User cognition in product operation

Ter herinnering aan mijn grootvader, J.G. Breekveldt.

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Proefschrift

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1. Introduction

1.1 The use of consumer products

This thesis deals with human-product interaction and, more specifically, with the cognitive aspects of human - consumer product interaction. The underlying question is how the functioning of products can be tailored to the cognitive abilities of the consumer.
The use of consumer products is a frequently recurring activity in daily life. People can operate several products at the same time, because most of the operations are performed without effort or difficulty. For example, a driver can turn the car stereo low while answering her cell-phone in a moving car. However, with some products the user will have difficulties because of unfamiliarity, complexity or the obscurity of the operating system. Problems with product operation can sometimes lead to accidents, but the majority lead to frustration. Given the large quantities of individual products manufactured, the frustrations of every individual user will add up to a serious problem.
Over the last decades many studies have focused on human-product interaction, many of them from an ergonomic point of view. However, neither the answer to these problems nor a fundamental understanding of the causes of cognitive operating difficulties are available.

Factors determining product use
In general, three factors are involved in the functioning of a product: features of the product, actions of the user and characteristics of the environment as far as these are relevant for the functioning of the product. The state of these three contributory factors determines the product functioning at any given moment during the human-product interaction (Kanis, 1993).

Product
A product has been supplied with functionalities by the designer in order for the product to serve a purpose. Often multiple functionalities are available within a single product. However, the product provides functionalities only in so far as these are perceived by the user. At the same time a product imposes constraints on the interaction by allowing only a limited number of operations to occur. There is an enormous variation in consumer products available, each with its own specific function(s) and appearance, requiring a particular method of operation.

User
The user determines the goal and the nature of the product functioning. Considering the user, three aspects can be distinguished: physical characteristics, characteristics of perception and cognitive characteristics. These three aspects play a role during the use of products, either interrelated or in isolation. Interaction with products may vary between users, as different users will react differently to the same product. Moreover, repeated use of a product does not always mean identical operation. The use of a device may differ from one occasion to another due to a change in user characteristics, for example due to increased experience.

Environment
The environment can steer the expectation of the function of a device (for example, a mechanical device next to a closed wine bottle and a glass is more likely to be a corkscrew than a can-opener). Also, the need for specific functioning can determine the use of a product (using a chisel for opening a paint can). The way other users (as part of the environment) act can influence the use of a product in a similar way to training or use instructions.

Cognitive aspects of product use
Taking into account all the above-mentioned elements of product use, the main focus in this study is on the cognitive activities of the user. The cognitive interaction determines which goal must be fulfilled, which strategy is applied to reach that goal, and which actions are required to execute the chosen strategy. These actions constitute the observable result of the cognitive action control of the user, concerning the operation of the product. The aim of this study is to understand the cognitive aspects of everyday product use, which will involve considering the role of the other aspects of user, product and environment in the cognitive action control.

The practical aim of investigating cognitive action control is to increase understanding of how consumer products can be designed in such a manner that they are better adjusted to the characteristics of the user's cognitive action control, and hopefully to increase understanding of the causes of unsuccessful interaction with a product.

At the present time cognitive action in the context of the operation of everyday products is not well understood, and nor are its failure mechanisms. In ergonomic textbooks (e.g. Sanders & Mc Cormick, 1992) the topic of cognitive information processing is covered by a general description of theories and models on the structure of memory, attention, decision making and mental workload, combined with rules of thumb relating to compatibility. On the basis of such information it is virtually impossible to anticipate everyday product operating, as Norman (1988) describes throughout his text.

Presumably, the reason for this general description of information processing in the context of human factors is the inaccessible nature of human information processing compared to, for example, anthropometrics. While, for example, the dimensions of users are directly available, and indisputably relevant for usage, the information processing of the user is not directly accessible. Even the notion of cognitive control of action is a topic of debate. Furthermore, available methods of investigating cognition are allegedly susceptible to bias. The often used analyses of 'thinking aloud' protocols is criticized (e.g. Ericsson & Simon, 1984) because subjects have no access to automated cognitive processes (Nisbett & Wilson, 1977). Verbalisation may also interfere with task execution**,** and the result of verbalisation can be an unstructured protocol which is difficult to analyse. Nonetheless, the importance of the cognitive involvement of the user does not decrease because of the difficulty in accessing the cognitive processes.
When the demands on the physical performance are within feasible limits the cognitive performance must ensure the successful conclusion of a set task.
The increasing application of electronics and digital interfaces adds to the cognitive element of product use.
Although the everyday use of consumer products, like any other human activity, involves action control, most of the ongoing use does not require extensive cognitive attention. While this common behaviour constitutes a large part of everyday product use, it is not sufficiently understood.

This study sets out to investigate the cognitive aspects of usage during the actual use of products. Basic operating difficulties will be initially investigated by analysing relatively simple product operation. *Simple* refers here to the fact that these products have only one function, i.e. a mechanical functioning that can be observed by the user.

Designer
The underlying question of this study is how the functioning of products can be tailored to the cognitive abilities of the consumer. Insight into the mechanisms governing cognitive product operation can be applied during the design of a product**,** in an effort to anticipate and prevent operating difficulties.
The designer has the task of preparing a satisfactory interaction between the product and the future user. During the design process, the designer provides a product with characteristics which supposedly enable the use of the product. Ideally, these characteristics *inter alia* constitute an interface that ensures that future users can operate the product smoothly and well. However, literature on failures in product use and on cases of product liability shows that human-product interaction still needs to be improved. The designer is partly to blame for these interaction failures. One of the reasons is that the designer often takes himself as

the standard user when testing the appropriateness of the interface. This method gives no guarantee that all future types of interaction have been anticipated. In reality, the eventual interaction may deviate considerably from that anticipated by the designer. Unanticipated types of interaction may result in a marginal functioning of the product, or in the user spending too much time and effort on making the product work satisfactorily. Use which is different from the intended use can even result in unsafe product use as shown by Weegels (1996).

1.2 Operating difficulties

In the daily use of consumer products unsuccessful product use inevitably occurs, and these failures are an important reason for presenting this study, which deals with the cognitive aspects of those operating problems. Frequently mentioned examples of such problematic tasks are the programming of a VCR and opening doors of public buildings. Norman (1988) describes a large number of problems related to human-product interaction, which he argues originate from the cognitive aspects of product use.

Such problems tend to be trivialised because they appear to be of a temporary nature, in the sense that training in the use of these products would solve the problems. But operating problems can also be of a permanent nature, as shown by Vuick (1993). She investigated the reasons why people sometimes do not make use of products that they have in their homes. She found an average of 11 unused products or product functions per interviewee, and of these 10 % was because the product was seen as too difficult to use. Loopik et. al. (1994) found a large number of operating difficulties with vacuum cleaners which did not disappear with continued use. They conclude that the majority of these difficulties are of cognitive origin, in the sense that subjects misunderstand product information or falsely apply pre-learned operating procedures.

This means that people can become confused when attempting to operate consumer products. The cause of this confusion is described by Norman as follows: *"Humans do not always behave clumsily, they do not always err. But they do when the things they use are badly conceived and designed."* (1988, p.VII).

Another reason for trivialising these problems is the relatively small ‘costs’ they cause. Whether the problems are temporary or not, they most often simply result in irritation and repeated or elaborated operating attempts. Individually such costs may be seen as negligible, but when the large numbers in which industrial products are manufactured are considered, small individual costs multiply into large collective costs and should no longer be acceptable. Besides, more serious consequences of problematic use may also occur.

A more fundamental argument for taking the problematic use of everyday products seriously, is the apparent lack of theoretical insight into the mechanism of this everyday behaviour. Such insight could help to prevent the occurrence of the common operating difficulties.

1.3 Research related to human-product interaction

Reconsidering the three factors determining the functioning of a product (product, environment and user), it follows that a reduction of operating difficulties could, in theory, be reached by altering one or more of these factors. However, this would require in-depth understanding of the interdependence of the three factors and their mutual influence. When looking at the role of cognition in product operating this understanding is limited. There is hardly any scientific research published on the theoretical understanding of the cognitive aspects of operating problems with consumer products. Insight into the topic is therefore mostly provided by general theories on operating behaviour and/or information processing.

The absence of specifically relevant literature may be due in part to the extreme variety of events in human-product interaction which may appear to render them inaccessible to conventional research. Nevertheless, available literature from these and other relevant disciplines will be mentioned in order to develop a starting point.

1.3.1 Modeling human performance

Within the interaction with a product, it is specifically the cognitive interaction with products that is under consideration in this study, as opposed to the physical interaction. Cognitive interaction is all about information and processing that information. The product supplies information, the user is equipped with information based on training or experience and this combination of information is the basis for the decision of a user on whether and how a product is to be used.
In general, the processing of information is typically a topic dealt with by cognitive psychology. It deals with the acquisition of knowledge, how this knowledge is stored and retrieved and how it is processed. The study of using consumer products in this sense fits in with what psychologists refer to as the study of human performance.

Models of human performance generally describe the human being as an information processing system. Human information processing is initiated by incoming information through the sensory system. This information is processed together with information from memory and this results in a response, for instance

a motor action. The results of the action in the world may result in feedback that is perceived, once again, through the sensory system (e.g. Wickens 1990).
This basic process has been the topic of many theorists. The resulting models vary considerably in the level of detail, predictability and inclusion of elements from the basic process. Some models are relatively focussed, describing only a part of human performance, like the classic model of capacity of working memory (Miller, 1956). In contrast, other models describe human performance on a more global level. These models compensate for a lack of detail with the models applicability to a much less confined range of activities. Unlike the quantitative model in the example mentioned, the more general models are mainly qualitative. In his 'consumer guide' Reason (1988) provides an overview of available models and discriminates between two basic types, local theories and framework models. Framework models provide descriptions of the mental processes involved in complex performance and should at least account for the storage of memory, the processing of information and the way memory is organized. If anything, this type of model is most likely to be relevant in understanding the processes involved in operating consumer products.

1.3.2 Information processing and operating consumer products

In principle the basic information-processing model mentioned in the previous section should be applicable to the use of consumer products (Dirken, 1997). Operating everyday products involves processing of information by the user. The user perceives information provided by the product and the conditions of the task. In addition, the user may have knowledge about how to operate this product, based on experience, training, use instructions, examples set by another user, etc. These sources of knowledge are processed in combination and this leads to some type of action and/or operation. The effect of the action can serve as feedback that might lead to subsequent actions.
To determine the starting point for the study, in the following sections the three topics Reason mentions as elementary for an explanation of cognitive information processing will be elaborated on.

Memory storage

Knowledge is stored in memory, but memory cannot be considered as one complete entity. Therefore different types of memory are distinguished by different authors. These distinctions are made to illustrate the information processing nature of memory.
The model proposed by Broadbent (1984) illustrates the information processing view by supposing a sensory store, an abstract working memory, a motor output store and a long-term associative store. Each of these stores is linked with the central processing system and in each location persistent information or

representations are stored. The representations are translated between the stores by processes executed through the central processing system. The distinction between different types of memory is not specific for this model. It is generally accepted that memory consists of different parts.
As early as 1890 James (1890) made a distinction between a primary memory, being temporary and volatile, and a secondary memory, a more permanent collection of knowledge.
This distinction corresponds with the Long Term Memory and Short Term Memory distinction made by Atkinson & Shiffrin (1968). A similar view is adopted by Newell & Simon (1972), Norman & Shallice (1980), Baars (1983), Rasmussen (1986), McClelland & Rummelhart (1985). In the short-term memory the abstract working memory (Broadbent, 1984), a workspace (Baars, 1983) or problem space (Newell & Simon, 1972) is located.
Card, Moran & Newell (1983) make a further distinction within the short-term store in their Model Human Processor between a number of specialised storage-units. They mention the perceptual system, the motor system and the cognitive system. Anderson (1983) makes a further distinction within the Long Term Store between declarative and procedural memory. These differences can be ascribed to the specific aims of the models demanding a more detailed description. These detailed distinctions, however, do not conflict with the basic distinction between Long Term Memory and Short Term Memory.
Related to the storage of memory is learning. In the light of the operation of products, acquiring operating knowledge is basically learning. Although the literature on learning theories is extensive here only the view of Anderson (1987) will be mentioned. Elements of his model will be used in later chapters. In his description of the acquisition of skills he distinguishes between declarative and procedural knowledge. Simply put, declarative knowledge concerns factual knowledge, knowing what. Procedural knowledge concerns operational knowledge, knowing how. The process of the acquisition of skills is described by Anderson. In his ACT* model declarative knowledge is applied to an operating task resulting in an operating procedure which is in time stored as such in the production memory. Anderson refers to this process as proceduralisation.
Rasmussen (1990) describes a similar process. In novel situations an operating problem is controlled at the so-called knowledge-based level (see below), and through experience the control shifts in time to lower levels. The original knowledge which was applied on the knowledge-based level is replaced by specialised rules or even skills which are situation specific but, given that situation, more efficient.

Neither model explains specifically where the original knowledge, declarative (Anderson) or general knowledge stored in mental models (Rasmussen) originates

from. Sein & Bostrom (1989) assume there are three ways in which new information is internalised:
- Mapping via usage of the system or the device. The role of the system interface is important.
- Mapping via analogy. The user's prior referent experience with similar systems plays a crucial role.
- Mapping via training. The user acquires a mental model of the system through a conceptual model that is provided during training.

With the acquisition of skills, not only the amount of prior knowledge increases but also the nature of the knowledge will change. In general, increased experience, compared to little experience, leads to different ways of organising available knowledge (Dochy, 1992). With increasing expertise larger amounts of procedural knowledge become organised into larger units which can be applied at once. These larger units enable the experienced user to approach an operating problem on a more global level, because there is less need to deal with details. The inexperienced user has to make sense out of the details, which prohibits a global approach.

Knowledge organization

Norman (1988) states that experience is not the only information source available to the user of a product. He makes a distinction between the two kinds of knowledge involved in product operation:
- Knowledge in the head, i.e. knowledge the user has stored in memory; this knowledge is acquired by interaction with products in the past, and
- knowledge in the world, i.e. the type of knowledge stored in the product by the designer. Product graphics, layout and shape can be vehicles to store this type of knowledge. Knowledge in the world is a passive source of information, which will only become meaningful if the user perceives and understands it.

In general, successful operation of a product requires the correlation of user knowledge on the one hand with the product requirements necessary to operate the product on the other. The cognitive efforts of the user involve both knowledge in the head and knowledge in the world, and should meet the demands imposed by the product. A product designer cannot influence human behaviour directly except by arranging the knowledge in the world, the product features, in such a manner that the user is guided towards a successful operation. Norman (1988) reasons that the information needed to operate a product successfully is rarely stored entirely in the user's head, i.e. through remembrance of previous interactions or experiences, but almost invariably the user receives guidance from activation of knowledge in the world.

The different sources of knowledge are manifest in a number of representations. Not only does the user have such a representation, so has the designer while creating the future product. Norman (1986) distinguishes three types of representations or models in this context, the *design model*, the *user model*, and the product's *system image*. The relationship between these three is illustrated in Figure 1.1.
The design model is the conceptual model of the designer. This is materialised into the product or system. On the basis of the interaction with the product the user builds a mental model, the user model. The system image results from the physical product and the product graphics, including the accompanying instructions and documentation. The designer expects the user model to correspond with the design model, but the connection between these two is intermediated by the system image. If the system image does not communicate the design model correctly then the user ends up with a user model which deviates from the design model, giving way to confusion around the product and its use.

