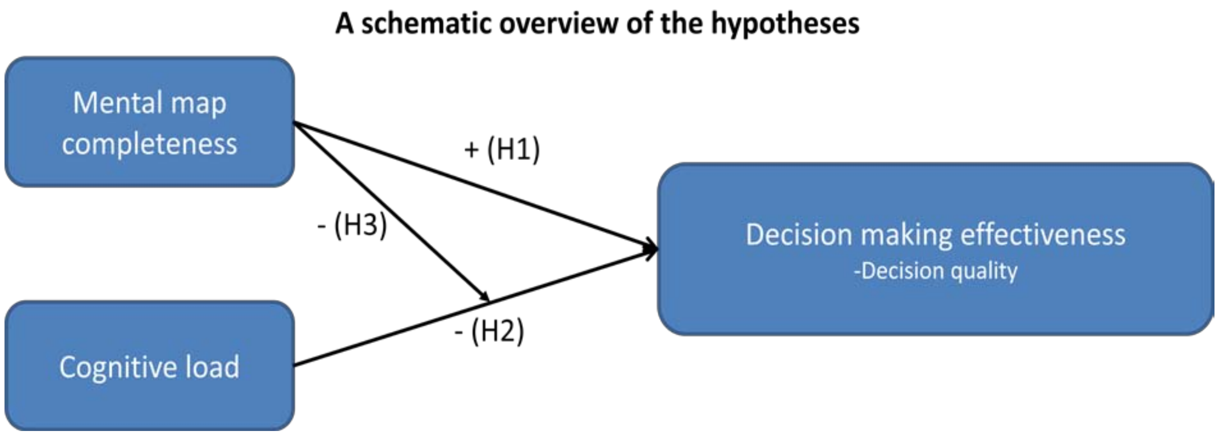

Figure 3.2.: schematic overview of the hypotheses: it is expected that a more complete mental map will increase decision making effectiveness, cognitive load will decrease decision making effectiveness and presence of a complete mental map will decrease the detrimental effects of cognitive load on decision making effectiveness.

4. Dashboard examples and pretest

4.1 Dashboard examples

In order to gain insight in the current status and use of information dashboards we searched for solutions on the market. We found KPMG willing to share their information dashboards with us. We examined the dashboards KPMG offers to clients, gathering information about the number of information items on a dashboard, the structure in which information was ordered, goals driving dashboard development and the use of dashboards at clients. The specific dashboards we examined are named ‘bucket-approach’-based dashboards. These dashboards are used to examine the efficiency of processes related to purchasing orders of a company. Based on these impressions we developed a set of stimuli, which we pretested to see if they were perceived as intended. While developing the stimuli, we focused on increasingly applying structure to the information presented.

4.2 Pretest

As we expected that an increase in structure of the data in the form of a mental map would aid the participants in decision tasks, we tested if difference in structure was present between conditions and corresponding stimuli. We developed the stimuli used in these different conditions as prior research has not investigated mental map completeness in combination with the decision quality as an outcome before. Stimuli consisted of sixteen processes of an imaginary company and differed in amount of structure among conditions. That is, as mental map completeness increased, we added more structure to the data and sorted the processes more logically on the screen. To verify that participants perceived the stimuli as more structured, we conducted a pretest. That is, six individuals were requested to sort our stimuli ranging from least structured (i.e., aiding) in processing the information to most structured (i.e., aiding) in processing the information. We ran Spearman's rank order correlation on the designed order increasing in structure and the orders participants sorted the stimuli in. Results showed a positive correlation between the designed order and the order the participants sorted the stimuli in, with an average of $r_s = 0.75$.

Besides testing the stimuli in terms of increasing structure, the amount of time people needed in order to make sixteen arithmetical computations was measured. Times varied between one and three minutes among five different individuals.

5. Method

5.1 Participants and design

Participants

A total of 100 individuals participated in this research, all in the age of eighteen to 61. The average age of all participants was 24.08 (*SD* = 7.02). The participants were individuals who responded to an inviting e-mail sent by the JFS participants database, requests to participate on social media or convenience sampling near the laboratory, located at the Technical University of Eindhoven (TU/e). The majority of the participants were college students. Among the participants were 63 males and 36 females and one participant of which gender was not recorded. Participants were rewarded with either a financial compensation (€5, - for TU/e students and €7, - for others) or college credits. The experiment lasted 30 minutes per participant.

Design

A mixed factor design was used in this experiment. The five between subject conditions differed in the completeness of a mental map within the information display. The conditions ranged from a mental map being absent (i.e., a meager Excel list which was not sorted logically) to a display in which the mental map was complete and all the data was structured logically. Appendix A shows examples of the visual stimuli used in each of the conditions. Furthermore, there were two within subject conditions, that is a condition with high additional cognitive load and a condition with low additional cognitive load. All participants experienced both a low cognitive and a high cognitive load condition. Counterbalancing was performed in order to eliminate sequence effects, meaning that half of the participants performed the high additional cognitive load trial first and the other half performed the low additional cognitive load trial first. Participants with limited hearing capabilities were excluded from participating, as they would not be able to perceive the additional cognitive load stimuli.

5.2 Apparatus and materials

Visual stimuli were presented on a personal computer which was placed on a desk in an office setting. Audible stimuli were presented by means of a personal computer in combination with headphones. For presenting stimuli and recording responses of participants, Macromedia Authorware 7.0 was used. The shown information consisted of either graphical, textual or audible stimuli. A survey (Appendix B) was constructed and presented on the personal computer. The survey contained five questions dealing with information overload, which was measured by its consequences and direct measurement as described by Lee and Lee (2004). Besides information overload, the questionnaire contained three questions, measuring cognitive overload in terms of mental effort and performance, as described by Paas (1992) and one question on task complexity (Ayres, 2006). At last there was a sheet of paper, depicting a calendar with several appointments in it (see Appendix C) and a pencil, which were both located on the desk next to the personal computer.

5.3 Procedure

Upon arrival at the laboratory waiting room participants were invited to enter the laboratory and read and sign an informed consent form. After the participants signed the consent form, they were escorted to a cubicle with a personal computer and received instructions. Participants were instructed to wear the headphones during the experiment and were asked to contact the experiment leader if something would be unclear during the experiment. They were told that they had the right to abort their participation in the experiment at any given moment without repercussions.

At the start of the experiment, participants received visual instructions of an imaginary (car or light bulb producing) company in which they had the role of Chief Executive Officer (CEO). They were told that the imaginary company consisted of four divisions (i.e., categories) and sixteen processes of which they were in control. After initial instruction on how to process the company's information participants received a practice trial to get familiar with the task. Subsequently, an example of an incoming phone call was played and instructions on how to process these stimuli in combination with the calendar were given. It was emphasized that the incoming phone calls had to be processed and could not be neglected.

After the instructions, participants were asked to complete five trials in which they had to select the optimal process for each category among the sixteen presented processes. In order to reach a selection, participants had to make arithmetical computations (Gillie & Broadbent, 1989). During the trial a clock in the lower left corner would indicate the remaining time for the current trial, out of the available time limit of 90 seconds. Between two trials, the text 'Next trial…' was displayed for three seconds in the center of the screen. Following the five trials and corresponding choices, participants were asked to complete a questionnaire. Upon completing the questionnaire, participants received another introduction story for a different company with different divisions and processes. Again, participants received a practice task followed by five trials in which they had to determine the optimal processes. Furthermore, we used the same questionnaire upon completion of the second set of trials to create a second set of measurements. The difference between the first and second set of earlier trials consisted of the amount of additional cognitive load applied.

All participants were presented with two blocks of trials, one being in the low additional cognitive load condition and one in the high additional cognitive load condition. In the case of low additional cognitive load, participants only had to process an incoming phone call in the third trial. In the high additional cognitive load condition participants had to process an incoming phone call in every trial. The incoming phone calls consisted of pre-recorded audio files with a male voice communicating instructions to the participant. The instructions given were all related to the calendar situated on the desk, (existing) appointments had to be altered, deleted or created. The phone calls started approximately fifteen seconds after the visual display with information became visible and lasted twenty seconds on average. Of those twenty seconds, around six seconds were used to let a phone ring twice and to convey a message in about eight to ten seconds.