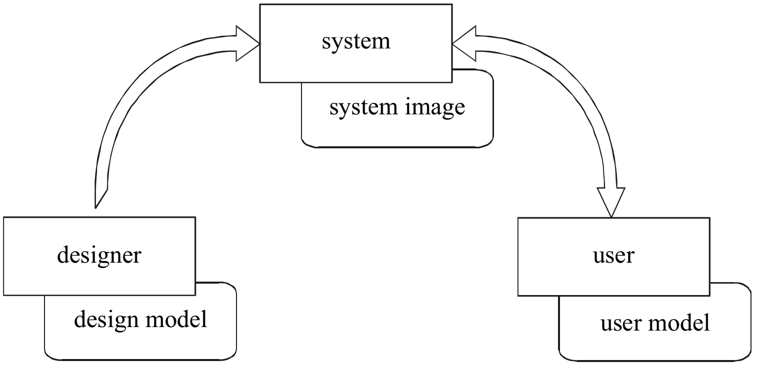


Figure 1.1
Three types of representations and their relationships (Norman, 1986).

Norman stresses the importance of similarity between the design model and the user model, and he also stresses the criticality of the system image, where the designer must ensure that everything about the product is consistent with, and exemplifies, the operation of the proper design model. Only when due consideration to these aspects is given may the user "*acquire the proper user's model and find support for the translation of intentions into actions and system state into interpretations. Remembering, the user acquires all knowledge of the system from that system image*." (Norman, 1988, p.190).

Knowledge representations
What Norman labels 'user model' is more generally referred to as knowledge representation. Different authors provide descriptions of knowledge representations as either containing knowledge required to execute automated behaviour, such as condition action pairs (Anderson, 1980) and rules (Rasmussen, 1983), or knowledge required to execute attentional behaviour, such as schemata mentioned by Norman, Reason and Baars.

These types of representations are not unique to the above-mentioned framework models. Within the artificial intelligence literature, condition action pairs are very common and for schemata many related concepts exist. Bartlett (1932) already mentioned schemata and Craik (1934) mentions an internal representation. More recent variants of the schema concepts are frames (Minsky, 1975), scripts (Schank & Abelson 1977), mental models (Gentner & Stevens, 1983; Johnson-Laird, 1980; Wilson & Rutherford, 1989; Rasmussen, 1990), and conceptual models (Norman, 1988). Each of these concepts is given a specific meaning by the authors. Mental models are a popular notion, although the term mental model is used by different authors with different meanings. Wilson & Rutherford (1991) provide an overview of the differences between the appreciation of mental models as described by different authors.
Norman (1988) provides an extensive description concerning the conceptual representations made by the users of consumer products. Conceptual models are built on the basis of knowledge about the use of products. Since not every detail, once perceived, is stored these models are also based on expectations. For missing information default values are used, derived from past experiences. This is an efficient mechanism because for the use of products only information that cannot be extracted from the outside has to be stored. Also, the model itself is built to match the requirements of the current operating task. This can mean that mental models are incomplete, unstable and lack firm boundaries. The models are constrained by such things as the user's technical background, previous experience with similar products and the structure of human information processing (Norman, 1983)

The processing of information
Concerning information processing, a number of aspects are of relevance. I. The level of processing, II. The attention required for processing and III. the location of control. The first two aspects are described in some detail, the third aspect will be only briefly mentioned since it is beyond the scope of this discussion.

I. Level of processing
In general, cognitive activity is seen as being guided by a complex interaction

between the two levels of cognitive control described by Reason (1990). Automatic control is fast, requires no effort, seems to have no limitations concerning capacity, and works on the basis of simple heuristics. It can handle routines and repetitions, but it is often ineffective in unfamiliar situations. It is not conscious, only the results are conscious. Conscious control is slow and elaborate, has a limited capacity and works analytically. It is essential for coping with unfamiliar situations, but not suitable for lengthy use. It is accessible to consciousness.

II. Required attention
The amount of conscious attention required to execute a task is referred to as 'cognitive load' (Beacker & Buxton, 1987). Generally accepted among authors is the tendency of human beings to minimise the amount of cognitive attention, the cognitive load, during the execution of tasks. (Reason, 1990). He states "*In short, human beings are furious pattern matchers. They are strongly disposed to exploit the parallel and automatic operations of specialised, pre-established processing units: schemata (-), frames (-), and memory organising packets (-). These knowledge structures are capable of simplifying the problem configuration by filling in the gaps left by missing or incomprehensible data on the basis of 'default values'.*" (p 66).

III. Location of control
Most models locate conscious processing within a restricted area in the cognitive system. This area is labelled the workspace (Anderson, 1980), short-term store (Shiffrin & Schneider, 1977), problem space (Newell & Simon, 1972) or global workspace (Baars, 1983). Within this area powerful elaborations and routines are operational on a limited amount of information. This information is retrieved from the long-term store and from current observations. The capacity of this workspace is limited, which can lead to an informational overload. On the other hand it leads to possible selectivity and to coherence of the operation.

According to many models the human processing of information is assumed to take place within this working memory. Only the way in which processing takes place differs between the above mentioned models. As described by Reason (1988), basically two types of processing are distinguished, controlled or conscious processing and automatic or unconscious processing. However, this distinction is not always incorporated within the various models. Card, Moran & Newell (1983) designate specific processors to each memory subsystem, but make no explicit distinction between automated and conscious processing. Anderson (1980) assumes a centralised processing system in which all the information is processed in the workspace. This system accounts only for the higher level, conscious, cognitive activities, although automatic processing is mentioned and is brought about through knowledge compilation. Baars (1983) assumes a large number of processors are active within the global workspace, producing both automated and consciously controlled actions. Norman & Shallice (1980) also assume a large number of independent processors grouped in horizontal and vertical threads that correspond to automated and consciously controlled actions.

Rasmussen (1983, 1986, 1990)
This author refers to the processing of knowledge, available from different sources in order to execute an appropriate action, as cognitive action control. Knowledge in the world is perceived, interpreted and subsequently compared to knowledge in the head. On the basis of this combination a decision concerning action is taken. Such a decision is not necessarily a consciously taken or an elaborate decision.

Rasmussen distinguishes six steps of decision taking or problem solving. According to the Rasmussen model (Figure 1.2), information can be processed on different levels. Depending on the familiarity of the perceived information a response can be produced at three levels.

- Performance at the skill-based level is governed by stored patterns of pre-programmed instructions or action schemata, and takes place without conscious control. This level contains highly routinised actions and a 'signal' is enough to activate the appropriate scheme.
- At the rule-based level, action is determined by memorised rules or procedures, learned in the past. An appropriate rule is triggered by recognition of a situation previously encountered.
- In situations not previously encountered new responses are derived at the knowledge-based level. General knowledge is consciously analysed in order to produce a behavioural strategy.

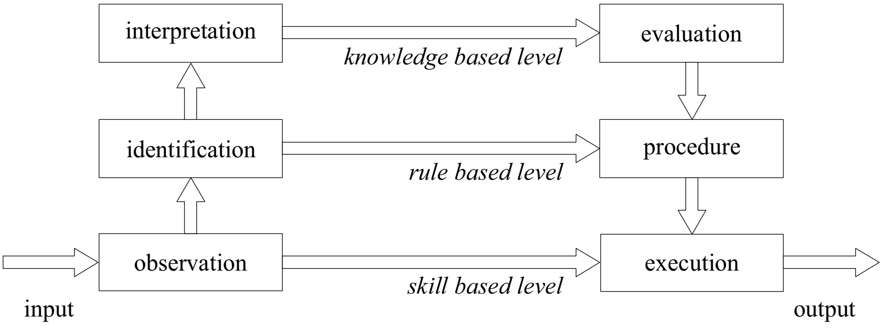


Figure 1.2
Rasmussen model of cognitive action control.

For each level a different type of knowledge resource is available. a) At the skill-based level a collection of automated routines or reflexes determine the possible responses. b) At the rule-based level a collection of rules or procedures derived from past experience are available, and c) at the knowledge-based level general knowledge stored in the format of what is referred to as a mental model, an internal representation containing general knowledge determining the possibilities of the analytic process.

Practicalities
Action control in this model may take place on different levels simultaneously, since different aspects of one operating task may be controlled at different levels. The amount of conscious attention increases with each level. The execution of skills requires little or no attention, while processing at the knowledge-based level can only take place with conscious attention. In daily life, most of the action control is governed by the skill-based and rule-based level, and only a limited amount of problem solving takes place at the knowledge-based level. For the operation of consumer products it may be assumed that most cognitive control is performed at the skill-based or rule-based level. By frequent interaction with products a large number of rules and procedures determining the operation of familiar products is stored in memory. This accounts for the large number of problem-free operations of products that take place every day. Only in unfamiliar situations is processing at the knowledge-based level required to cope with novel circumstances. Successful ways of operating, derived from knowledge-based reasoning, are stored in memory as a rule. When a similar situation emerges this stored rule can be re-applied, which leads to processing at the rule-based level.

Implications
In an ideal situation the designer would supply the user with such knowledge in the world (in the product) that the correct knowledge in the head would be triggered, regardless of the level of cognitive control on which this should take place. However, in order for the designer to provide such knowledge within the product, understanding of the effect that knowledge in the world has on the user is required. This insight is often not available at a sufficiently detailed level. Also, the described contributions of Norman and Rasmussen contain key elements that are unobservable and therefore difficult to apply in the design process, for example the internal representations, such as mental models containing user knowledge and system image resulting from the product .

Applicability of HCI research
The work in the field of Human Computer Interaction (HCI) seems so closely related to that of Human Consumer Product Interaction that a special paragraph

might be justified. It is safe to say that most of the research concerning the cognitive aspects of product use has been done in the field of human-computer interaction. However, the generalisability of the findings in this field to that of human - 'consumer product' interaction is troublesome and therefore doubtful. The main goal of HCI is "*to ensure that the systems produced by designers for people to use are comprehensible, consistent and usable*" (Maddix 1990, p.9). *The system* in this case refers to a computer based system, but current research would embrace a similar goal for consumer products. However, the way this goal is normally achieved in HCI is by evaluating the use of a system and consequently by trying to improve the system. The systems under investigation in HCI are obviously all computer based systems, systems in which the specific interface is displayed on a monitor. Functionally, these are all very complex systems compared to, for example, a power switch. The descriptions and domain specific insights resulting from HCI have a corresponding level of complexity and are most often product specific. These insights are simply misplaced when applied to the use of a (computer) power switch or similar functions.

1.3.3 Discussion

Although in general any clarifying description of the processing of information can be relevant for understanding the problems involved in the operation of consumer products, in practice this relevance appears to be limited.
This is because of difficulties with the domain specificity, the lack of attention to failing performance, the rationality underlying the described performance, the influence of the type of information that is perceived, and finally the influence of the task and the task environment.

Domain specificity

The models of human performance are mostly descriptive and explanatory, while predictive models only apply to a specific domain. Application to a specific domain such as product design is therefore difficult. Fields of research that do specifically focus on product use are Human Computer Interaction (HCI) and Cognitive Engineering, and authors such as Norman (1988) and Kanis (1993) who specifically address the ergonomics of products.

Failing performance

Descriptions of human operating performance deal with the way people perform tasks, but they hardly ever include why people can fail in performing tasks. Unless it is specifically the topic of the description, little is said about failed performance. Models specifically dealing with failing performance are Reason (1990), Norman (1988) and Rasmussen (e.g. 1993).

Rationality of the performance
Due to the complexity of explaining cognitive information processing as such, very few models include a performance that takes place without conscious processing. Skilled everyday performance takes place most of the time without conscious involvement. Exceptions to this are made by authors like Reason and Rasmussen, but also by Anderson (1983) with the introduction of concept proceduralisation.

Type of perceived information
In the descriptions of information processing the influence of the type of information that is perceived (e.g. the product) is seldom elaborated, whereas the role of the product is essential in this study. Kanis (1993) does elaborate on the role of the product and another obvious exception is the research in the field of HCI.

Influence of the task and task environment
Finally, in the models very little attention is given to the influences of the task and the task environment . Descriptions that do pay attention to these aspects are those provided by Ecological Psychology (e.g. Gibson, 1977) and Interactionists (e.g. Suchmann, 1987, Winograd and Flores, 1986). Both approaches stress the way in which action is shaped and fitted to the ad hoc and local contingencies of the situation in which it occurs, rather than executed according to some predesigned plan, which is the underlying assumption in the cognitive tradition. Within the field of HCI the social environment is at the heart of the attention of the so called Computer Supported Cooperative Work (CSCW). However, this approach is obviously closely related to the object of study which cannot be replaced by the individual use of consumer products.

Conclusion
On the basis of the review of available descriptions the approach Norman (1988) chooses is most appealing for answering the questions underlying this research project. He does not provide an explaining theory but rather an explanatory framework. The strategy underlying his work seems to answer the above-mentioned shortcomings of the available theoretical insights. Based on analysis of actual operating behaviour, including operating problems, design relevant mechanisms should be described and made available to designers for them to consider. The role of the concepts derived from available theories and translated into the design of consumer products should be further examined by advancing experimental work.

1.4 Terminology

In discussing the various aspects of human-product interaction a number of concepts are of importance. These concepts are sometimes closely related and may be labelled with the same name. To prevent misunderstandings or confusion a coherent terminology is proposed.

Describing the interaction between user and product in detail requires labelling of different aspects of both **user** and **product**.
Of the product**, physical form** and the **function** should be labelled. On the user side**, physical control** and the **cognitive involvement** must be distinguished. These four elements can be labelled on several levels.

Product appearance
At the most basic level a product consists of **parts** (door lock). Together these parts form a complete product, a specific **model** (my office entrance door)**.** Several **models** can be of the same **type** (sliding doors). Different **types** of a product can have the same **function** (closure of an entrance).

Product functioning
The functioning of a part is an **action** (locking the movement of the door). Together these **actions** combine into the **working** (blocking the entrance of my office) of the specific **model**. Although the **working** can vary, **models** of the same **type** function according to the same **principle** (opening and closing with a sliding movement). There may be more functioning **principles** possible to serve the functioning **purpose** (closing an entrance).

User physical control
A **manipulation** (unlocking the door) is the physical control of both a product **part** and the **model** at hand. Since the **model** only consists of **parts** there is no point in making a distinction between the control of **parts** and the control of the **model**. However, the **manipulations** required to make a **model** function can consist of a string of **manipulations** that make various **parts** function. The control of a **type** of product is referred to as an **operation** (locking doors). A similar **operation** on different **models** of the same **type** can be brought about by different **manipulations**.

User cognitive control
The cognitive control by the user has no direct link with the previous three aspects. The cognitive control does not solely depend on the product but rather on the users' knowledge of the control of the product. Nonetheless, four levels are

labelled, similar to the levels of processing mentioned in the Rasmussen model. Required for the execution of very frequent tasks without conscious control is a **skill**. Required for the execution of frequent tasks with little conscious control is a **procedure** or a **rule**. The cognitive control during infrequent cognitive elaborate reasoning results in a **strategy**. The ultimate aim of cognitive control is to reach a set **goal** with the product. Such a **goal** can be reached by the mere execution of a **skill** in some cases, but in other cases the formulation of a **strategy** may be required that has to be translated into **procedures** which in turn must be translated into the execution of **skills** which eventually lead to product functioning.

In Table 1.1 the concepts described above are ordered hierarchically in columns. The hierarchy is the level of abstraction.

Table 1.1
Overview of terminology

product physical form	 functioning	**user** physical control	 cognitive control	level of control (Rasmussen)
function	purpose		goal	knowledge-based
type	principle	operation	strategy	knowledge-based
model	working	manipulation(s)	procedure/rule	rule-based
part	action	manipulation(s)	skill	skill-based

1.5 Research strategy

To study the cognitive aspects of human-product interaction one must consider the reason why users operate a product in a particular way. For the product designer, altering the products' characteristics and functioning is the only available way to influence the future operation of the product. The alternative, e.g. training the user, is usually not practical when it concerns consumer products. With simple domestic appliances it would just be ridiculous. Therefore any attempt to improve product operation faces an inherent complexity. *Although in the operation of products the user is the only real operator, influencing this operation can only be established by changing the product.*

Within the interaction between product, user and environment, from a design perspective, the product is the only factor that is to be controlled directly. By means of this direct control the operating behaviour of the user should be indirectly influenced in such a way that proper product functioning can be ensured.

Rejected strategy
In this study the product features and the cognitive characteristics of the user are the only independent variables. The actions of the user and the results of those actions are the dependent variables. Theoretically this would lead to a research strategy whereby product features are used as stimuli on a group of selected people, whose response to the stimuli is then observed. In such experiments these people are to be confronted with controlled and isolated product features in order to clarify the influence of these features on users' operating behaviour. Supposing controlled laboratory conditions, it should then be possible to account for the influence of a single contributing product feature, because changes to this feature can be artificially arranged and the effect on users' behaviour observed. However, in real life product operation can never be attributed to single, isolated product features. Other product-, user- and environmental characteristics also play a role. Therefore, following this theoretical research strategy would only result in the control of a few of the relevant factors, while the influence of other variables remained unknown. This would indeed make specific conclusions on the influence of a *single* contributing factor difficult, if not impossible. Such a strategy might only be successful when hypotheses concerning the effect of individual factors could be derived from a specific theory concerning the operating behaviour on consumer products.
However, as discussed above, such a theory is not available. Moreover, as said before, concentrating on the effects of isolated product features will lead to a limiting of the generalisability to the large number of different consumer products. Covering all product features of all products would result in a never-ending exercise, which would indeed be meaningless.

Chosen strategy
Given these reasons, it was decided to try to make the influence of products on user cognition observable at a more general level. Therefore the independent variables were varied in the experiments by using different products with identical purposes, with no stress on the differences in product features. Certainly in the initial stage, this type of research can best be described as explorative.
Products, or combinations of products, were selected so that the observed operation of those products by the subjects would lead to an understanding of the cognitive processes underlying the observed operations. The experiments were designed in such a way that differences in performance during the use of the

products could be attributed, as much as possible, to user characteristics and not necessarily to the differences between the products.
The insights derived from these explorative experiments will be combined with existing theories developed in another context. Finally, hypotheses concerning the effect of users' experience on product operation will be formulated and tested.

Starting empty handed
Due to the absence of explanation for failing product operation the exploration of this subject sets out as simply as possible. The complex and wide nature of the subject makes a one step at a time approach inevitable. Therefore the first experiments might seem bewilderingly simple. But if the operating difficulties with seemingly simple products cannot be understood there is no point in moving on to more complex products.
Besides, the purpose of the first explorative experiments is to determine whether the theory from other domains (e.g. operating behaviour of operators on process industry power plants, Rasmussen, 1983) is applicable to the operating behaviour on consumer products. Intuitively one would expect it not to be so, because the underlying difference of this theory seems to preclude the additional applicability. Professional task performance is often trained performance and takes place under controlled, designed circumstances. This reduces the influence of inter-individual variation, while consumers can use products in a variety of circumstances in the manner they believe to be best. In addition, the consequences of failing consumer product operation in a single case are often less serious and less irreversible than with professional product or system operation. Nonetheless, professional task performance and the use of consumer products do share a common element, as both are performed by humans, with their ability to perceive, reason and act. There is no reason to assume that these basic abilities depend on the type of task performance.

1.6 Thesis plan

The research work described in this thesis investigates cognitive causes of product operating difficulties. An attempt was made to gain insight into the actual occurrence of these difficulties with real-life consumer products. Initially, this was done by the execution of four explorative experiments, in which both successful and unsuccessful product operations were evoked. Then an attempt was made to provide a theoretical explanation of the phenomena observed in the explorative experiments. On the basis of the theoretical understanding two hypotheses were formulated, and these hypotheses were then tested with two additional experiments. In total six experiments were conducted.

Can-openers and corkscrews
In Chapter 2 a survey is given and two experiments are described. The products used in these experiments are simple domestic appliances, namely can-openers and corkscrews. Subjects have had extensive experience with both products. The purpose of Experiments 1 and 2 is to study the influence of experience on the operation of unfamiliar models with a familiar product function. This is compared to the operation of familiar models with the same product function.

Telephone memory
Chapter 3 describes another explorative study. In this chapter two experiments concerning the operation of the memory facility of telephones are described. The subjects in Experiment 3 have little experience with this memory facility. The purpose of this experiment is to see how knowledge of the telephone memory retrieval task evolves during the experiment, and how this newly acquired experience influences the operation of other telephones included in the same experiment. In Experiment 4 the same subjects will be invited to re-use the telephones to see how their knowledge has evolved with time.

Explaining operating difficulties
In Chapter 4 theoretical notions concerning the cognitive control of action are considered, to see whether these describe phenomena observed during the two explorative studies. This description considers theories provided by the fields of cognitive psychology, cognitive engineering and learning theories. The results of this comparison are reviewed for their possible implications and applicability for product design. Two relations are then formulated concerning the theoretical implications.

Testing the suspected relations
In Chapter 5 two experiments are described in which the two suspected relations are tested. Experiment 5 concerns the direction of rotation of controls for controlling the flow of liquid from a coffee-distributing device. In this experiment an attempt is made to show the effectiveness of four design strategies for the operation problems observed in Experiments 1 and 2. In Experiment 6 the influence of knowledge on product operation is revisited. Again the product used in this experiment is the memory function of telephones. In this experiment the question to be answered is more detailed, and concerns the influence of the different types of experience the subjects have acquired through training they received prior to the actual experimental tasks.

Discussion
In Chapter 6 a final discussion of the research project is presented and the implications of the research described in the previous chapters are considered.

2. Using products with a familiar function

2.1 Introduction

More or less familiar products

The aim of the experimental work described in this chapter is to investigate cognition in the use of simple domestic products by exploring the influence of user knowledge during the use of the products. Familiarity with the use of a product indicates knowledge of the product and its operation, and such knowledge is considered an important component of the cognitive control of operating behaviour. Therefore the experiments had to be such that the operation of the included products depended on the kind of knowledge possessed by the subjects. This was done by varying the familiarity of the products.

Everyday use of domestic products provides familiarity with specific products. However, it does not provide familiarity with all products with the same product function. To investigate the influence of familiarity, both familiar and unfamiliar products embodying the same product-function were taken into consideration, and their respective kinds of operation compared. For these operating tasks no external directions for use were given, so that the operation was based solely on knowledge in the head and knowledge in the world, as provided by the product

To determine the familiarity of a range of products with the same product function a survey was carried out. Next, in Experiment 1 subjects were asked to operate both familiar and unfamiliar products with the same product function. By analysing the differences between the use of these product models it should be possible to determine the effect of familiarity and, indirectly, the effect of knowledge. The study of Kanis & Wendel (1990) into the use of a newly designed coffee-creamer cup showed this combination to be potentially useful.
Finally, to see whether the observed effects of familiarity would be comparable when using other products, a second product function was used in Experiment 2.
The survey and the two experiments involved can-openers. The can-opener was chosen for two reasons. Firstly, a can-opener has a very common product function, probably familiar to all Dutch adults. Secondly, can-openers are available in a large variety of shapes, sizes and operating types. This facilitates the selection of both familiar and unfamiliar models. For the same reasons the corkscrews were selected for Experiment 2.

Internal representations
As mentioned in Chapter 1, a traditional aspect of knowledge involved in the use of products is the assumption of internal representations. In the exploration intended in this chapter the meaning of internal representations in the context of product operation, i.e. how it can be operationalised and its added value to the understanding of product operation, will be considered.
One way to make the internal representation explicit is to ask people for a description of their knowledge of a given product-function. In the experiments this was done by asking subjects to make a drawing of their image of the product at the start of the experiment and to describe the operations involved in using the device. In addition, the subjects were instructed to think aloud while carrying out the operational tasks. Although the think-aloud method has its disadvantages, as mentioned in Chapter 1, it was nevertheless applied. The think-aloud protocols were meant to provide additional information about the actions subjects displayed, and might possibly provide some understanding of the motivations for the observed actions.

2.2 Surveying familiarity of can-openers

The aim of this survey was to establish a general impression of the familiarity of the users with different can-opener models. On the basis of this impression it was to be decided which models would be used in the experiments. Although familiarity with can-opener models obviously differs between individuals, can-openers for Experiment 1 were to be selected for their (un)familiarity on the basis of this survey study. This method of determining the (un)familiarity of the can-openers did not exclude the possibility that individual subjects in the experiment would be familiar with a supposedly unfamiliar model, or vice versa. Nevertheless, this method was chosen because questioning individual subjects about their experience with can-openers at the start of an experiment is likely to induce a priming effect on the execution of tasks.

2.2.1 Method

The subjects were 200 students from Leiden University. They all participated during a single session involving several paper-and-pencil experiments. A pictorial checklist, consisting of 12 pen-drawings of different can-openers divided over two sheets, was presented to the students. The can-openers in the list were selected to provide what was expected to be a reasonable coverage of available models. The sequence in which the two sheets were presented was varied: 100 subjects started with Sheet 1 and 100 with Sheet 2. The subjects were asked to indicate 1) which can-opener(s) they used at home and 2) which one(s) they had used in the past.

The subjects were explicitly asked not to mark any can-openers they had only seen before, but not actually used.

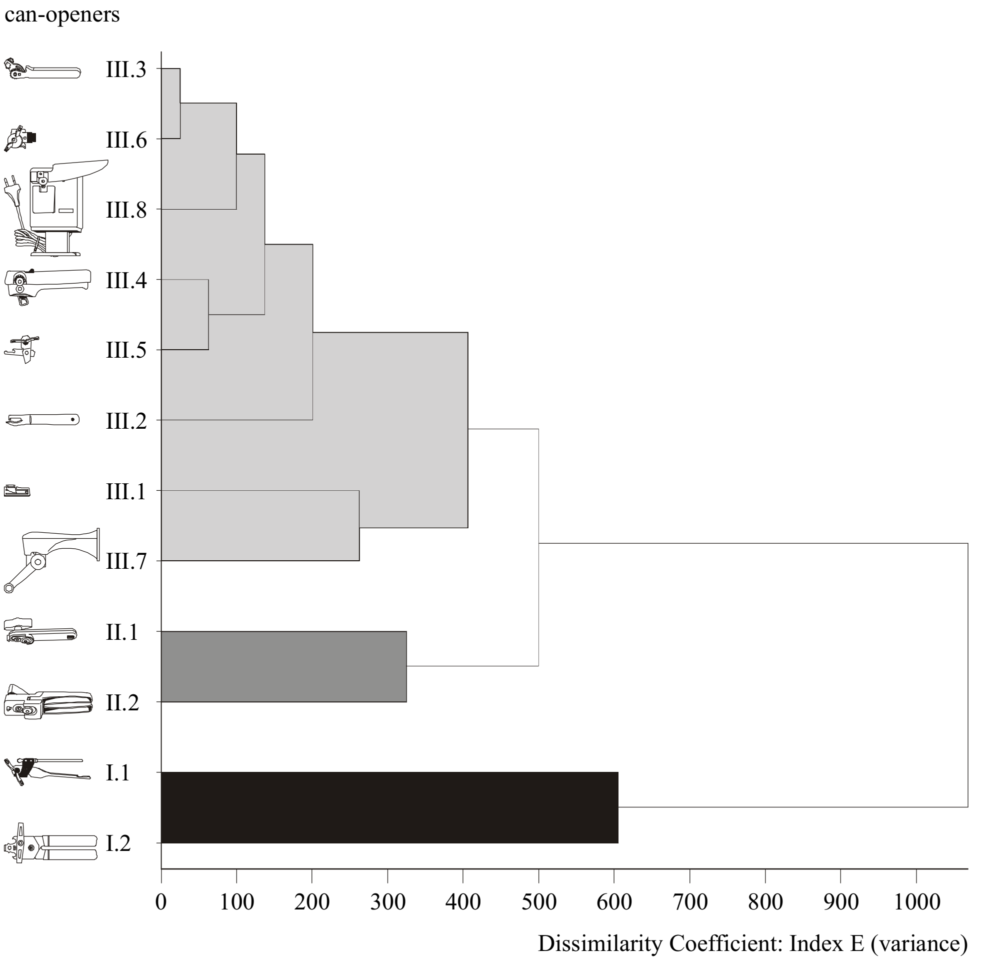


Figure 2.1
Dendogram, based on cluster analysis, illustrating the dissimilarities between the can-openers. The highest dissimilarity scores were used to distinguish between three groups of can-openers.

2.2.2 Results

Familiarity with the can-openers ranged from 10% to 98%. A complete overview of the familiarity scores is provided in Appendix A. On the basis of the combination of the two familiarity scores (model used at home and models used in the past) a cluster analysis was made according to Ward's Clustering Method. This method clusters models in order of increasing dissimilarity. The result is illustrated

in a dendogram in Figure 2.1. Larger pen-drawings of the can-openers corresponding to the numbers mentioned in Figure 2.1 can be found in Appendix B, which is a reproduction of the checklist given to the subjects.
On the basis of the clustering, three sub-groups are distinguished. The three highest dissimilarity scores were used for this distinction. Conveniently, the first group contains two can-openers with a high familiarity level (the black area in Figure 2.1), the second contains two can-openers with a low familiarity level (the dark-grey area) and the third contains eight can-openers with variable familiarity levels (the light-grey area). The can-openers are numbered according to the three distinguished groups. On the basis of these results, in the following experiments, the models from the black area will be considered to be familiar while models from the dark-grey area will be considered to be unfamiliar. The groups with the extreme familiarity levels (high and low) differ from each other on the operating mechanism. The difference is illustrated in Figure 2.2.