The timestamp of starting at fifteen seconds into the trial was chosen because a participant is maximally disrupted when interrupted in the completing phase of a task (Adamczyk & Bailey, 2004; Monk, Boehm-Davis, & Trafton, 2002). We estimated that after fifteen seconds a participant would be at least mid-task (giving a bit less than maximal disruption) or near completing a (sub) task and, therefore, this would result in a maximal disruption. According to Monk et al. (2002), this way it would cost the participant the most mental effort to take up the original task after the interruption.

Depending on their condition, participants received the information in a display on which a mental map was absent ranging to a display showing a full mental map. We used the following five levels of mental map completeness and corresponding information displays: mental map absent, uncolored unsorted mental map, colored unsorted mental map, colored partly sorted mental map and complete mental map (for visual examples, see appendix A). In all conditions, the display presented the same information; name of the processes, value of the processes, percentage of possible improvement and name of the category to which the process belonged (fully written or indicated by a capital letter).

In the condition in which the mental map was not present, participants viewed a meagre excel list (sorted alphabetically on process name, which is not very convenient for the task). The uncolored unsorted mental map condition consisted of white blocks ordered semi-randomly which displayed the information described above. Processes of the same division could not be located next to each other. Additionally, this (and following) condition(s) contained a small image depicting the process. The third, condition, (i.e., the colored unsorted mental map), was identical to the previous condition except that blocks with processes in the same division were of the same color. The fourth condition (i.e., the colored partly sorted mental map), contained the same blocks, but the blocks were now partly sorted. That is, two blocks of the same color were listed next to each other at the left side of the screen. The other blocks were semi-randomly divided so that processes of the same division were not located next to each other. The last condition (i.e., the complete mental map), differed from the previous one by the ordering of the processes. All processes of the same division where now placed in the same corner in a logical structure, depicting the production line from start to end (e.g., purchasing of parts is followed by fabrication is followed by marketing is followed by sales).

In all the trials it was ensured that the product of the value of a process and its percentage of possible improvement resulted in a unique value for that category. That is, the outcome of the product for two different processes within the same category could not result in the same value. Besides unique answers, the trials were set up such that in every category an optimal value was present (the process with the highest product of value and possible improvement percentage).

When participants completed both trials and corresponding questionnaires, they were instructed to leave their cubicle and contact the experiment leader in order to receive their compensation or course credits. Participants received additional information about the experiment upon their request and were thanked for their participation.

Figure 5.1 shows a schematic overview of the procedure followed and the tasks performed in the experiment by the participant on the personal computer.

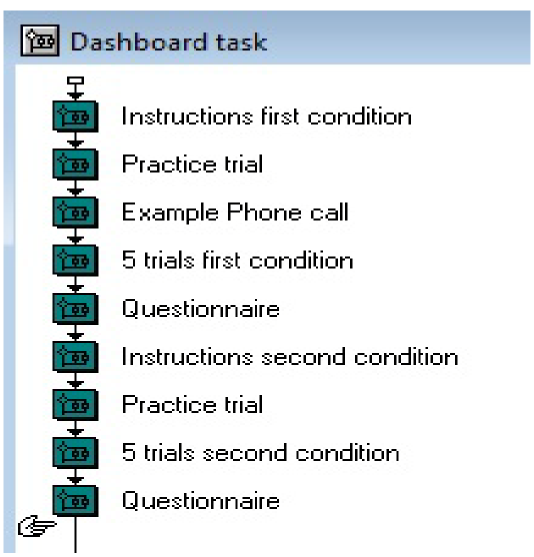

Figure 5.1: A schematic overview of the order of the experiment's elements performed by the participant on the personal computer.

Measures

To measure information overload we posed five questions to participants such as, "The amount of information to be processed is too much.". Two of these questions addressed the phenomena of information overload directly and three measured the consequences of information overload. Based on participants' answers to these five questions, we constructed two reliable measures for information overload per individual in both the low (α = .794) and high cognitive load condition (α = .768). To measure experienced cognitive load we posed four questions to participants. For example, "It is easy for me to process all the information and to handle the calls.". Based on their answers to these four questions, we constructed two reliable measures for experienced cognitive load for each individual in both the low cognitive load (α = .825) and high cognitive load condition (α = .874). The questionnaire was posed twice to the participants, to record experienced cognitive load and information overload after completion of each condition. All questions were rated on a seven-point Likert scale and can be found in Appendix B.

The options selected by the participants (one per category) were recorded as well, which resulted in four different values per trial. Since an optimal process (i.e., choice) was present in all the trials, we used this information to construct scales for participants' performance. Two scales were created, namely one binary scale consisting of the number of correct (i.e., optimal) choices, ranging from zero to four since there were four choices per trial. The second scale covered the non-optimal answers as well. The optimal answers were rewarded with four points, the second best answers with three points, etc. The total of participants' choices could therefore add up to sixteen points per trial on this scale.

When a participant failed to select a process within the set time restrictions, for one or more categories, zero points were awarded for the corresponding category in both scales.

We also recorded the time taken by participants in order to come to their four choices per trial. When participants had selected one process per category a button stating ‘Continue’ became clickable allowing the participant to proceed to the next trial or questionnaire. This way it was possible to record when participants needed less time that the time limit set on each trial (90 seconds). When the time limit was reached, the program would automatically proceed to the next trial or questionnaire. We created one variable per trial, containing the time the participant took to come to an answer. Values of this variable ranged from zero to 90 seconds.

Participants had to modify the calendar situated on their des according to the instructions received by means of incoming phone calls. Their performance on this secondary task was also registered as a measure of cognitive load. By means of their notes on the calendar we were able to construct a binary measurement of the amount of interruptions correctly processed. In total participants received one and five interruptions in the low and high additional load condition respectively. A processed interruption in the form of a new note on the calendar received a score of one if (at least) the subject was noted and was placed at the correct day and time. For changes to existing appointments, a score of one was achieved when an appointment was crossed out (in case of deletion) or a note stating the same message was made. Rescheduling of existing appointments could either be done by means of an arrow or crossing out and rewriting, both ways resulted in a score of one. In total this could lead to scores ranging from zero to five for the high additional cognitive load condition and a zero or a one for the low additional cognitive load condition.

6. Results

6.1 Outliers

Before conducting the analyses, we checked our data for outlying values and irregularities. All data of one participant as well as the data of one trial of another participant were incomplete because of malfunctioning of Authorware in recording their responses. Another two participants did not make any notes on the calendar, resulting in suspicion on whether or not they heard the distracting stimuli (i.e., incoming phone calls). If the distracting phone calls were not processed, our manipulation of additional cognitive load failed for those two persons. Since we were not sure whether or not the stimuli had not been processed or had been processed with an incorrect result, we conducted our analysis with and without these two participants' data. As no differences were found, we did not exclude these data points from our data set. At last there were ten outlying values on the decision quality scores, detected by means of Tukey's method for outlier detection (Hoaglin, Iglewicz, & Tukey, 1986). Based on Hoaglin et al. (1986), we determined the threshold for outliers to be three times the interquartile range (i.e., difference between the maxima of the first and third quartile). Furthermore, we used the method of Cook (1977) to check if there were single observations which had a disproportionate influence on the regression coefficients. This resulted in two observations which were considered outliers, which were already detected using Tukey's method. Examination of centered leverage values and DfBeta values did not reveal other observations with unacceptable deviations from predicted values and too influential observations respectively. We ran the analysis with and without these outliers and checked for differences in outcomes. As no differences were found, we did not exclude data points from our data set.

6.2 Manipulation check

Besides controlling for outliers, a manipulation check was performed on the effectiveness of our cognitive load manipulation. We had two measurements, namely a direct measurement by means of items in the questionnaire measuring cognitive load and the secondary task, which needed to be conducted in the experiment parallel to the main task. We checked if there were significant differences on experienced cognitive load between the high and low additional cognitive load conditions by means of paired sample t-tests. For the questionnaire, the difference between the low additional cognitive load ($M = 3.85$, $SD = 1.32$) and the high additional cognitive load ($M = 3.99$, $SD = 1.43$) was not significant; $t(98) = -1.47$, $p = .146$. For the secondary task, the difference between the low additional cognitive load ($M = 0.840$, $SD = 0.368$) and the high additional cognitive load ($M = 0.802$, $SD = 0.212$) was not significant either; $t(99) = 1.16$, $p = .249$. These results indicated that the difference in experienced cognitive load was in the right direction, that is participants experienced a higher cognitive load and performed worse on the secondary task in the high cognitive load condition, but that these differences were small and not statistically significant. Because the correlations between the measurements of cognitive load created by the questionnaire and the secondary task were weak, that is $r = .272$, $N = 99$, $p = .006$ for the low additional cognitive load and $r = .355$, $N = 99$, $p < .0005$ for the high additional cognitive load, we did not integrate both measurements in a factor but used them separately in our analyses.