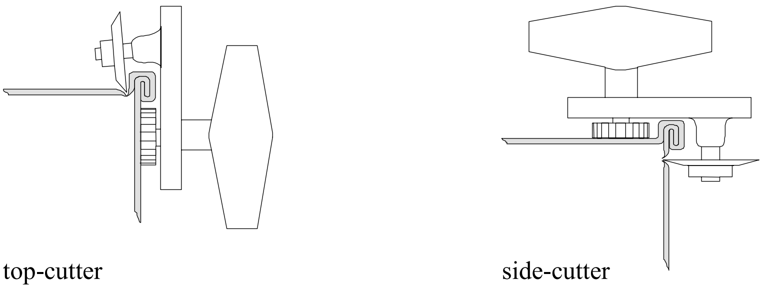


Figure 2.2
Two opening principles for can-openers. Left the familiar principle, right the less familiar principle.

Can-openers of the familiar cluster open a can by cutting through the lid (top-cutter). Can-openers in the unfamiliar cluster open a can by cutting through the side just underneath the rim (side-cutter). Most can-openers available in the Netherlands are top-cutters and all subjects (100%) were familiar with at least one of the top-cutting can-openers. The side-cutters were mentioned less: 39% of the subjects claimed to be familiar with one of the two side-cutters presented in the list. Only 8.5% of the subjects indicated regular usage of one of the side-cutters. An overview of the familiarity scores is given in Appendix A.
A significant effect was found to be due to sheet order, determining the sequence in which the can-openers were presented (Chi square test; $p<0.01$). Openers on the top sheet were more often selected than openers on the second sheet.

2.2.3 Conclusions

The aim of this survey was to establish a general impression of the familiarity of the users with different can-opener models

Familiarity of can-openers

The survey did show a range in familiarity scores for the can-opener models. Within this range three groups were distinguished. The two groups with the two most extreme familiarity scores differ mainly in functioning principle. In following experiments the distinction between top-cutters and side-cutters will be used to determine familiar and unfamiliar can-opener models.
As mentioned, the results of the survey only indicate the range of familiarity for the participating population and do not necessarily account for the familiarity per individual.

Sequence effect

The influence of the sequence in which the sheets were handed out indicates that the results obtained should be regarded with caution. If can-openers on the top sheet have a higher chance of being selected by both groups this could mean that subjects make a less than accurate selection of the can-opener models on the basis of the pictures provided. An explanation could be that the resemblance in appearance between the various can-openers misled subjects into recognising can-opener models. This similarity might also mislead users when operating unfamiliar can-opener models. This is further addressed in the following two experiments.

2.3 Experiment 1, can-openers

The aim of Experiment 1 is to explore how users' knowledge influences the operation of models which are unfamiliar but have a familiar product function. Users' knowledge was investigated by exploring mental representations, containing knowledge of a device and its operation. Subjects were asked to draw 'a can-opener' while verbally explaining its operation, and were also questioned about their experience with can-openers. The influence of available knowledge on can-opener operation was examined by observing and comparing the operation of both familiar and unfamiliar can-openers.
The familiarity with a product may concern three aspects of the device, the function, the type and the model (see Section 1.4). In this experiment there is only a single product function, familiar to all subjects. However, the used models and their type can be both familiar and unfamiliar.

- When a model is familiar it means that the applied functioning principle is also familiar (***fam****iliar***Mod**el, ***fam****iliar***Typ**e).

- A model might be unfamiliar to the user, while the operating principle, its type, is familiar (*unfam*Mod, *fam*Typ).
- A model is unfamiliar as model and as type (*unfam*Mod, *unfam*Typ).

The fourth combination, a familiar model of an unfamiliar type (*fam*Mod, *unfam*Typ) is, of course**,** not possible. The indicated abbreviations will be used throughout this chapter.

2.3.1 Method

Subjects

Twenty-three subjects participated in this experiment. These subjects were members of a university subject panel. The panel consisted of a heterogeneous group of inhabitants of the city of Delft, who regularly participate in experiments. From this panel the subjects were selected only on the basis of their age, i.e. between 35 and 55 years.

Procedure

After an introduction in which the topic and the purpose of the experiment were briefly explained, three tasks had to be performed. Each subject performed these experimental tasks individually. Subjects were asked to;

- make a drawing of their image of 'a can-opener' and at the same time explain the way in which it functions.
- operate four different can-openers. These openers were selected on the basis of the two operating systems illustrated in Figure 2.2, i.e. two side-cutters and two top-cutters.

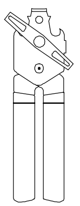
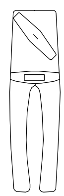
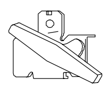
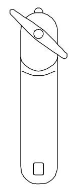
To establish the experience of each subject with can-openers, the pen drawings used in the survey study were presented. If the subjects had indicated, while sketching, that they had a specific model in mind they were asked to select that model from the provided drawings. Following this the subjects were asked to a) select the drawing that resembled their own can-opener and b) to mention which of the other represented openers they had used before.
Subjects were instructed to think aloud while performing the tasks

Included can-openers

In Table 2.1 the operating sequence during the experiment is combined with illustrations of the four models. In addition, the assumed familiarity regarding type and model is indicated. An identical opener to the can-opener which the subjects had described as 'their own opener' was the first to be operated (*fam*Mod, *fam*Typ). In Table 2.1.only one example of the models mentioned is shown (model O). With one exception, for all the subjects the opener(s) described as their own was a top-

cutter. This exception was a subject who also described a side-cutter.
The second opener, model A, was a side-cutter (*unfam*Mod, *unfam*Typ), the third, model B, was a (*unfam*Mod, *fam*Typ). Finally, subjects were asked to operate another unfamiliar side-cutter, model C. The type was familiar since it was identical to model A (presented earlier in the sequence) but the model itself was unfamiliar (*unfam*Mod, *fam*Typ).

Table 2.1
Summary of characteristics of the can-openers in Experiment 1, this model O is just one example of the 'own' models mentioned.

operating sequence	1st	2nd	3rd	4th
				
model	O (own)	A	B	C
type	top cutter	side cutter	top cutter	side cutter
model familiar	yes	no	no	no
type familiar	yes	no	yes	yes

The subjects' own opener, model O (*fam*Mod, *fam*Typ) was included in order to register the most well-trained operating behaviour. Model A (*unfam*Mod, *unfam*Typ) was included to see how knowledge of the familiar opener would influence the operation of a can-opener with unfamiliar functioning and partially corresponding appearance. Model B (*unfam*Mod, *fam*Typ) was included to see how subjects would perform with a can-opener with familiar functioning but of different appearance. Model C (*unfam*Mod, *fam*Typ) was included to see how newly acquired operational knowledge, gathered during the operation of the previous can-openers, would influence the operation of a can-opener which

functioned according to the newly-discovered principle but was still unfamiliar in appearance.
If subjects were not able to open the can with one of the can-openers after four minutes they were given hints by the experimenter to guide them towards the solution. All the subjects' actions and comments were recorded on video.

2.3.2 Results

Task I; making a drawing

All subjects indicated that drawing a can-opener was a difficult task and that they had difficulty producing a consistent representation of a can-opener. An example of the drawings made is shown in Figure 2.3. Reproductions of all the drawings made by the subjects are provided in Appendix C.

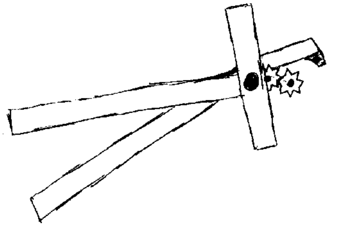


Figure 2.3
Example of subject's drawing of 'a can-opener'.

Combining the drawings and the accompanying comments of the subjects indicated that the drawings were realised by adding various parts of the opener, e.g., handles, knife and rotating control. These parts were linked by a description of their functional relationship. For example: ".. *and then there is this turning control which must be rotated to make the knife cut through the lid*." However, the mechanical relationship between the parts was not clearly stated, neither in the drawings nor in the comments, as illustrated by: "..*and there is a second gearwheel somehow linked to the mechanism*" (see Figure 2.3).

An overview of the drawings is given in Table 2.2. Five subjects drew more than one model, therefore the total number of drawings made exceeded the total number of subjects. One subject was familiar with a supposedly unfamiliar principle and she sketched, and later selected from the line drawings, one of the side-cutters. One sketched model could not be recognised on the basis of the drawings, nor on the comments. The models are referred to by the same coding as used in Appendix B. All but one of the subjects drew a can-opener model which they used themselves on a daily basis. All subjects mentioned as parts, for at least one of the models drawn, a) the handles (for Model I.1 a base frame was mentioned since this model has no handles), b) a rotating device and c) a part for cutting (either a wheel or a knife). Less frequently a grip wheel was mentioned.

Table 2.2
Drawing results in figures.

models per drawing	**subjects**	**models sketched**
1	18	18
2	4	8
3	1	3
total	23	29

model (see Fig 2.1)	**models sketched**
I.1	10
I.2	13
II.1	1
III.1	4
undetermined	1
total	29

frequency of use	**models sketched**
daily	26
incidental	3
total	29

parts	**number mentioned and/or sketched**
handles	24
base frame	4
rotating device	24
grip wheel	15
cutting wheel	13
cutting knife	12
total	92
average per drawing	3.2

Task II; operating the can-openers
The operations of the subjects are quantified by number of trials. A trial is a sequence of actions which starts when the opener is placed on the can and ends when the opener is removed from the can. The average number of trials needed to open a can with model O (the 'own' model) (*fam*Mod, *fam*Typ) was one, the lowest possible score. In operating model A (*unfam*Mod, *unfam*Typ) subjects needed, on

average, considerably more trials to open the can. For the operation of top-cutter B (*unfam*Mod, *fam*Typ) and side-cutter C (*unfam*Mod, *fam*Typ) subjects needed less trials compared to the operation of model A. The average results and ranges are illustrated in Figure 2.4.

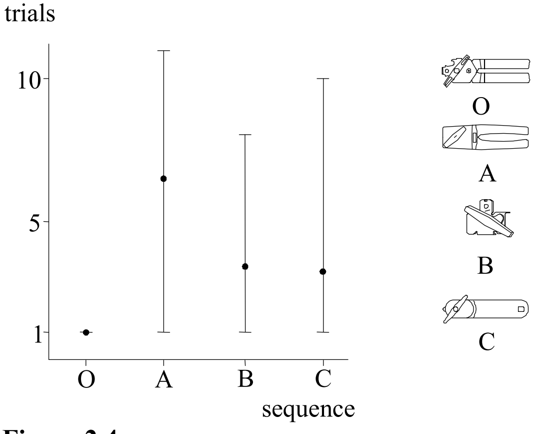


Figure 2.4
Averages and ranges of number of trials needed for the operation of can-openers.

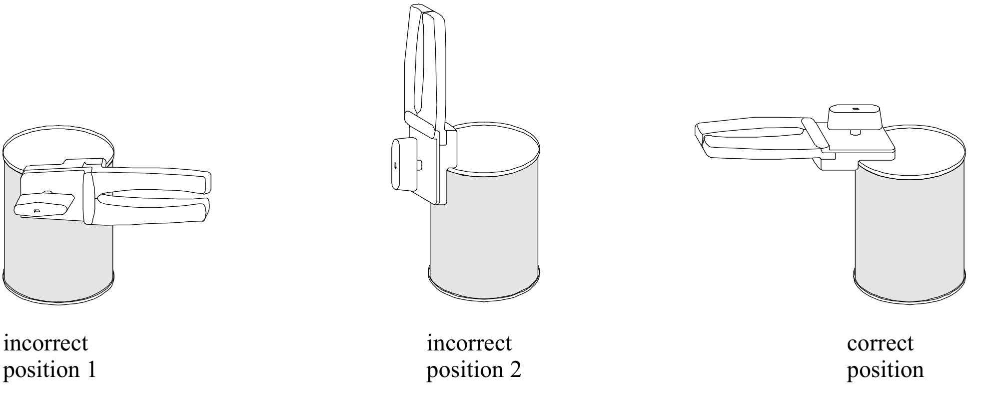


Figure 2.5
Three common positions in which the side cutters were held.

In operating model O (*fam*Mod, *fam*Typ) subjects showed automated behaviour. They were unable to verbalise this behaviour and no mental effort was involved. When asked to verbalise their considerations subjects simply said to: "*...just put it in its place and rotate the control*". While using model A (*unfam*Mod, *unfam*Typ) subjects showed surprise at not being able to open the can. Although they were well aware of the problem they were facing this did not lead to a successful result. Nearly all subjects repeatedly applied the same, inappropriate position 2 (Figure 2.5) and only one subject was able to find the appropriate position without the help of the experimenter. This subject, however, already had experience with the side-cutting principle. During their attempts to find the correct position in which to hold the can-opener subjects were observing the can-openers' mechanism.

In trying to operate the side-cutter A (*unfam*Mod, *unfam*Typ) subjects held the opener in different positions. Three of these positions are shown in Figure 2.5. Positions 1 and 2 were common but incorrect. In incorrect position 1 the opener is held in the same position as a top-cutter and in incorrect position 2 the opener is held in such a way that the cutting wheel and grip-wheel are in the same position**,** as they are with top-cutters. Of all trials 9.8 % were in position 1 and 47% in position 2. Both positions were assumed to be related to the experience with the familiar top-cutter can-opener and this was confirmed by the subjects' comments.

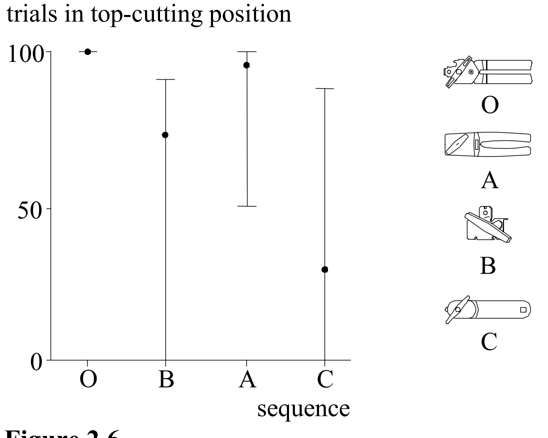


Figure 2.6
Averages and ranges of percentages of top-cutting positions, incorrect for the side-cutter.

In Figure 2.6 the percentage of top-cutter related positions out of the total amount of trials is given for the four different can-openers. For the top-cutters (O & B) this was the correct position but for the side-cutters (A & C) this position cannot lead to the opening of the can. With the exception of one subject, all were successful in operating side-cutter C (*unfam*Mod, *fam*Typ)**,** but the successful subjects all needed several trials before they achieved the correct position.
Details of the results of Experiment 1 are provided in Appendix A.

2.3.3 Conclusions

The aim of the experiment was to explore the influence of users' knowledge during the operation of a product.

Sketching a mental representation of a can-openers

The drawings made by the subjects show that a mental representation of can-openers can be made explicit. Subjects said they had a specific model in mind while drawing, and in all but one case this model is the one they use themselves daily. The actual models drawn are the same as the models mentioned most frequently in the survey study.

These representations of 'a can-opener' are, however, incomplete as supposed by Norman (1983). Subjects sketch a limited number of parts and mention the required manipulations as a description of how a can-opener works, but they are unable to explain the functioning of a can-opener, they only explain its manipulation.

Can-opener operating difficulties

Although the mental representations may be incomplete, the success rates showed that this does not prevent the operation of a can-opener, as long as it is of a familiar type. Operational difficulties emerge when subjects try to use an unfamiliar can-opener model.