6.3 Description of the data

In general, time needed by participants to come to a decision seemed to depend on the amount of structure present (by means of a mental map) in the displays. As figure 6.1 demonstrates, in the two conditions with the least structure participants needed more time (in seconds) to come to a decision compared to the three conditions with more structure. Furthermore figure 6.1 demonstrates that across all conditions, participants completed the second condition faster (M = 61.60, SD = 18.46) than they completed the first condition they were presented (M = 66.33, SD = 18.92).

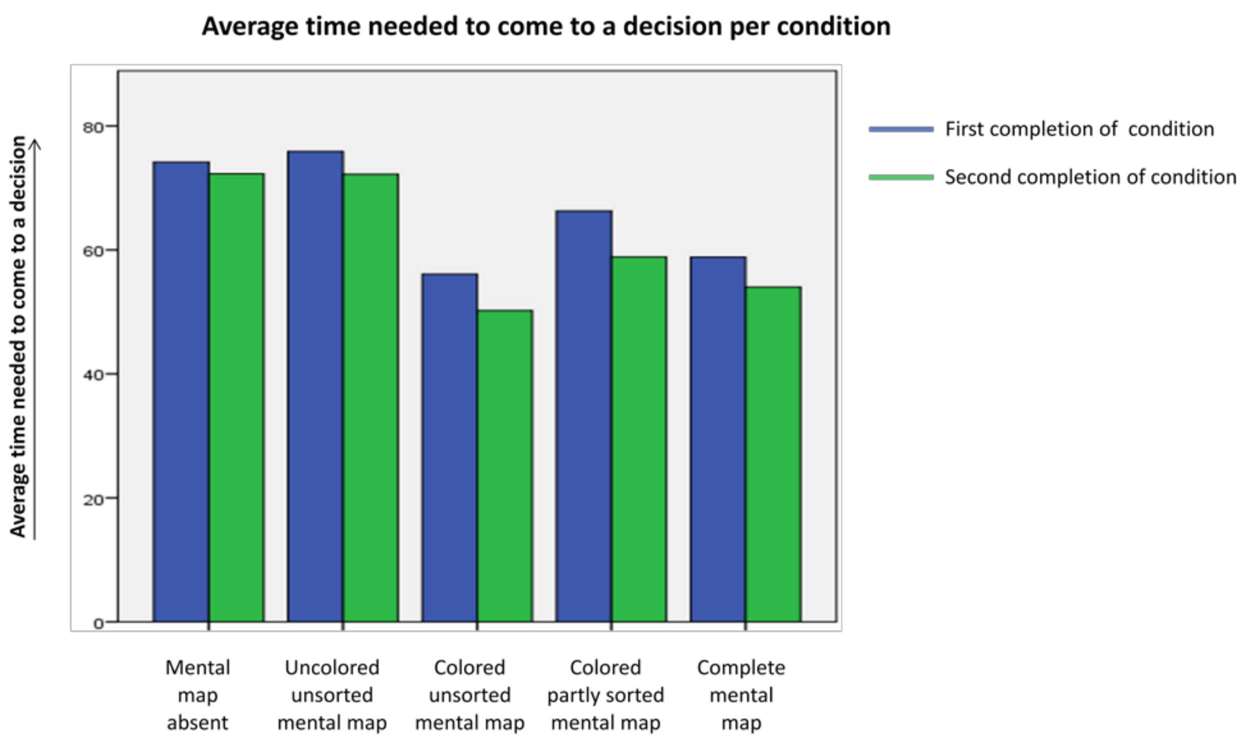

Figure 6.1: Average time needed to come to a decision per condition, displayed by first or second completion of the condition. Overall, the second completion led to a shorter time needed to come to a decision.

As indicated by tests of Kolmogorov-Smirnov (D(989) = .305, p < .0005, corrected by Lilliefors (1969)) and Shapiro-Wilk: (D(989) = .663, p < .0005 (Shapiro & Wilk, 1965)), decision quality was not normally distributed. Figure 6.2 contains the frequencies of decision quality scores per trial (the minimum is zero and the maximum is sixteen) over all the trials and participants. With a mean decision quality score of 14.41 (*SD* = 2.824), this distribution is not normal, but skewed towards the left. Furthermore, the residuals of predicted values appeared to be negatively increasing in a linear way related to decision quality, indicating that the assumption of homoscedasticity had been breached. As a result of these violations, which could not be solved using data transformations, we used a regression model with robust standard errors in order to test our hypotheses. Furthermore, 55 percent of the variance in our measurements of decision quality is explained at participant level.

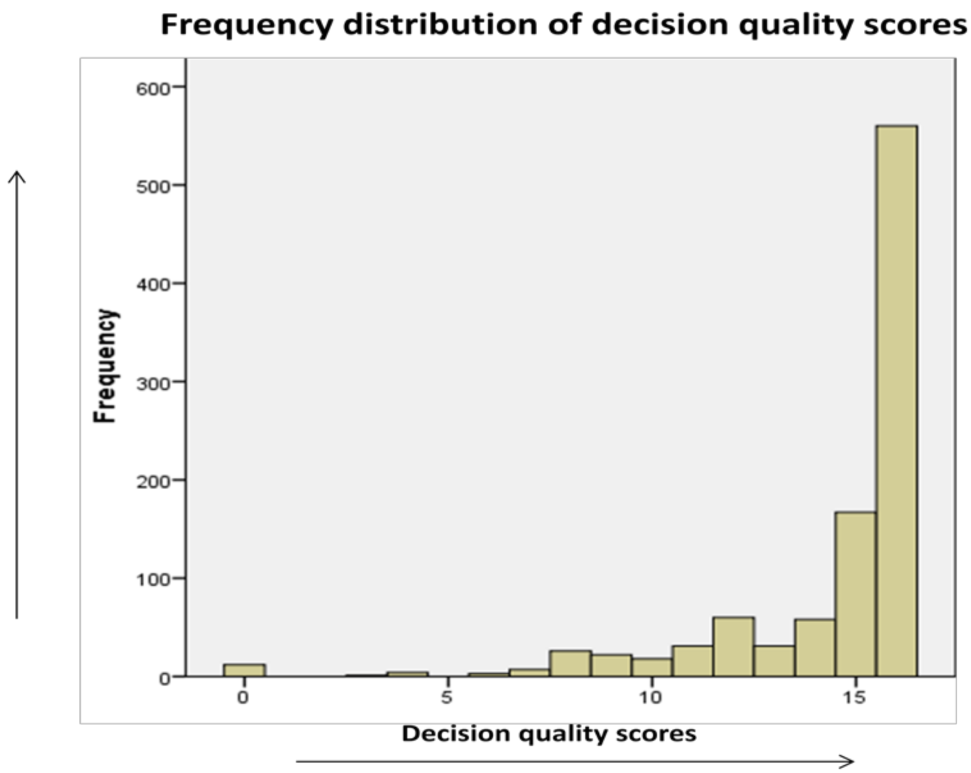

Figure 6.2: Distribution of decision quality, in terms of frequencies, over all 989 trials and 99 participants used in the analyses.

6.4 Covariates

In our experiment, consisting of 5 (mental map completeness, stepwise increasing) X 2 (low vs. high cognitive load), we controlled for several factors. Firstly, we controlled for the order in which participants received the low and high cognitive load trials. The order in which participant completed both conditions did not have a significant effect on decision quality (*Wald* χ^2 = 2.066, p = .151). However, when we controlled for the presence of a learning effect between the first and second condition we found a significant difference, (*Wald* χ^2 = 5.285, p = .022). That is, participants scored higher in the second condition they completed (*M* = 14.66, *SD* = 2.54) compared to the first condition they completed (*M* = 14.16, *SD* = 3.07). As demonstrated by figure 6.3, this effect held for all conditions of mental map completeness, although these differences were smaller for more complete mental maps.

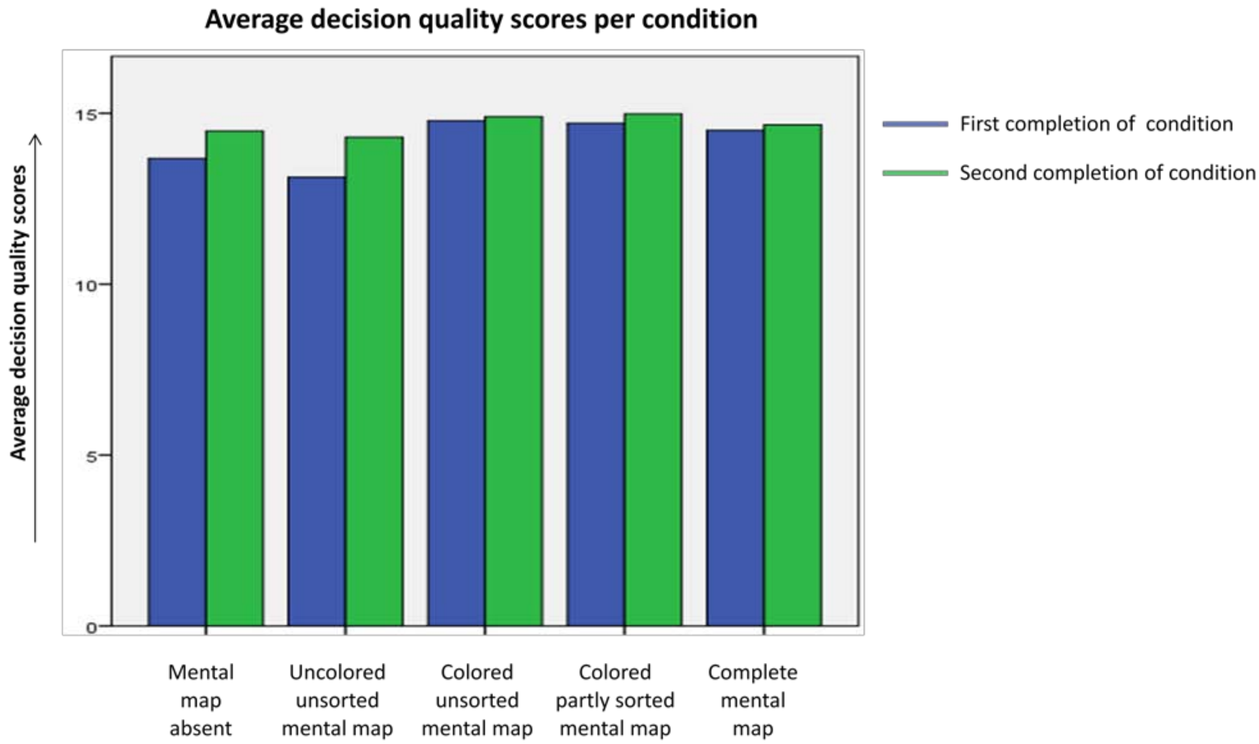

Figure 6.3: Average decision quality scores per conditions, displayed by first or second completion of the condition. Overall, the second completion led to a higher decision quality score.

Secondly, as literature suggested that decision quality would decrease with age, we controlled for age in our research. For example, decision quality of elderly is said to decrease as a result of using simpler strategies to reduce cognitive effort (Mata & Nunes, 2010). Paas, Camp, and Rikers (2001) also mentioned age interacting with cognitive load, resulting in decreased performance for older adults. The age of participants had a significant effect on decision quality (*Wald* $\chi^2 = 49.016$, $p < .0005$), when participants were older they showed a decrease in decision quality scores.

Thirdly, we controlled for the time taken by participants in order to reach their decision. We expected that this would influence results as time pressure is known to have an effect on decision quality, and increases chances of information overload (Hahn, Lawson, & Lee, 1992). As participants neared the set time limit, time pressure could occur influencing decision quality and information overload. The time taken by participants to reach their decisions had a significant effect on decision quality (*Wald* χ^2 = 44.716, p = .030). More specifically, when participants took more time to reach a decision, it resulted in a decrease in decision quality compared to those who took less time to make their decision.

At last, we controlled for information overload as it can lead to decreased satisfaction with decisions, less confidence in the decisions made, more confusion, loss of job satisfaction, and stress, which all contribute to a decreased decision quality (Edmunds & Morris, 2000; Lee & Lee, 2004; Lewis, 1996). The perceived information overload had a significant effect on decision quality (*Wald* χ^2 = 30.985, $p < .0005$), showing that an increase in the perceived information overload resulted in a decrease in decision quality.

6.5 Hypothesis testing

In partial support for our first hypothesis (indicating that increasing mental map completeness leads to an increase in decision quality), results of the regression showed that decision quality scores significantly differed as a result of different levels of mental map completeness, (*Wald* χ^2 = 22.623, $p < .0005$). Table 6.1 displays the means and standard deviations for all levels of mental map completeness.

Level of mental map completeness (ascending in structure)	**Mean**	**Standard deviation**
Mental map absent	14.15	2.881
Uncolored unsorted mental map	13.72	2.737
Colored unsorted mental map	14.84	2.063
Colored partly sorted mental map	14.85	2.069
Complete mental map	15.43	1.181

Table 6.1: Means and standard deviation for decision quality scores per level of mental map completeness (ascending in structure).

Bonferroni corrected post hoc comparisons did not reveal a significant difference between the first (mental map absent) and second level (uncolored unsorted mental map) of mental map completeness (*Wald* χ^2 = .000, p = 1.000). However, the difference between the second and third level (colored unsorted mental map) of mental map completeness was significant (*Wald* χ^2 = 9.830, p = .007). That is, the third level had significant higher scores than the second level of mental map completeness. The difference between the third and fourth (colored partly sorted mental map) level of mental map completeness was not significant (*Wald* χ^2 = 5.362, p = .082). At last, the difference between the fourth and fifth level of mental map completeness was significant (*Wald* χ^2 = 17.273, $p < .0005$). That is, the fifth level had significant higher scores than the fourth level of mental map completeness. The average estimated performance scores per trial, including confidence intervals of 95 percent are shown in figure 6.4 for the different levels of mental map completeness. These results demonstrate that decision quality is not increasing along with the stepwise increase in mental map completeness in our experiment.

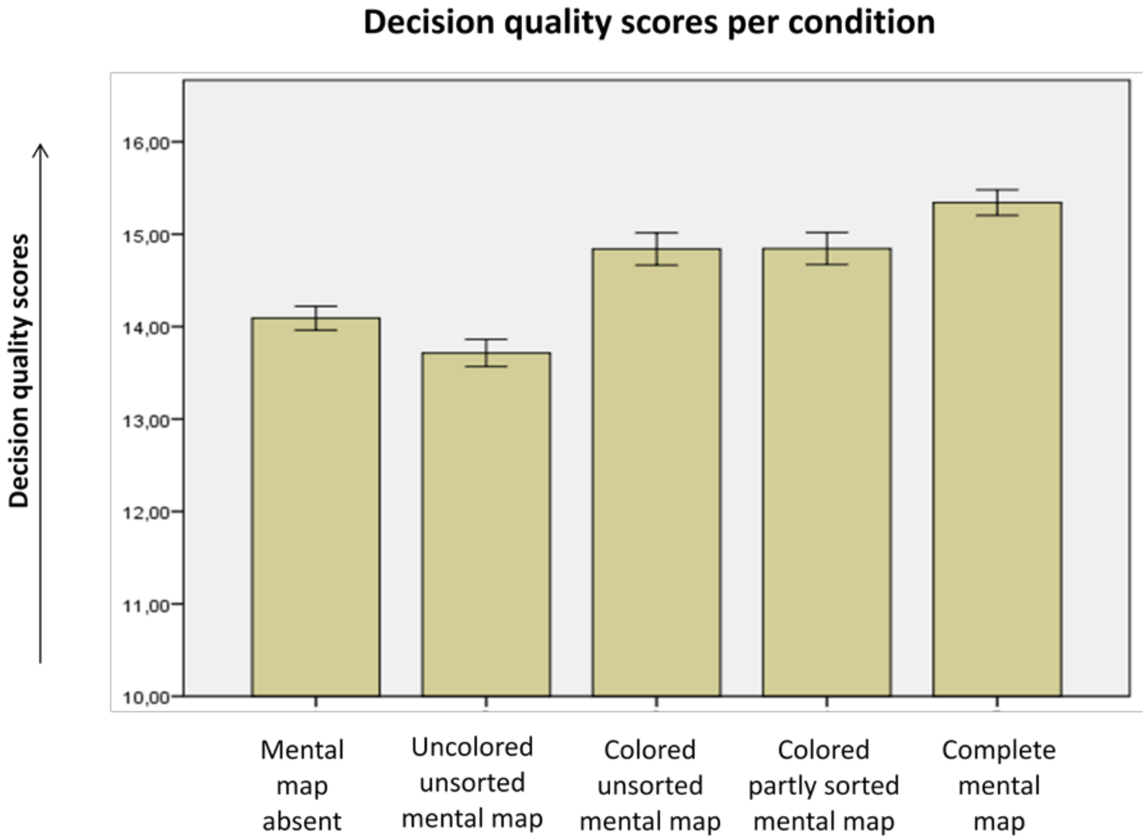

Figure 6.4: Average estimated scores for the different levels of mental map completeness, ascending in amount of structure. Confidence interval of 95% is included by means of bars.