I. Unfamiliar model but familiar type

When asked to operate model B (*unfam*Mod, *fam*Typ) the number of trials needed was higher in comparison to the number required for their own opener, model O, (*fam*Mod, *fam*Typ)**,** but most of the subjects were able to find the appropriate position for this opener after some trials. The differences in appearance between the model O and model B did not prohibit a successful operation.

II. Unfamiliar model and unfamiliar type.

Serious operating difficulties were observed when not only the can-opener model was unfamiliar but it also functioned according to an unfamiliar principle (*unfam*Mod, *unfam*Typ).

No subject unfamiliar with the side-cutting principle was successful in operating model A (*unfam*Mod, *unfam*Typ) without help. Subjects tried to apply the familiar operating procedure, with some minor deviations, and did not seem to question the fact that the opener should cut through the top of the can. A possibly misleading factor is that the difference between the appearance of models O and A is small. The parts mentioned in the drawings are all available in model A, making it an obvious can-opener.

When the applied position failed to lead to the expected result subjects explained the repeated application of the position by stating that they might have applied the position incorrectly or perhaps the device was out of order. Two subjects even wondered whether they were being fooled.

2.4 Experiment 2, can-openers and corkscrews

Experiment 1 showed that subjects found it difficult to operate an unfamiliar product with a familiar product-function. The operational difficulties were assumed to be caused by the fixation of the subjects on pre-learned operating knowledge, linked to the task of operating a can-opener. This fixation could be caused by a similarity in appearance between the familiar and the unfamiliar can-opener, but also by the fact that the can-openers have the same function.
On the basis of Experiment 1 no definite conclusion could be reached as to the cause of the fixation. The main reason for this uncertainty was the absence of sequence variation between the groups of subjects. Furthermore, the appearance of the selected can-opener models could, in combination, have misled the subjects, leading to the operational difficulties. Finally, the reinforcement of subjects' experience prior to the experimental tasks may have had a priming effect. The aim of Experiment 2 is to increase the understanding of the role of user knowledge, acquired both prior to and during the experimental operations. The findings of Experiment 1 can also be replicated.

In order to do this, Experiment 2 involves the operation of familiar and unfamiliar products with familiar functions. Unlike Experiment 1, the products are used in different sequences by groups of subjects and another product, a corkscrew, is added.
With the inclusion of a second product-function an attempt was made to replicate the operational difficulties observed with the can-openers. The corkscrews were presented to the subjects in a similar sequence to that of the can-openers, so that a comparison between the two product functions could be made. The variation of the sequence in which the models are presented to different groups of subjects made possible consideration of the transfer of acquired knowledge from the operation of one model to the operation of the next. By comparing operations of the same model by different groups of subjects in different locations in the sequential strings**,** the operation of all models without any operating knowledge acquired during the experiment can be observed. To get an additional view on the learning effect during the experiment, subjects were asked to repeat the operation of one of the unfamiliar models after operating the three models.
In Experiment 1, when subjects were asked to demonstrate the operation of their own can-opener (*fam*Mod, *fam*Typ) it showed, not surprisingly, that the subjects

were experts with that can-opener. The operation was successfully performed without any hesitation. Having witnessed this in Experiment 1 it was considered unnecessary to include the ‘own’ can-opener in a subsequent experiment. The repeated registration of trouble-free operation would add little to the search for factors influencing operational difficulties. Also, the omission of the 'own' can-opener lowers the chance of unwanted contributing to the fixation effect, witnessed in Experiment 1.

2.4.1 Method

Subjects

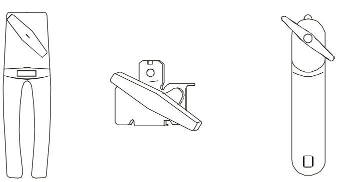
The subjects were 27 members of the same panel from which the subjects of Experiment 1 were recruited. As in Experiment 1 the subjects were selected from the 35-55 age group. In addition, the number of males and females participating was balanced. None of the subjects had participated in Experiment 1.

Procedure

Subjects were given a brief introduction explaining the purpose of the experiment and then two experimental tasks were performed.

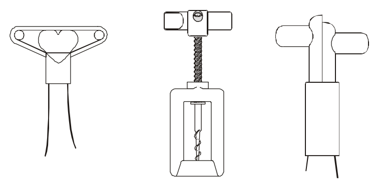
Task I; operating can-openers

Each subject was asked to operate three different can-openers (Figure 2.7). One of these can-openers was 'top-cutter' model B. However, while the mechanical principle was familiar, the shape of the can-opener - without handles - was not (*unfam*Mod, *fam*Typ). The other two openers were 'side-cutters' models A and C. These were known to be unfamiliar to the subjects both in model and type (*unfam*Mod, *unfam*Typ*).



A side | B top | C side

Figure 2.7
Three can-opener models.



A side | B centre | C side

Figure 2.8
Three corkscrew models.

* As in Experiment 1 the type of these models changes during the experiment from unfamiliar to familiar.

In Figure 2.2 the difference between top-cutter and side-cutter is illustrated. The different sequences in which the products were operated are mentioned in Table 2.3.

Task II; operating corkscrews
The subjects were next asked to operate three different corkscrews models (Figure 2.8). To make a comparison with the can-openers, similar circumstances had to be established. The function of a corkscrew was considered familiar and a large number of different corkscrew models are available. Among these models different functioning mechanisms can be found. The most common is a spiral that is rotated into the cork to provide a grip on it. The cork can then be pulled out, either by direct manual force or by some mechanical transmission such as levers or threads. The very word cork*screw* already indicates such a functioning. This mechanical functioning was regarded as familiar. Model B functions according to this principle (*unfam*Mod, *fam*Typ). In contrast a different functioning was chosen for the unfamiliar type. A survey was not conducted (see Section 2.2), since such a study could only give an indication of familiarity in general. Moreover, the unfamiliar type of corkscrew had to have a different functioning mechanism in order to create a comparable situation to that of the can-openers. With this particular unfamiliar 'corkscrew' the cork is removed by means of two metal blades which are inserted between the cork and the bottle. The cork can then be twisted out (models A and C). This method of removal was presumed to be unfamiliar to the subjects (*unfam*Mod, *unfam*Typ[*]). Afterwards this proved to have been the case.

Although the differences in operating principle were now comparable to those of the can-openers this does not mean that the differences in appearance between the corkscrews and the can-openers are identical. With the corkscrews the difference in appearance between the familiar and the unfamiliar types seems more obvious than for the two types of can-openers.

Sequences
The sequences in which the can-openers and corkscrews were presented were identical. Based on Experiment 1 it is expected that acquired knowledge within the experiment influences the operation of the unfamiliar types. For this reason only unfamiliar models were used in this experiment. Model B is of a familiar type (*unfam*Mod, *fam*Typ), the models A and C are not (*unfam*Mod, *unfam*Typ). Two groups started with model B followed by A and C (or C and A). The other two groups started with either A and C (or C and A) which were followed by model B.

[*] As with the can-openers, the familiarity of the type of corkscrews of the unfamiliar models changes during the experiment from unfamiliar to familiar.

Whether or not the type of model A and C was familiar at a certain point depended on the sequence. Operated as first, the type was unfamiliar (*unfam*Mod, *unfam*Typ) and operated as second, the type was familiar (*unfam*Mod, *fam*Typ). The sequence in which model B was operated between A and C is not included in this experiment since this was already observed in Experiment 1. In Table 2.3 the applied sequences are summarised.

Table 2.3
Overview of the sequences in which the corkscrews were presented.

1	**B** (*unfam*Mod,*fam*Typ)	**A** (*unfam*Mod,*unfam*Typ)	**C** (*unfam*Mod,*fam*Typ)
2	**B** (*unfam*Mod,*fam*Typ)	**C** (*unfam*Mod,*unfam*Typ)	**A** (*unfam*Mod,*fam*Typ)
3	**A** (*unfam*Mod,*unfam*Typ)	**C** (*unfam*Mod,*fam*Typ)	**B** (*unfam*Mod,*fam*Typ)
4	**C** (*unfam*Mod,*unfam*Typ)	**A** (*unfam*Mod,*fam*Typ)	**B** (*unfam*Mod,*fam*Typ)

The meaning of the sequences
Subjects starting with model B were confirmed in their pre-learned operating procedures and then challenged to find an alternative procedure for model A or C. Subjects starting with either model A or C were given no reinforcement on the pre-learned operating procedure within the experiment. Instead, they were confronted with a new operating procedure to be applied for the second model**,** but which was in turn not applicable for the third model. Finally, the comparison between subjects operating A after C versus C after A produced information on the possible influence the differences in appearance had in finding the alternative operating procedure.
After the subjects had operated the three different products they were asked once more to operate the first model with the unfamiliar principle (*unfam*Mod, *unfam*Typ). This was either model A or C, depending on their sequence group. Because subjects had operated this model previously, the fourth model was by this time familiar both as model and as type (*fam*Mod, *fam*Typ). This repetition was introduced to observe how well subjects reproduced the newly learned operating procedure on the same type.

Subjects were again asked to think aloud while operating the products. If they were not able to open the can within 4 minutes they were given hints by the experimenter to guide them towards the solution. Subjects were asked first to open cans and then to remove corks from wine bottles. After the experimental tasks the experience of the subjects with the product function was investigated by asking them to select the models they were already familiar with. The subjects' operations and corresponding comments were recorded on video.

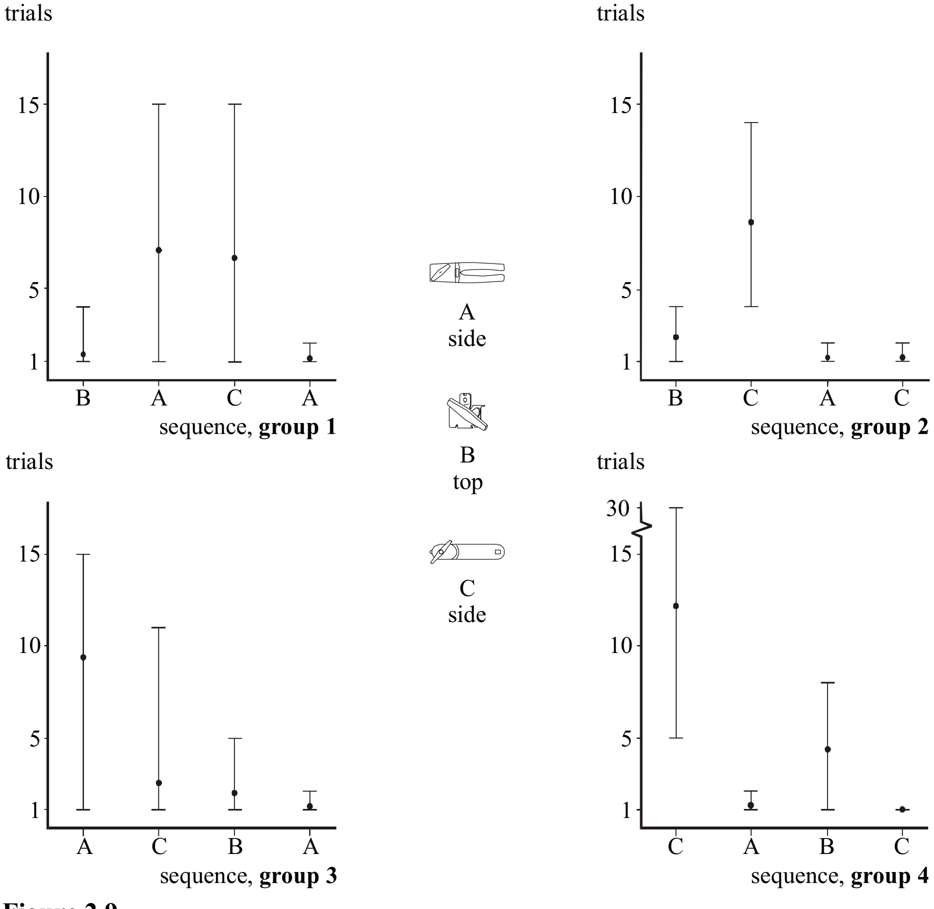


Figure 2.9
Averages and ranges of number of trials subjects took to operate the can-openers. Each graph depicts a sequence group.

2.4.2 Results

Can-openers

Figure 2.9 shows the average number of trials with different can-openers. In the first graph the numbers of trials are shown for those subjects who started with model A (sequence groups 1 and 2). In the second graph the numbers of trials are shown for the subjects who started with model B or C (sequence groups 3 and 4). By comparing the numbers of trials needed for different can-openers, or the same can-openers in different places in the sequence, the influence of learning within the experiment can be established.

The sequence in which the can-openers were operated clearly had an influence on performance. Starting with opener A (*unfam*Mod, *fam*Typ) subjects needed fewer trials to operate this model, but the operation of the same model after operating the models B and C needed slightly more trials (significant between group 1 and 4, Wilcoxon Mann-Whitney; p=0.015). Model A after the sequence B - C (group 3), needed significantly less trials than after the sequence C - B (group 4) (Wilcoxon Mann-Whitney; p=0.022).
Overall the operation of the first unfamiliar type (A or C) needed the highest number of trials in all groups. Specifically, this first unfamiliar can-opener needed significantly more trials than model A within Groups 3 and 4 (group 3, Wilcoxon signed ranks test, p=0.003; group 4, p=0.02). Within each sequence group the first side-cutter needed significantly more trials than the second side-cutter except for Group 1 (Wilcoxon signed ranks test, group 2, p= 0.063; group 3, p=0.004; group 4, p=0.002).

There was no difference in the numbers of trials needed between the second side-cutter (*unfam*Mod, *fam*Typ) and model A (*unfam*Mod, *fam*Typ) within groups, except for Group 4, where A needed more trials. (Wilcoxon signed ranks test, p=0.008).
For the operation of model B less trials were needed compared to model C, both used as first unfamiliar type (Wilcoxon Mann-Whitney, p=0.000; p=0.073).

Based on Experiment 1 it was expected that the subjects would start holding the side-cutters in the 'top-cutter position'(see Figure 2.5). Figure 2.10 shows the averages and ranges of percentages of this phenomena out of a total number of trials for each model. In reading the graph it is important to realise that the top-cutter position, when applied to a top-cutter, leads to success but applied to a side-cutter can not lead to success.