Results of our analysis did not provide support for our second hypothesis (stating that an increase in experienced cognitive load would lead to a decrease in decision quality), but showed an effect in the opposite direction, *Wald* χ^2 = 24.913, p < .0005. Participants who received high additional cognitive load by means of interruptions scored higher on decision quality (M = 14.68, SD = 2.299) compared to participants who received low additional cognitive load (M = 14.50, SD = 2.397). Furthermore, our cognitive load factor constructed from the questionnaire did not have a significant effect on decision quality (*Wald* χ^2 = .865, p = .352). The secondary task used for measuring cognitive load did not have a significant effect either, *Wald* χ^2 = 3.543, p = .060.

Results did not provide support for our third hypothesis, which claimed that an increase in mental map completeness would reduce the detrimental effects of cognitive load on decision quality. Despite the fact that our analysis showed that decision quality significantly differed as a result of the product of mental map completeness and experienced cognitive load, *Wald* $\chi^2 = 63.200$, $p < .0005$, the direction of the effect found was not as expected. As figure 6.5 demonstrates, participants who received high additional cognitive load scored lower on decision quality without mental map, scored higher on decision quality in the first two levels of mental map completeness and on the two levels with the most complete mental maps the results are comparable to participants who received low additional cognitive load.

Figure 6.5: Participants who received high additional cognitive load scored lower on decision quality without mental map, scored higher on decision quality in the first two levels of mental map completeness and on the two levels with the most complete mental maps the results are comparable to participants who received low additional cognitive load.

A schematic overview of the results answering our hypotheses is shown in figure 6.6. It shows that hypothesis one, a positive influence of mental map completeness on decision making effectiveness, is partially supported. For hypothesis two, a negative effect of cognitive load on decision making effectiveness, an effect is found but in the opposite direction. Hypothesis three, mental map completeness reduces detrimental effects of cognitive load on decision making effectiveness, is not supported.

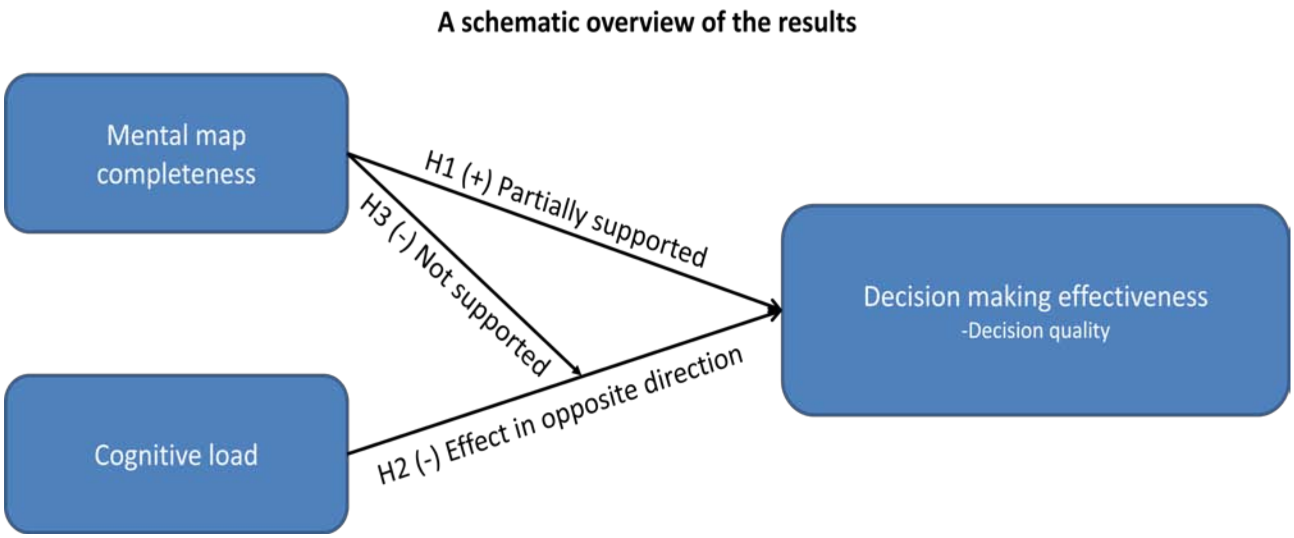

Figure 6.6: A schematic overview of the answers to our hypotheses. Hypothesis one, a positive influence of mental map completeness on decision making effectiveness, is partially supported. For hypothesis two, a negative effect of cognitive load on decision making effectiveness, an effect is found but in the opposite direction. Hypothesis three, mental map completeness reduces detrimental effects of cognitive load on decision making effectiveness, is not supported.

6.6 Explorative analyses

Exploratory analyses revealed a number of interesting and significant effects. For example, when we clustered the levels of mental map completeness and compared these clusters, we did find significant differences. We compared the first two levels of mental map completeness with the three levels of most mental map completeness, since we expected the contrast between those clusters to be the biggest. We found a significant difference between the clusters on decision quality, *Wald* $\chi^2 = 16.038$, $p < .0005$. Participants who had received information displays from the three categories with a more complete mental map scored higher on decision quality ($M = 15.03$, $SD = 1.846$) compared with the two categories with a less complete mental map ($M = 13.93$, $SD = 2.815$), indicating that increasing mental map completeness results in an increase in decision quality.

To verify if the hypothesized cognitive offloading takes place, we performed another explorative analysis. We checked if the perceived cognitive load differed over the levels of mental map completeness, for all measurements used: direct measurements by means of the questionnaire (both the mean of the score on a seven-point Likert scale and the corresponding factor extracted) and the secondary task which had to be performed parallel to the main task. Table 6.2 shows the means of these measurements over the different levels of mental map completeness ascending in structure present in the displays.

Level of mental map completeness (ascending in structure)	**Mean cognitive load factor score (*SD*)**	**Mean score questionnaire items on cognitive load (*SD*)**	**Mean score on secondary task (*SD*)**
Mental map absent	.219 (.918)	4.21 (1.26)	.785 (.334)
Uncolored unsorted mental map	.370 (1.09)	4.43 (1.51)	.780 (.332)
Colored unsorted mental map	-.052 (1.01)	3.85 (1.38)	.845 (.275)
Colored partly sorted mental map	-.105 (.847)	3.78 (1.16)	.840 (.273)
Complete mental map	-.460 (.919)	3.30 (1.25)	.847 (.278)

Table 6.2: Means scores (and standard deviations) of different cognitive load measurements: direct measurements in the questionnaire, the factor extracted from these questions and the secondary task.

A similar pattern is to be found in both methods used to measure cognitive load. In the first two levels of mental map completeness participants experience the highest cognitive load (higher scores on the questionnaire and lower scores on the secondary task) compared to the three levels with the most mental map completeness; $F(1,989) = 61.1$, $p < .0005$.

We used these clusters in order to increase our confidence in the fact that an interaction effect, caused by mental map completeness and cognitive load, on decision quality was not present. We used this grouping as the differences in effects of both cognitive load and mental map completeness on decision quality seemed to be best distinguished between these two clusters. In line with the outcome of the previous test of our third hypothesis, on the interaction effect of cognitive load and mental map completeness, we did not find a significant interaction effect, *Wald* $\chi^2 = 0.444$, $p = .505$.

A dummy variable which represented whether or not a participant was interrupted during a trial had a significant effect on decision quality, *Wald* $\chi^2 = 25.883$, $p < .0005$.

Thus, when a participant was interrupted this resulted in a lower score on decision quality (M = 14.41, SD = 2.523) compared to when a participant was not interrupted (M = 14.85, SD = 2.035).

Furthermore, when we ran the created model with the factor for information overload excluded, our factor for cognitive load is highly significant, *Wald* χ^2 = 18.264, p < .0005. Upon inclusion of the constructed information overload factor, cognitive load becomes insignificant, *Wald* χ^2 = 0.319, p = .572. That is, when a participant perceived more cognitive load this results in a decrease of decision quality. Although the factors for cognitive load and information overload are correlated, r = .686, p < .0005, these results indicate that an interplay or a large proportion of common variance between cognitive load and information overload might be present in our data.

7. Discussion

In the context of a world in which we are overloaded with information and cognitive stimuli, this research investigated a possible solution for these issues, namely the use of mental maps. By means of cognitive offloading, mental maps should help users cope with today's amounts of information and stimuli. Prior research revealed disadvantages, such as incompleteness and inflexibility of mental maps, when used in information displays. However, none of these disadvantages have been proven empirically and the exact relation of completeness on decision making effectiveness has not been investigated yet. Therefore, this research focused on determining under which conditions, in terms of completeness of a mental map and under cognitive load, it is profitable to use a mental map in an information display.

Our results provided evidence to partially support our first hypothesis, stating that an increase in completeness of a mental map would result in an increase in decision making effectiveness. Differences between levels of increasing completeness of the mental map were not significant. However, a contrast between the two groups with the least complete mental maps and the three groups with the most complete mental map revealed a significant difference, suggesting that an increase in completeness of the mental map leads to an increase in decision making effectiveness.

Furthermore, current results provided no evidence to support our second hypothesis that an increase in experienced cognitive load would result in a decrease in decision making effectiveness. On the contrary, when participants received high additional cognitive load they scored higher on decision making effectiveness. These findings might be explained by means of the social facilitation effect (Zajonc, 1965), stating that performance on simple tasks increases when in presence of others. Thus, the incoming phone calls could have led to a feeling of presence of others, resulting in better performance, and thus, in an increased decision quality in the high cognitive load condition. Finally, current results provided no evidence to support our third hypothesis that an increase in mental map completeness leads to a decrease of the detrimental effects of experienced cognitive load on decision making effectiveness.

In general we concluded that the main task which had to be performed by the participants was too easy. As task performance was very good in general, there was not much variation in the measurements. As a consequence, an easy task might result in a low perceived cognitive load for participants who are processing the task and corresponding information. Future research should pretest the perceived cognitive load (as well as the information load) more extensively to ensure that the task at hand is more similar to the environment as described in the introduction (i.e., a world full of information and distracting stimuli in which individuals face complex decisions or situations).

Additionally, we ran an analysis which checked the impact of our manipulation of cognitive load over the conditions. Results revealed that the difference in experienced cognitive load (based on self-reported observations of participants, and their performance on a secondary task) between the high and the low cognitive load condition was insignificant. This finding suggests that our manipulation was not successful. However, as figure 7.1 shows, we found a significant decrease in decision effectiveness in the low cognitive load condition on trial three. Trial three was the only trial in which participants received a distracting phone call (compared to all trials in the high cognitive load condition), which demonstrates that our stimulus was distracting and hampering decision effectiveness.

Figure 7.1: The average scores per trial under both high and low cognitive load. In the low cognitive load condition participants received a distracting phone call in trial three, in the high cognitive load there was a distracting phone call in each trial.

Further development of the interrupting stimuli, including more extensive pretesting of their intrusive power (and accompanying extra cognitive load) is recommended for future research. For example, an alternative interruption in the form of a confederate entering the environment of the participant to pose a question might be more intrusive for the participant than a phone call and thus might induce more cognitive load.

Furthermore, a dummy variable indicating that a participant was interrupted in a trial had a significant effect on decision quality, indicating that an interruption led to a decrease in decision quality. Another dummy variable indicating to which cognitive load condition a trial belonged was highly correlated with the previous dummy variable (as five out of six interruptions are located in the high additional cognitive load condition).

This variable had a significant effect in the opposite direction, that means increased decision quality for the high additional cognitive load, and thus largely ‘compensated’ the negative effect of the interruption for the trials in the high additional cognitive load condition. It might be possible that participants in the high cognitive load condition got used to the workload or the distracting stimuli and therefore did not experience negative influences on their decision effectiveness (Banbury & Berry, 1997). Another explanation might be found in the model on information overload of Hwang and Lin (1999). The constructed factors for cognitive load and information overload were highly correlated in our experiment, and our analysis suggested that they explained a large proportion of common variance.

The model of Hwang and Lin (1999) described three states in relation to decision quality: information underload, an optimum and overload. The information load applied to the individual determines the state an individual is in. When our low cognitive load condition resulted in a person being underloaded in terms of information, an increase in information by means of interrupting phone calls in the high cognitive load condition might increase performance as this brings the individual closer to his or her information load optimum. In short, further investigation on how to manipulate cognitive load successfully in the context of information overload is necessary to increase accuracy of measurements on performance and to reduce the influence of covariates such as information overload.

In addition to the question whether or not cognitive load was effectively manipulated in the experiment, we investigated how the experienced cognitive load changed under influence of mental map completeness (and the results of these two factors on decision quality). As an explorative analysis showed that cognitive offloading occurred (see table 6.2), this argument in our line of reasoning holds. These findings indicate that mental maps facilitate cognitive offloading. More specifically, the more complete a mental map is, the more cognitive offloading occurs. This principle can be applied in information displays, regardless of the influence of cognitive load, and thereby assisting users in their tasks by reducing experienced cognitive load.

Besides, our manipulation of mental map completeness (no mental map present to full mental map present) could have led to less time spent searching for information and thus more time for decision making. Future research could take these kind of inherent benefits into account by correcting for the reduced time spent on searching information, which will lead to an improvement in accuracy as all participants have a more equal amount of time to make their decisions. Other types of tasks need to be considered as well. Part of the task used in the current research, searching for information, is influenced by the inherent benefits of a more complete mental map (i.e., more structure). Another task such as a reading and comprehension task might be affected les by inherent benefits of mental maps.

A number of important limitations of our research need to be considered. Firstly, our results cannot be generalized since the participants showed limited diversity in terms of culture, education and age. Secondly, we did not use natural tasks nor did we create a natural environment with options such as silencing a phone. It is not likely that a person is called every 90 seconds and picks up every time when invoked in an important and difficult task. Besides, a phone call in which a person has to respond verbally will be more likely to add cognitive load than only listening to a spoken message and note something down, as it will require cognitive processing of the message and the formation of a response. However, these limitations were necessary in order to be able to control the amount of interruptions and to make sure all participants could perform the task.

Future work could increase the difficulty of the task, as the performance on the task was very good in general. If the time limit for processing the information and making a decision is reduced, the task will become more difficult which will affect task performance. In our research time was already limited but participants still only needed two-thirds of the time limit in order to process the information and make their decision. Future research is recommended to decrease the time limit as it would be interesting if performance scores are more widely spread.

Future work needs to take the experimental design into consideration as well. As a learning effect was present, it is clear that practicing with the task at hand and a display containing mental maps improves speed and performance (see figures 6.1 and 6.3). In order to reduce the influence of a learning effect, a research design can be chosen in which participants complete only one condition. However, as 55 percent of the variance is explained at the individual level, it would be good to compare a participant's performance when using multiple mental maps. This can be tested with a research design in which participants complete multiple conditions with varying mental maps. As the latter has more impact on the results, it is recommended that future research design uses a within subjects approach for mental maps.

The fact that 55 percent of the variance is explained at individual level might be caused by individual differences in task related talents (such as arithmetical capabilities). For example, earlier research suggested that working memory capacity is related to perceived information overload (Lohse, 1997). The perceived information overload is a significant covariate in the present research, thus it would create a more complete image of the influence of mental maps if we incorporate these type of factors.