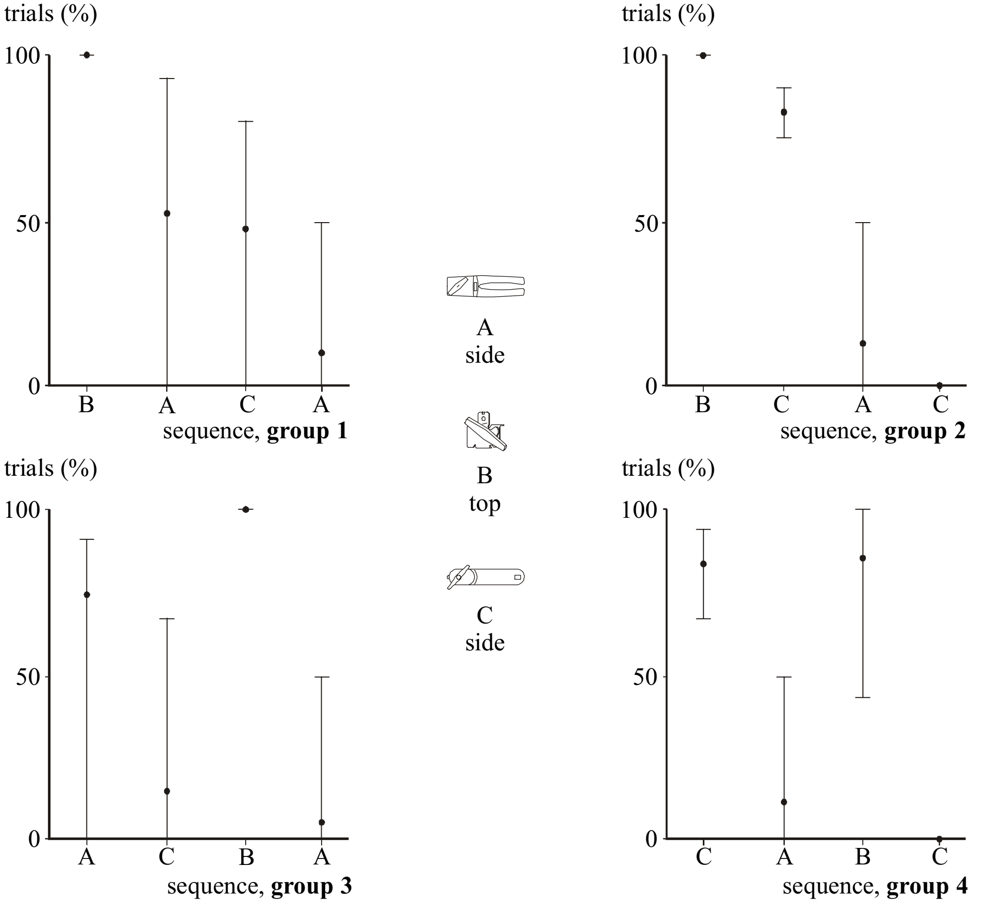


Figure 2.10
Averages and ranges of percentages of top-cutting positions, incorrect for the side-cutters.

Subjects in Group 1 and 2 who started with model A all (100 %) applied the appropriate top-cutter position. The same can-opener used after the two side-cutters (group 4) gave some false positions before the correct position was found. When starting with one of the side-cutters, 74% of the trials in Group 3 and 83% of the trials in Group 4 were in top-cutter positions. When a side-cutter was used after a top-cutter in Group 2 a similar percentage of the wrong position was found (82%) but in Group 1 a lower percentage was observed (52%). On the other hand, an obvious finding was the decrease in wrong positions when the side-cutter principle was used a second time. (significant for groups 2, 3 and 4, Wilcoxon signed ranks; respectively p=0.063, p=0.002, p=0.002).
Model B was easier to operate than C when used as second side-cutter (Wilcoxon

Mann-Whitney, p=0.016; p=0.021). Details of the results of Experiment 2 are summarised in Appendix A.

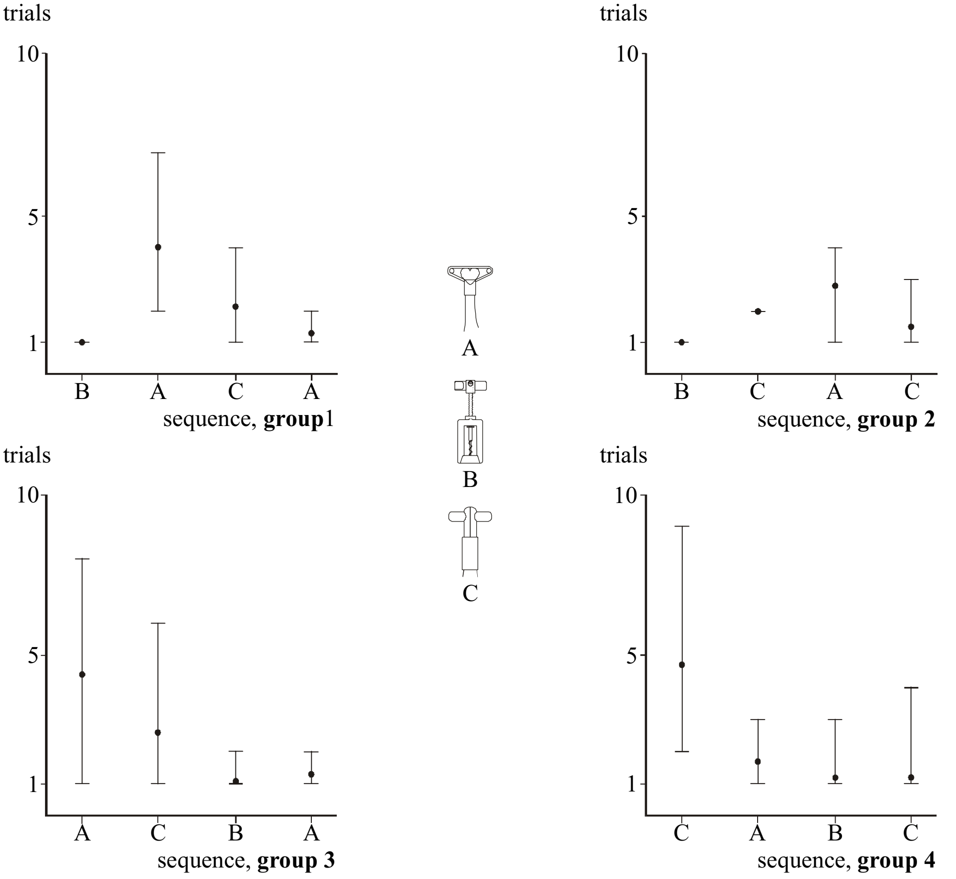


Figure 2.11
Averages and ranges of the number of trials subjects took to operate the corkscrews.

Corkscrews
In Figure 2.11 the range and average number of trials with the corkscrews are presented. In the first graph the numbers of trials are shown for the subjects in sequence Groups 1 and 2 who started with corkscrew B (*unfam*Mod, *fam*Typ). The second graph shows the numbers of trials for the subjects in sequence Groups 3 and 4 who started with either corkscrew A or C (*unfam*Mod, *unfam*Typ). When starting with model B (*unfam*Mod, *fam*Typ) the subjects had no difficulties, they opened the bottle with this type in one trial. After model A or C (*unfam*Mod, *unfam*Typ) it took on average more trials. This difference is only significant within Group 1, between B and A (Wilcoxon signed ranks test, p=0.031). The subjects

starting with model A or C (*unfam*Mod, *unfam*Typ) needed the highest number of trials for this. The number of trials decreased with the second model C or A (*unfam*Mod, *fam*Typ) (within group 3, A and C; p=0.037, within group 4 , C and A; p=0.003) and lowered to the optimum of only one trial with the third opener model B (*unfam*Mod, *fam*Typ). Difficulties occurring in all sequence groups with model B did not concern the way to position the corkscrew on the bottle, but the way to withdraw the cork from the bottle.

Difficulties in operating the unfamiliar types, models A and C, did concern the position of the opener in relation to the bottle. Different positions and procedures were tried. For this reason, as with the can-openers, the positions in which the models were applied were analysed. In Figure 2.12 the correct positions for both the familiar and the unfamiliar types of corkscrew are illustrated. The corresponding familiar position will be referred to as 'centre position' and the unfamiliar as 'side position'. The centre-position not only refers to the position in which the screw or blades are placed but also to the subsequent rotating movement.

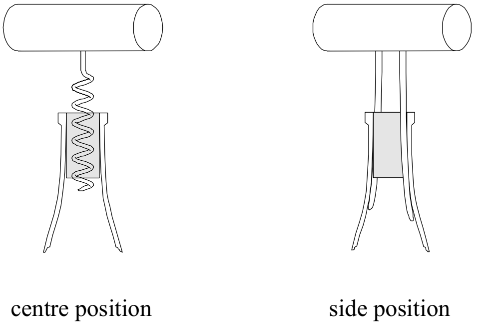


Figure 2.12
Correct positions for the familiar and the unfamiliar types of corkscrew (schematic view).

In Figure 2.13 the range and average number of centre positions are given in percentages for the first three models in all four sequences. The positioning of the spiral of model A in the cork in this position is correct, but the same position applied with the unfamiliar type of corkscrew, models B and C, is incorrect. Those subjects starting with corkscrew A all (100%) applied the correct centre-position. When starting with model B or C, 27% and 34% respectively of all trials were in the centre position. Whether or not an unfamiliar type, e.g. model B or C, (*unfam*Mod, *unfam*Typ) is preceded by model A (*unfam*Mod, *fam*Typ) does not make a substantial difference to the number of wrongly applied positions (p>0.2).

The decrease in the number of wrong positions when the second unfamiliar type (*unfam*Mod, *fam*Typ) is used, as observed with the can-openers, can again be recognised. The percentage of wrongly applied positions with the first unfamiliar type (*unfam*Mod, *unfam*Typ) however, was lower in comparison to that of the can-openers, and consequently the decrease in the number of incorrectly applied centre positions was less (Wilcoxon signed ranks test, p=0.063; p=0.063; p=0.219; p=0.008). Details of the results of Experiment 2 are presented in Appendix A.

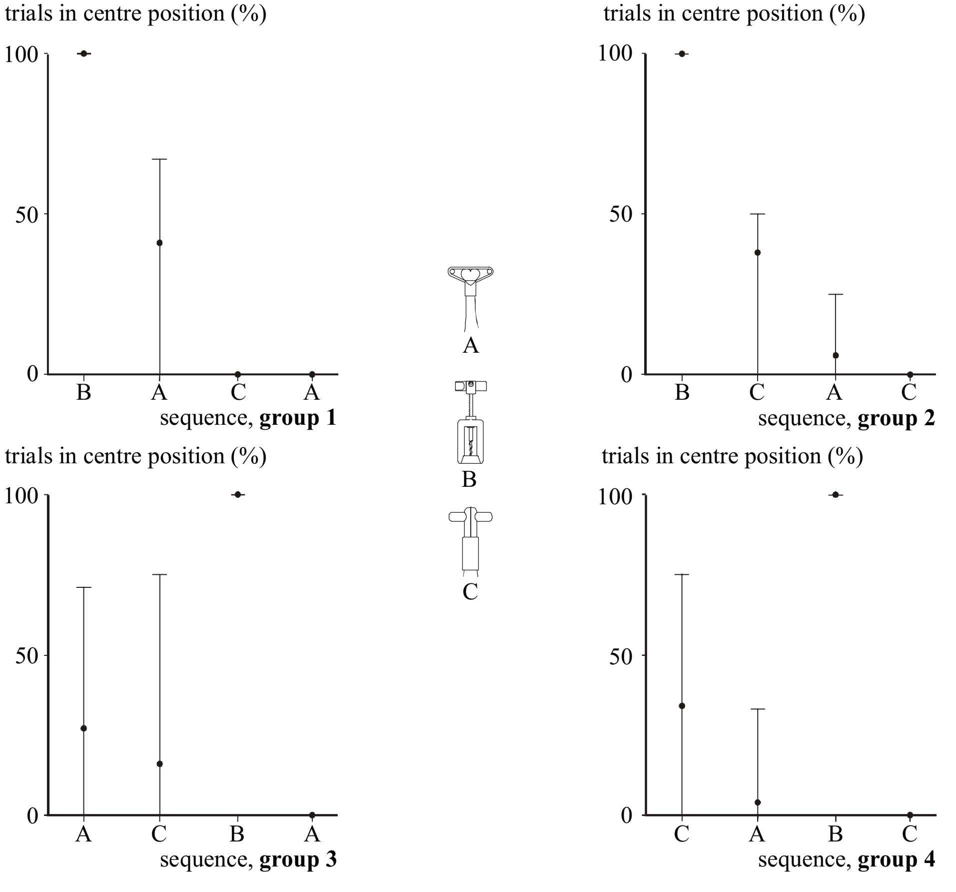


Figure 2.13
Averages and ranges of percentages of centre positions, incorrect for the unfamiliar type.

2.4.3 Conclusions

The aim of Experiment 2 was to investigate further the effects, found in Experiment 1, of users' knowledge on operating behaviour. It meant replicating and refining the results of Experiment 1 by controlling for carry-over effects and by evoking similar results with another product function (corkscrew).

Replication of Experiment 1

In general the results of this experiment replicate those of the Experiment 1. Again subjects are shown to be - as Reason (1990) states it - *furious pattern matchers*, i.e. they persist in applying the pre-established procedure on the unfamiliar can-opener types. They also show trial and error behaviour without evidence for knowledge-based reasoning. At first, subjects tried to operate the unfamiliar can-opener type (*unfam*Mod, *unfam*Typ) in the same position in which a familiar type of can-opener was operated. The comments of the subjects during their efforts indicated that they were trying to find a way to position the cutting and transportation wheel in a familiar position.

Carry-over effects

Three types of carry over effects were witnessed.

- Presenting a familiar can-opener type after an unfamiliar type led to a need for more trials.
- Subjects learn from their interaction with the models. The second time the subjects could all open the can using an unfamiliar type of can-opener, although a number of subjects still began by applying the procedure for the familiar type of can-opener.
- Sequence variation showed a difference in difficulty between the two unfamiliar types of can-openers. Operating A after C was easier than vice versa. This difference is referred to as asymmetrical transfer (Poulton, 1968)

Corkscrew

Surprisingly, the inclusion of the corkscrew in the experiment showed similar operating difficulties to those encountered with the can-openers. Surprisingly because the differences in shape and mechanics between the familiar and the unfamiliar versions of the corkscrew would seem to be more obvious; completely different parts could be recognised. Nonetheless, some subjects tried to use the blades of the unfamiliar type of corkscrew in a similar manner to the spiral of the familiar type. Yet in contrast to the can-openers, more than half of the subjects were able to find the appropriate operation for the unfamiliar type of corkscrews. Hence, in comparison to the can-openers, the impact of the introduction of a unfamiliar type of corkscrew was less dramatic. But the nature of the problems and the fixation on familiar operations remained the same.

2.5 Discussion

The aim of the experiments in this chapter was to explore the relation between the use of domestic utensils with a familiar function and the familiarity of their type and/or model

Summarised Experiment 1, involving can-openers, led to three observations.
- Subjects had difficulties making a drawing of 'a can-opener'. It proved to be hard to produce a coherent drawing of a functioning can-opener. Instead subjects drew a collection of parts and gave incomplete verbal descriptions of the relationship between those parts. The descriptions of the functioning of the can-openers were limited to a general description of their operating procedures.
- During the operation of the subjects' own can-opener model it proved to be hard to verbalise the displayed operation. Subjects had already operated the model before they could explain what they were doing. In retrospect, the verbal descriptions covered global actions and not the reasons or considerations behind those actions.

These two problems are, of course, only problematic in the context of the experiment. Neither of the two inhibited the operation of the familiar can-opener.