Practical implications of our research consist of the recommendation to integrate mental maps, as complete as possible, in information displays. The integration of complete mental maps results in a decrease of perceived cognitive load, faster decision making and decisions of better quality. Furthermore, being distracted by a phone call in which answering is not needed (e.g., processing voice-mails or listening in on a conference call) has no or very limited detrimental effects for computational and information gathering tasks at hand. In fact, for some tasks it will even improve task performance.

Summarizing, current research indicated that an increase in mental map completeness leads to an increase in decision making effectiveness. When experiencing high cognitive load, individuals scored higher on decision making effectiveness. However, an increase in mental map completeness did not lead to a decrease of the detrimental effects of cognitive load on decision making effectiveness. Cognitive offloading has been detected, increasing with mental map completeness. Finally, this research recommended several improvements for the research design and stimuli in future research. Altogether, this research indicates that mental maps in information displays can assist users in dealing with information overload and cognitive load in today's business environments.

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9. Appendix A (Example stimuli)

Choose 1 process per category which will result in the maximum improvement:
(Value X Percentage possible improvements)

Processes	Category	Value		Percentage possible improvements
☐ Assembling	Fabrication	€	5.000	10%
☐ Bending	Fabrication	€	6.000	8%
☐ Callcenter	Sales	€	2.000	7%
☐ Consultant	Sales	€	8.000	9%
☐ Cutting	Fabrication	€	3.000	6%
☐ Engines	Purchasing	€	4.000	6%
☐ Facebook	Marketing	€	2.000	6%
☐ Frames	Purchasing	€	3.000	5%
☐ LinkedIn	Marketing	€	5.000	10%
☐ Paint	Purchasing	€	6.000	7%
☐ Painting	Fabrication	€	4.000	10%
☐ Shop	Sales	€	3.000	8%
☐ Tires	Purchasing	€	2.000	6%
☐ Twitter	Marketing	€	1.000	5%
☐ Webshop	Sales	€	3.000	10%
☐ YouTube	Marketing	€	8.000	8%

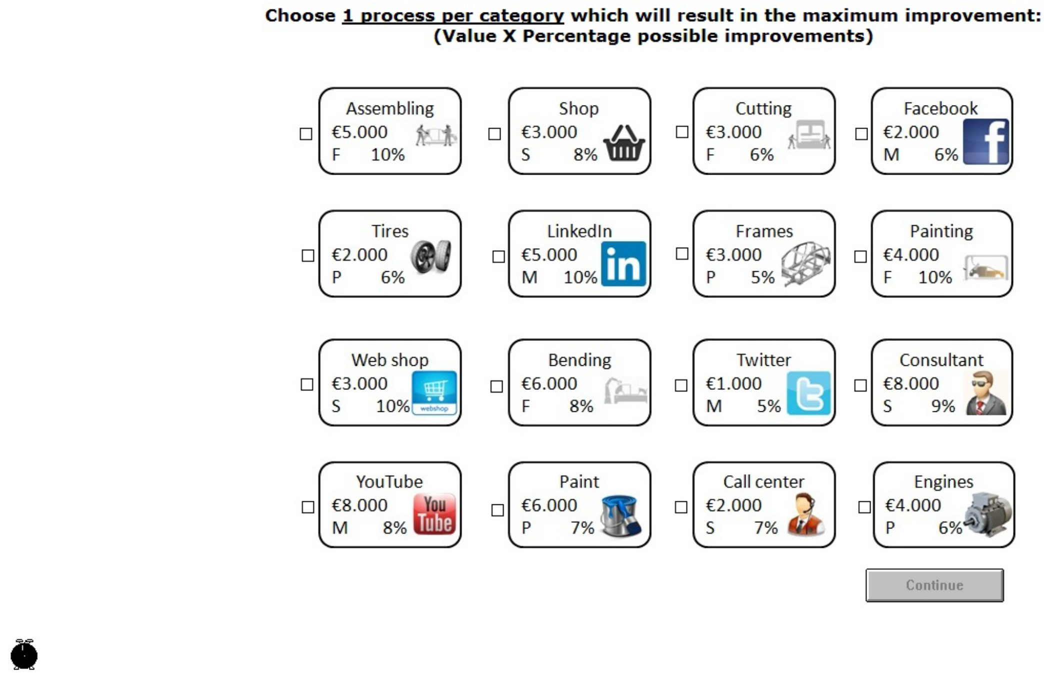
Continue

Choose 1 process per category which will result in the maximum improvement:
(Value X Percentage possible improvements)

Processes	Category	Value		Percentage possible improvements
☐ Boxes	Deliveries	€	3.000	10%
☐ Cooling	Fabrication	€	3.000	5%
☐ Heating	Fabrication	€	5.000	6%
☐ Internet	Orders	€	6.000	7%
☐ Markets	Orders	€	4.000	4%
☐ Metal	Deliveries	€	4.000	3%
☐ Newspaper	Advertising	€	2.000	6%
☐ Packaging	Fabrication	€	1.000	5%
☐ Radio	Advertising	€	3.000	6%
☐ Sand	Deliveries	€	8.000	3%
☐ Shaping	Fabrication	€	5.000	7%
☐ Social media	Advertising	€	6.000	8%
☐ Socket	Deliveries	€	3.000	6%
☐ Super market	Orders	€	4.000	5%
☐ TV	Advertising	€	3.000	8%
☐ Warehouse	Orders	€	8.000	9%

Continue

Figure 9.1: Examples of stimuli in the 'No mental map'-condition, both pictures depicting a company (producing light bulbs or cars) and corresponding processes.



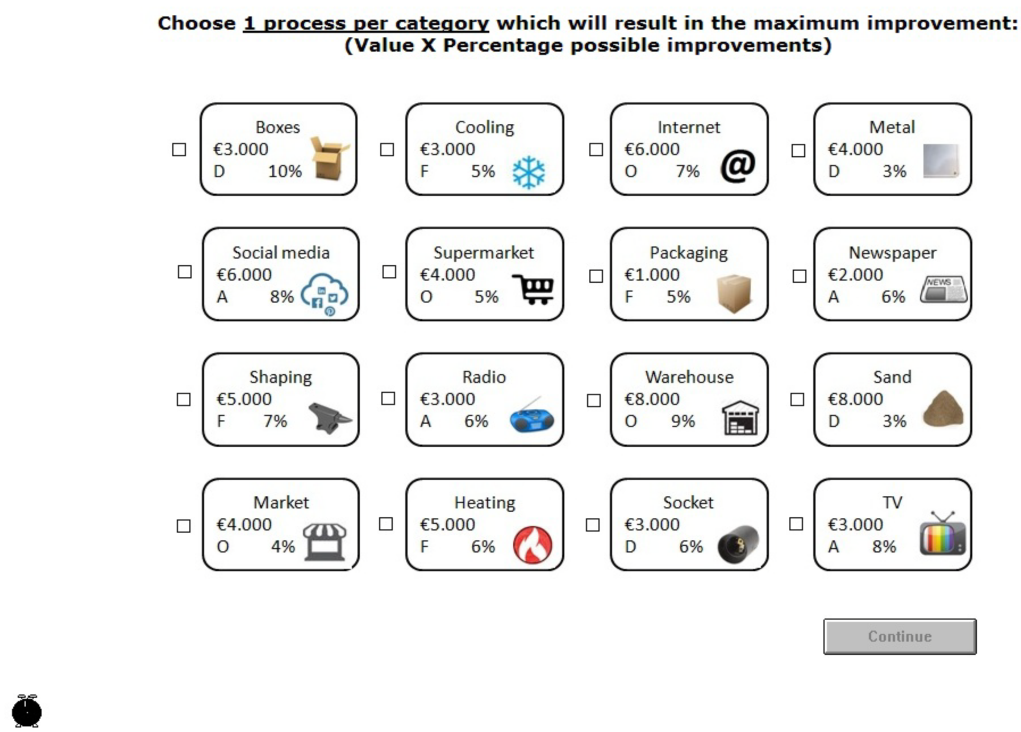


Figure 9.2: Examples of stimuli in the 'Simple visual display'-condition, both pictures depicting a company (producing light bulbs or cars) and corresponding processes.