- Difficulties in performance on the can-opening task were observed when the subjects were asked to use an unfamiliar can-opener model. When this model was of a familiar type the difficulties could be overcome, but when this model was of an unfamiliar type the difficulties persisted. In the latter case subjects seemed to be fixated on a familiar operating procedure, even though this procedure could not lead to success. Once the new operation was accidentally found, or explained by the experimenter, subjects were able to apply this operating procedure successfully when asked to operate a second model of this unfamiliar type.

Experiment 2 demonstrated, together with some of the difficulties mentioned above, three additional observations.
- The position in the sequence in which an unfamiliar type was presented influenced performance. One model proved to be harder to operate than another.
- Subjects who had just become familiar with a new operating procedure for an unfamiliar type of can-opener experienced more difficulties when returning to an already familiar type compared to subjects who were not yet familiar with the new type.

- When asked to operate different types of corkscrews, fewer difficulties were observed when operating the unfamiliar type compared to that of a can-opener, but the nature of the operating behaviour was essentially identical. Although subjects indicated that applying the familiar operating procedure was unlikely to succeed because of the absence of the required parts, they nevertheless applied this familiar operating procedure to the unfamiliar type of corkscrew.

Interpretation
In combination these statements lead to the assumption of mechanisms involved in the acquisition and application of experience in operating products.

Fixation
It proved to be very difficult to operate an unfamiliar product (*unfam*Mod, *unfam*Typ). Most subjects began their attempts to operate the unfamiliar type of can-opener by trying to apply the rule they had used while operating the familiar type of can-opener. If this rule proved to be inapplicable, subjects tried to find a new way of operating the can-opener. The great difficulty subjects had in actually finding the right way to operate the product can be explained by the way Rasmussen (1990) describes a 'knowledge based' mental model; "*..the mental model is a representation of the fundamental constraints determining the possible behaviour of the environment*." Although behaviour then becomes goal-orientated and a solution is sought on how to reach the goal, either by physical trials (and errors) or by thought experiments, it is restricted by constraints imposed by the mental model. It can therefore be concluded that subjects were imprisoned within the constraints of their mental model; fixated.
Usually relying on pre-learned operations is an efficient strategy, however in this experiment this efficient strategy turned into a disadvantageous fixation. Other authors found similar effects. Luchins (1942) already investigated this effect, referred to as 'Einstellung'. As a general problem-solving phenomenon the topic has been re-addressed more recently (Fingerman & Levine, 1974; McKelvie, 1985; Lane & Jensen, 1993). Kanis & Wendel (1990) also found a similar effect in a study concerning the use of a newly designed coffee-creamer cup. Groenewegen (1990) suggests that people try to solve a problem by immediate recognition of the situation. This recognition results in a hypothesis based on the fact that this hypothesis has been successful in the past, rather than on its correctness in the given situation.

Cognitive effort
The difficulties subjects had in drawing a functioning can-opener and explaining their operations while operating their own can-openers confirm the absence of higher cognitive control when carrying out procedures, as supposed by the Rasmussen model (e.g. 1986). The action control is governed by stored rules

appropriate to successfully operate not only subjects' own model but also a model that functions similarly.
When subjects start to experience operating difficulties in using the models functioning alternatively, the descriptions become more elaborate. Behaviour takes the form of trial and error, which according to Rasmussen is a strategy applied in order to mentally simulate the application of newly developed procedures (Rasmussen 1990).
However, in view of the reiteration of the same unsuccessful position, subjects seem convinced that the familiar solution is the only possible way to open a can. They lack the insight or the information needed to overcome the unfamiliarity of the operating principle. This behaviour resembles the description of Reason (1990), i.e. that people are strongly disposed to exploit the automatic operations of pre-established processing units.

Information provided by the product
Once a device is wrongly identified as being of a familiar type then a wrong procedure will be unsuccessfully applied. It then becomes very hard to produce an alternative operating procedure on knowledge-based level, since the knowledge available for such production, the related mental model, is derived from the same experience that built the wrong procedure in the first place. If the user is made aware of the unusual nature of the model before rule-based identification, the knowledge-based reasoning can be guided towards an alternative operating procedure. Such awareness can be triggered by means of knowledge in the world, e.g. an unusual appearance. This seemed to be the case with the unfamiliar type of corkscrew. Its operation caused less difficulties than that of the unfamiliar can-openers. The unfamiliar type of corkscrew did not look like a familiar corkscrew.

Acquisition of knowledge
Once the subjects had encountered the new way of operating an unfamiliar type, subsequent operating attempts could be expected to be less difficult. Indeed, this was observed in the two experiments and was described as a learning effect. However, in Experiment 2 it was also observed that when subjects were asked to operate a familiar type of can-opener after the two unfamiliar types, they seemed to be confused by the newly obtained knowledge and applied some incorrect positions. The discovery of the possibility of an operating procedure other than the one which is so familiar could lead to a change in the nature of the knowledge available. While at first the identification of, for instance, a can-opener could only lead to the selection of one operating procedure, now the awareness has risen that there are two (or more) potential operating procedures available and a choice has to be made.

Generalisability

Corkscrews were added to the can-openers to verify that the observed phenomena were not exclusive for can-openers. Operating difficulties observed with the corkscrews were fewer than with the can-openers. However, the nature of the problems was identical.

This suggests that the mechanisms underlying the problematic use of the can-openers also apply to other products. The difference in observed difficulties is not caused by the different product function but rather by the more obvious difference in appearance between the familiar and the unfamiliar types. Nevertheless, although the subjects indicated that they did not believe that the blades were meant to be forced into the cork, some subjects did attempt this.

3. The influence of experience

3.1 Introduction

In the previous chapter products were used that had only one function and the functioning of these products could, in principle, be deduced from the product itself. In contrast, in the current chapter a more complex product will be used, i.e. a telephone. The learning process of the experimental tasks had to be extensive enough to make the differentiation induced by experience both possible and observable.
By means of two experiments, which will focus on the operation of the memory retrieval function of telephones, the effect of developing knowledge on performance will be examined. Knowledge concerning each telephone’s operation has to be provided, either by the product's appearance or by the subjects' experience. Because it did not seem possible to use a product with which the subjects had no experience at all, experience acquired both prior to and during the experiment will be taken into account.

Establishing experience
Through operating products people become familiar with the product and its operation The knowledge gained from interaction with a product adds to one’s experience. To keep track of developing experience, it must be operationalised so that the state of experience can be established at a particular moment.
Based on the analysis of results in Chapter 2, experience can be operationalised in two ways.

I. Content
Experience can be described in terms of its contents**;** perhaps quantifiably as the number of telephone types known, or qualitatively as to which kind of types. However, when doing so, the issue of directly related experience and indirectly related experience (with other electronic devices) needs to be addressed. It is not possible to determine exactly which knowledge is relevant for the operating problem at hand. Consequently, it is not possible to say which knowledge of which products should be taken into account when experience is measured. For instance is knowledge of computers relevant for the use of telephones? This problem cannot be answered in general and certainly not *a priori*.

II. Level of abstraction
Another way of considering experience is to investigate in what format experience is stored and how this might change through time. Experience can lead to knowledge of procedures or to strategic knowledge of the functioning of the product. Procedural knowledge leads to a situation in which the product functions as a signal, triggering a specific operating procedure. This procedural knowledge can only be applied to a specific situation. Strategic knowledge is more generally applicable and is used at the knowledge-based level, leading to the conscious choice of a particular operating procedure. Through the use of products subjects may acquire new strategic information which can subsequently be applied to new situations. When a novel situation is encountered frequently, the strategic knowledge required can be transferred into a procedural format. Anderson (1987) refers to this process as proceduralization

3.2 Experiment 3, telephone memory

The aim of experiment 3 is to show the mutual influence between experience and product operation. In order to do so, a combination of product and subjects was selected that ensured an unfamiliar product function. Elderly subjects were asked to operate the memory retrieval function of four telephones.

The development of subjects' knowledge concerning the operation of the product function was monitored during a series of product operating tasks. Subjects knowledge was monitored by asking subjects to express their general view on the operation of the product function and express their current expectation towards the operation of a specific model.
The subjects' general descriptions regarding the operation of the telephone memory would give an indication of their knowledge of the telephone memory function. Their verbal expectations for each specific telephone would give an indication of the influence of current observation.
After the experimental tasks the subjects were asked to describe their experience with telephone memory retrieval, and to specify other products with a comparable operating procedure.

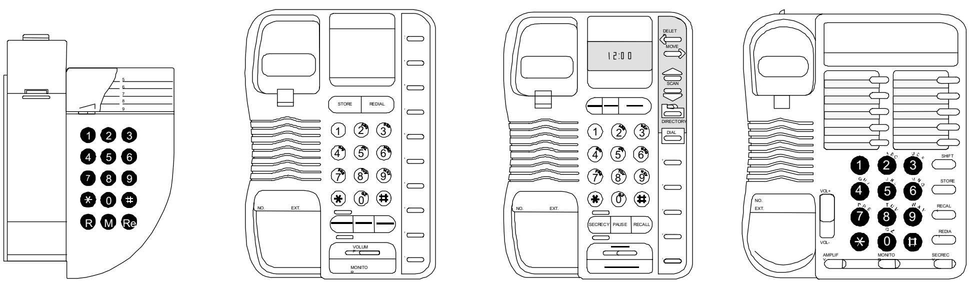
3.2.1 Method

Subjects
Twenty subjects participated in the experiment. Some of these subjects were members of a panel maintained at Delft University, and some were specially recruited for this experiment by means of a flyer distributed in Delft. The age of all of the subjects was over 65. The choice of elderly subjects was made because it

was expected that these subjects would have little experience with modern telephones.

Material

Four telephones were used, each requiring a different type of operation to retrieve a number from the memory. The four telephones are illustrated in Figure 3.1. These telephones were considered to be a reasonable representation of the memory retrieval functions available on modern domestic telephones. The four telephone models used in the study were KPN Telecom's Monza 10, British Telecom's Relate 200, Relate 400 and Converse 200. Larger drawings of the telephones, combined with a description of the required operating procedures, are provided in Appendix D. These particular telephones were selected because of the different methods each employ regarding the storage, and more particularly the retrieval, of phone numbers from the memory.



KPN's Monza 10 *BT's Relate 200* *BT's Relate 400* *BT's Converse 200*

Figure 3.1
The four telephones.

The telephones and an answering machine were connected to the university switchboard. The telephone number of the answering machine was stored in the memory of each telephone and for each telephone the experimental task was to contact the answering machine. On each of the telephones built-in indexes the term *'antwoordapparaat'* (Dutch for: answering machine) was indicated in handwriting.

To illustrate the differences in retrieval method, starting with the handset being lifted and the dialling tone heard, a brief outline is included in Table 3.1.
Two of these telephones did, in fact, have two retrieval methods combined. To make things even more complex, in addition to the procedures mentioned here, the Converse 200 and Relate 400 also incorporated single button retrieval systems but these forms were not examined experimentally.

Table 3.1
Retrieval procedures for the telephones.

telephone	*retrieval procedure*
KPN’s Monza 10	Enter the memory mode through the 'M' button and then, according to the hand written number index, select the desired keypad retrieval number.
BT's Relate 200	Press the memory key associated with the telephone number you require by referring to the hand written text next to the buttons.
BT's Relate 400	Press the 'DIRECTORY' key, 'SCAN' until the display reads the name and number you require, then press 'DIAL'.
BT's Converse 200	Press the 'SHIFT' button and then the memory key associated with the telephone number you require by referring to the hand written text next to the buttons.

Procedure
The subjects participated in individual sessions. At the outset of the experimental sessions the experimenter gave a brief introduction, then subjects were asked to describe their general conception of the retrieval of a telephone number from the telephone's memory. Once their reply had been recorded the subjects were given one of the four types of telephone to examine; the other three were kept hidden from view. For this specific telephone subjects were asked to give a description of how the appropriate telephone number should be activated from memory, and they were then invited to perform the actual retrieval task. During the operation of the telephones the subjects were invited to think aloud.

Table 3.2
Sequence groups.

1	BT's Relate 200	BT's Relate 400	KPN's Monza 10	BT's Converse 200
2	KPN's Monza 10	BT's Relate 200	BT's Converse 200	BT's Relate 400
3	BT's Converse 200	KPN's Monza 10	BT's Relate 400	BT's Relate 200
4	BT's Relate 400	BT's Converse 200	BT's Relate 200	KPN's Monza 10

Subjects were given a 5 minute period to operate the telephone and those who succeeded in retrieving the target number were rewarded by a recorded message. When the 5 minute limit was reached the operation of the telephone was explained to them by the experimenter. After trying to operate their first telephone, subjects were asked once again to describe their procedural operation. The same procedure was then repeated for the remaining three phones. The telephones were presented in four different sequences, as indicated in Table 3.2.
Once the practical side of the experiment had been completed subjects were asked a number of questions about their experience with telephone memories prior to the experiment. They were also questioned about other - in their view - related experience. This was done to get an impression of the experience they had obtained prior to the experiment. In total the subjects were given four tasks;

- give a description of the operation of the memory function in general, with no telephone available,
- specify your expectations of the operation of the four models separately,
- retrieve a telephone number from the memory of each telephone, and
- describe your experience regarding this telephone memory retrieval and specify other products requiring an operation believed to be comparable to the telephone memory retrieval task.

After the experimental tasks the subjects were questioned about their experience with the telephone memory retrieval function. All subjects' actions and verbalisations were recorded on video.

3.2.2 Results

Analysis of the results was split into two areas. One concerned the evaluation of the subjects' performance on the various telephones and the other concerned the effect of the subjects' experience.
Eight of the twenty subjects did have experience with the telephone memory concept on telephones but none were familiar with the particular models. Since in this experiment a distinction is made between different types of memory retrieval systems, henceforth the term *experienced* means experienced with a specific memory retrieval system prior to the experiment. The experienced subjects were familiar with a type of retrieval system similar to that of the Monza 10 model. One subject was also familiar with a Relate 200 type of system.

Performance

Basic performance can be expressed in terms of task success. Success was judged to have been attained when the subjects managed to receive the message from the answering machine. The number of subjects who were successful on the fundamental retrieval task is illustrated in Figure 3.2. The difference between the success scores on the different telephones was significant (Cochran Q test; p=0.001).

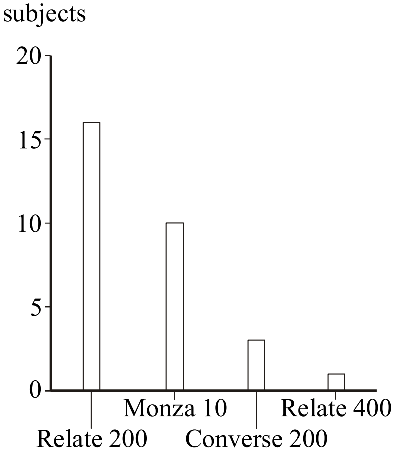


Figure 3.2
Success rate on the retrieval task divided over the four telephones.

Another method of quantifying subject performance was through the number of trials the subjects undertook. An experimental 'trial' began when the telephones' hook was disengaged, and ended, after one or more key pushes, when the subject re-engaged the hook by hand or replaced the handset.