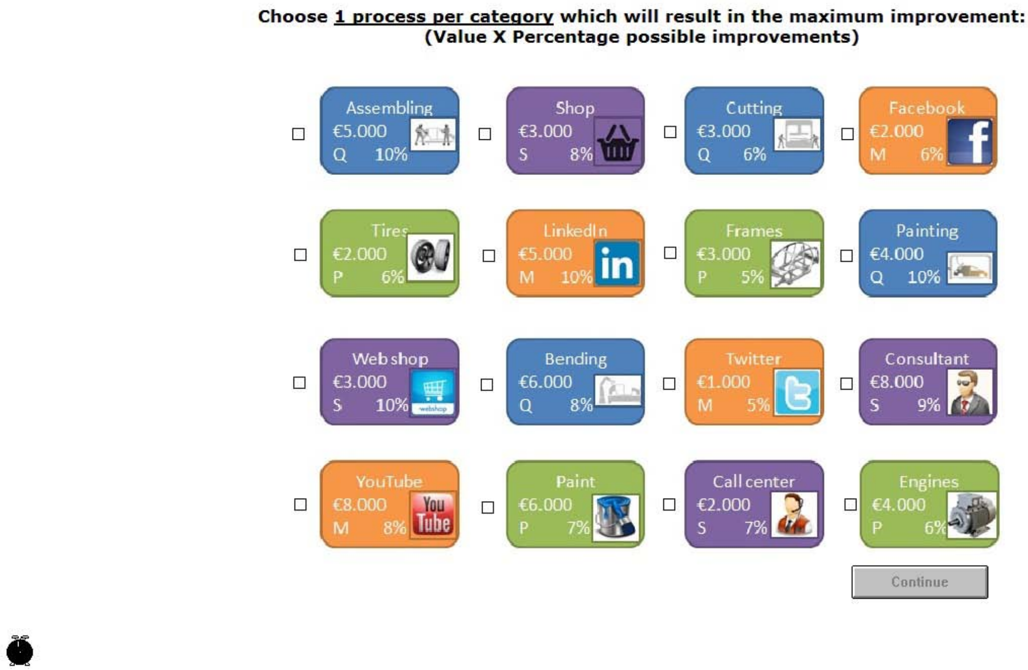
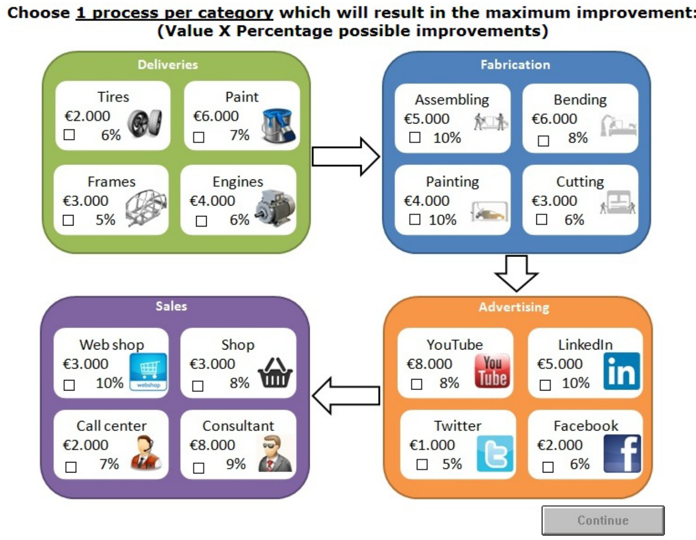


Figure 9.3: Examples of stimuli in the 'Colored visual display'-condition, both pictures depicting a company (producing light bulbs or cars) and corresponding processes.

Figure 9.4: Examples of stimuli in the 'Colored partly grouped visual display'-condition, both pictures depicting a company (producing light bulbs or cars) and corresponding processes.



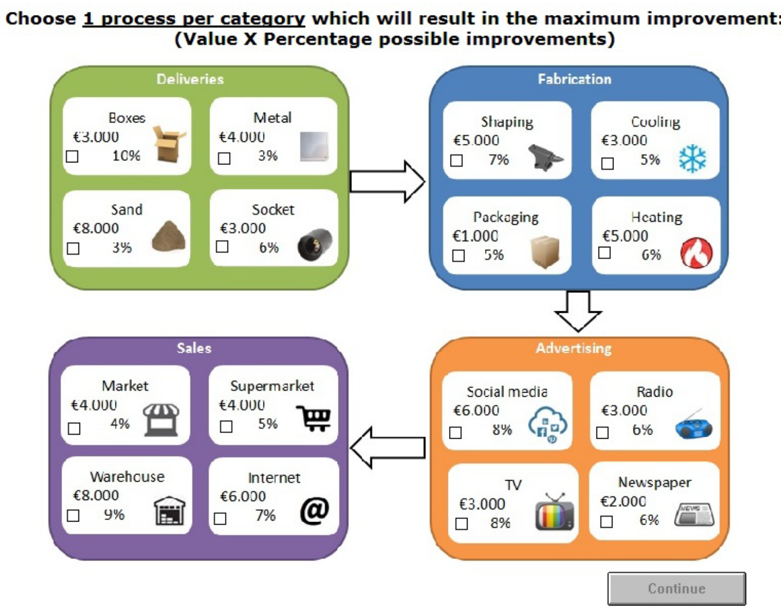


Figure 9.5: Examples of stimuli in the 'Mental map present'-condition, both pictures depicting a company (producing light bulbs or cars) and corresponding processes.

10. Appendix B (Questionnaire)

Questions measuring information overload:

"I am satisfied with my decision."

"I am confident with my choice."

"I felt confused while performing this task."

"The amount of information to be processed is too much."

"During the task, I do not feel overloaded with information."

Questions measuring cognitive load:

"It takes a lot of mental effort to make the right decision and to handle the calls."

"It is easy for me to process all the information and to handle the calls."

"Completing this task costs me a lot of effort."

"I find this task easy."

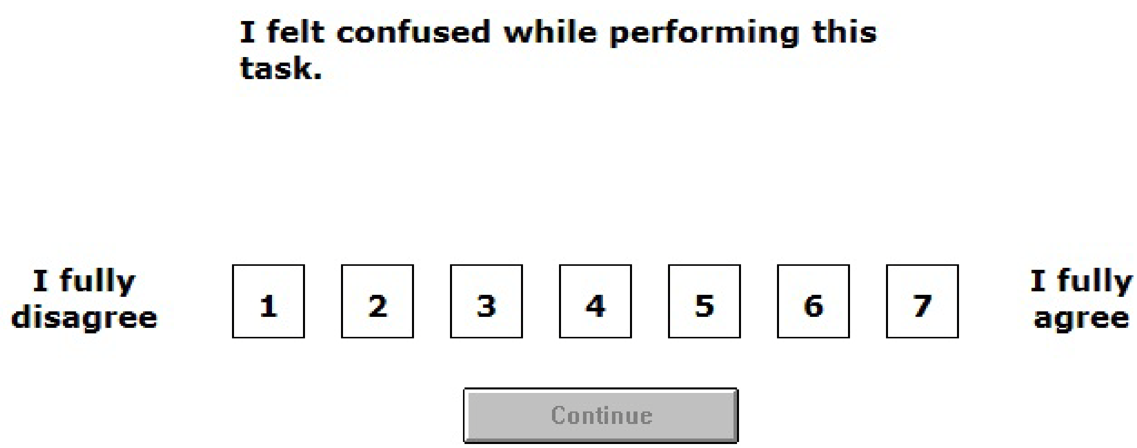


Fig. 10.1: An example of a question out of the questionnaire posed to the participant using Authorware 7.0.

11. Appendix C (Calendar)

	Monday		Thursday
9:00		9:00	
10:00		10:00	
11:00		11:00	
12:00	Lunch with head of production	12:00	Sales
13:00		13:00	call
14:00		14:00	
15:00		15:00	
16:00		16:00	
17:00		17:00	
	Tuesday		Friday
9:00		9:00	
10:00	Present proposal to client Y	10:00	
11:00	Present proposal to client Y	11:00	
12:00		12:00	
13:00		13:00	
14:00		14:00	
15:00		15:00	
16:00		16:00	Dentist appointment
17:00		17:00	
	Wednesday		
9:00	General Staff meeting	Saturday	
10:00			
11:00			
12:00			
13:00		Sunday	
14:00			
15:00			
16:00			
17:00			