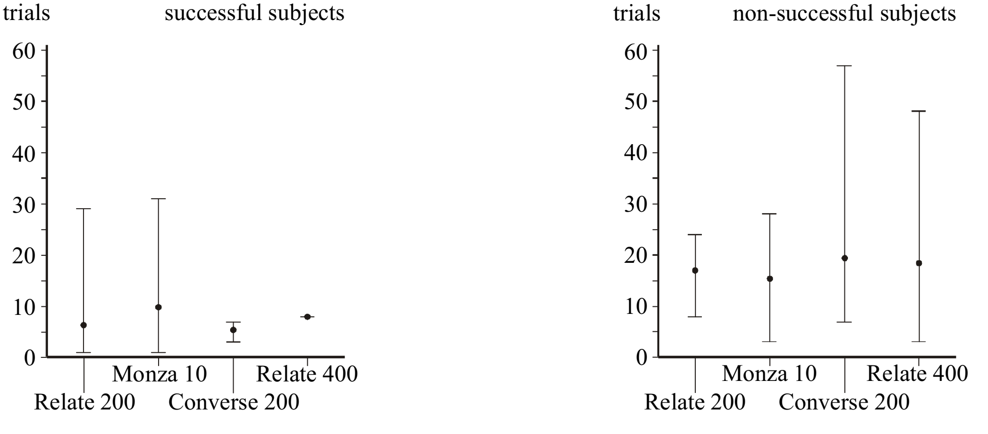


Figure 3.3
Averages and ranges of the number of trials for the successful and non-successful subjects.

In Figure 3.3 the averages and the ranges of the number of trials can be examined. In these figures a distinction is made between successful subjects and non-successful subjects. The number of trials of the non-successful subjects is not the number needed to finish the task but the number of trials performed before the 5 minutes had elapsed. If the non-successful subjects had been given time, and had they been able to operate the memory retrieval function, the number of trials would have been even higher. In spite of the difference in meaning of the measure 'number of trials' between successful and non-successful subjects, further analysis was performed on the number of trials of all the subjects. Rejection of the non-successful subjects in this context would lead to meaningless and non-comparable conditions because of the large proportion of non-successful subjects on some telephones (see Figure 3.2).

The telephones were presented to the subjects in four different sequences. These sequences were introduced to investigate the knowledge transfer between the telephones. Figure 3.4 illustrates the number of trials taken by the subjects in the different sequence groups. It shows that the performance was not related to the sequence in which the telephones were operated: Consequently, the difference in performance on the telephones for the four sequences was not significant (Kruskall-Wallis one-way analysis of variance; Relate 200, p=0.02, Monza 10, p=0.30, Converse, p=0.05, Relate 400, p=0.20).

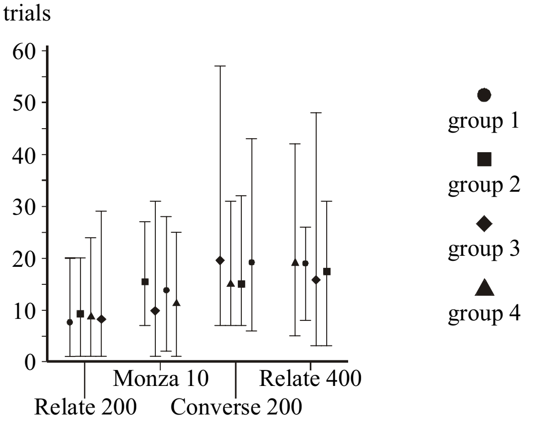


Figure 3.4
Averages and ranges of number of trials in each group.

Instead, most of the subjects appeared to rely more than anything else on trial and error behaviour, as illustrated by the following quotes "*I'm just trying at random, I don't recognise any sort of system.*", "*The only way to find out is to try everything,* *but that would mean that we would be here until sometime tonight* ". However, even the trial and error strategy was applied within the boundaries of the subjects' view on the general structure of the task.

Experience prior to the experiment

More than half of the subjects were novices with telephone memory retrieval. Of the others, seven had some experience with the Monza 10 type retrieval system and one with the Monza 10 and the Relate 200 type. The basic success rates (see Figure 3.2) can be split according to experience with each type of system. Of the subjects with no experience on the Relate 200 type, 15 (out of 19) achieved success. Likewise on the Monza 10, 4 (out of 12) novices managed the retrieval task, while only 6 of the 8 experienced users were successful. All figures are given in Table 3.3.

Table 3.3

Success rates of the novices and experienced subjects for each telephone.

	novice		**experienced**	
	successful	total	successful	total
Relate 200	15	19	1	1
Monza 10	4	12	6	8
Converse 200	3	20	0	0
Relate 400	1	20	0	0

Expectations

The experienced subjects expressed fewer false expectations than the inexperienced. They (experienced) expected procedures appropriate for 'their' telephone to be applicable to the other types as well. The inexperienced group came up with diverse expectations, many of which were not suitable for any telephone. Subjects' initial procedural expectations about the method of retrieval for the individual telephones are shown in Figure 3.5.

Again, the Relate 200 retained a high level of performance. Half of the total group conveyed the correct procedural information for that particular telephone. Figure 3.5 shows that nine out of ten successful subjects on the Relate 200 had no experience with such a memory retrieval system. Conversely, only one fifth of the subjects successfully operating the Monza 10 were novice users.

Of the eight experienced subjects, six expressed an expectation similar to their own experience, of which only one was correct for the Relate 200.

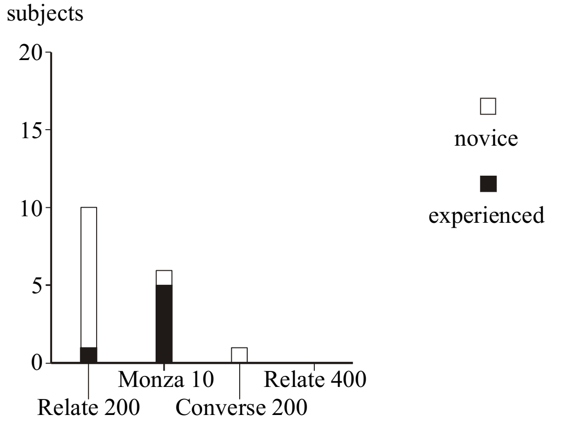


Figure 3.5
Correct expectations regarding operating procedures by the experienced and inexperienced subjects.

General questions
To gain insight into users' knowledge of the retrieval function, and whether this knowledge changed throughout the experiment, the subjects were asked how they regarded 'in general' the operation of a memory retrieval system in telephones. This question was posed five times, before the first telephone was presented and again after each telephone in the sequence.

Table 3.4
The types of responses given to the 'general' question.

response to type	*procedure*
Relate 200	Pressing a single quick-dial memory key.
Monza 10	Pressing first any of the keys other than the standard 0-9 number buttons, and then one of those 0-9 keys.
Converse 200	Pressing first any of the keys other than the standard 0-9 number buttons and then one of the quick-dial memory keys.
Other	Answers other than described above. Description of redial function, false non-related descriptions or no idea of how the function works.

I. Type of answer
All but two of the responses expressed by the subjects could be compared to the procedures incorporated in the three telephones presented, Relate 200 type, Monza 10 type and Converse 200. The response types were listed using those names. The procedure for the Relate 400 was not mentioned by the subjects. The types of response given then fell into four categories, described in Table 3.4.

Figure 3.6 illustrates that the number of response types to the general questions changed under the influence of the operation of the four telephones. The graph shows the increasing dominance of Monza 10 and Relate 200 type answers. Two subjects also began with an idea that the memory system had something to do with the 'redial' facility, but these ideas were quickly discarded as the experiment progressed. The content of the subjects' general descriptions depended on their experience; the experienced users mainly expressed verbally their experience prior to the experiment, regardless of the telephones they had operated during it. In contrast, inexperienced subjects developed various concepts, some of which were entirely new. The shift from Question 1 to Question 5 is indicated here, for reasons of clarity, as a straight line. In reality this was not proportional (see Figure 3.14).

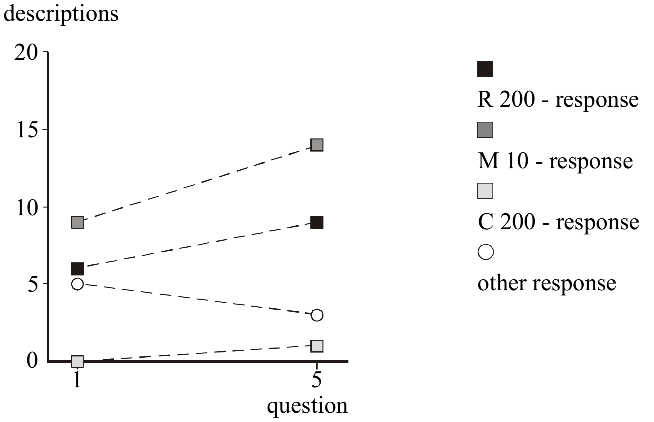


Figure 3.6
Subjects' type of response to the general question concerning the functioning of the memory in general.

The two graphs in Figure 3.7 illustrate part of the responses given to the 5 'general' questions of the experiment by the subjects. In this figure only the Relate 200 and Monza 10 type of descriptions are depicted, since these were the most frequent and the differences between the number of these descriptions between novices and experts were significant (Wilcoxon Mann-Whitney; Relate 200 type, p=0.004, Monza 10 type, p=0.004).

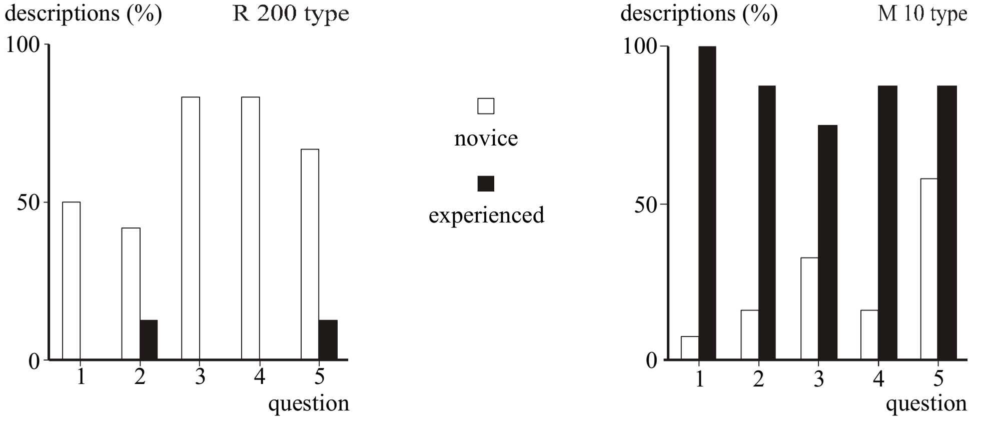


Figure 3.7
Relate 200 (right) and Monza 10 (left) type of description given by both novice and experienced subjects (proportion of total number of descriptions given the conditions).

As the experiment progressed the increase in Relate 200 type responses was considerable, especially from those participants with no previous experience. The Monza 10 type response, on the other hand, saw a consistently high level of such responses from the experienced user, and an increasing proportion of the novices answers.

Table 3.5
The types of responses given to the general question.

description	type
Based around specific buttons to be pressed in a certain order	procedural
A 'higher level' description covering the topic more universally, and indicating the reason for pressing certain buttons.	strategic
Subjects indicated not being able to give a general description.	don’t know

II. Level of abstraction
Subjects’ general perception of the retrieval function can be analysed further by looking at the level of abstraction of the descriptions they gave. The categories in which the answers are classified are mentioned in Table 3.5.

Figure 3.8 shows the progress of broader response types (Table 3.5) through the 5 'general' questions. There is a dominance of procedural descriptions and far less strategic views. It also indicates that a good proportion of subjects were totally confused and just did not know what to say when asked for their general opinion.

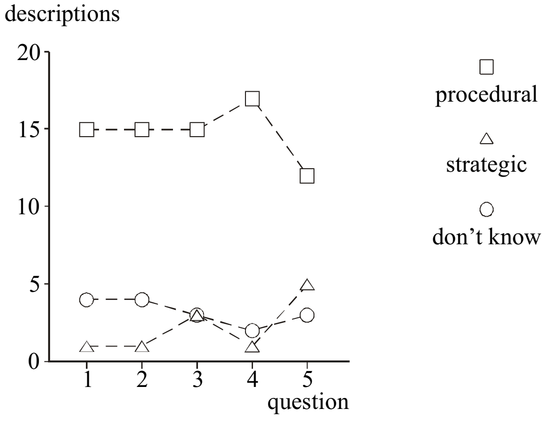


Figure 3.8
Level of abstraction in describing the memory function in general.

3.2.3. Conclusions

The aim of this experiment was to investigate the influence of knowledge on the operation of the memory retrieval function. Within the experiment three aspects of operation were monitored.

- subjects' performances, the actual operation of the telephones,
- subjects' expectations towards the operating procedure of a specific telephone,
- subjects' general descriptions of the concept of telephone memory retrieval.

Performance

The success rate of subjects' performances on the telephones varied widely. The most obvious influence on this variability was the complexity of the telephone designs. Moreover, the complexity of the procedure to operate the retrieval function varied per telephone. The sequence in which the telephones were presented affected neither the level of success nor the number of trials the subjects needed to operate the telephones. The differences in performance of the subjects can probably best be explained by the varying level of *guessability* (Jordan & O'Donnel, 1992) between the telephone models. (*a measure of the cost (e.g. in terms of time and errors) to the user in getting going on a task - the lower the costs the higher the guessability* p.404)

This experiment, however, focussed not on the influence of the design of telephones but on available knowledge. The influence of experience acquired

during the experiment would have been demonstrated by differences in performance as a consequence of the order in which the telephones were presented. However, such a difference was not found, meaning that if experience played a role as described, its effect was too small to be measured.
Prior experience, on the other hand, did have an effect on performance. The experienced subjects, all with experience on the Monza 10 type of retrieval system, performed better on the Monza 10 in comparison to the novices, but this experience did not improve their performance on the other telephones.

Expectations
The expectations expressed for each model did show a similar pattern to the performance during the operation of the telephones. The recording of the subjects' expectations concerning the operation of each model provides a direct indication of the *guessability* on each model. These recordings also showed that the experience acquired during the experiment had little influence on this *guessability*. Prior experience did, however, influence the subjects' expectations in the sense that more than half of these experienced subjects, familiar with the Monza 10 type of system, guessed the correct procedure for this type, whereas all but one of the inexperienced subjects were unable to guess correctly.

General descriptions
The *guessability* of the telephones could not affect the general descriptions, since the subjects were not asked to describe the functioning of one specific telephone but of a telephone retrieval system in general. In particular, the first description subjects gave could not have been influenced by any telephone within the experiment, since this question was posed before any telephone had been presented to the subjects. However, subjects did give general descriptions of the Relate 200 type, though they had no prior experience with that type of system.

The nature of the subjects' general descriptions changed during the experiment, which indicates that subjects learned from their interaction with the telephones. Here again the high *guessability* of the Relate 200 led the subjects to give general descriptions of the Relate 200 type. Descriptions of the Monza 10 type also increased in number during the experiments, whereas descriptions of the other types became less frequent.

Prior experience also influenced the general descriptions. Experienced subjects described 'their' type of system (i.e. the Monza 10 type of system) far more often than novices did, and this did not change much during the experiment, whereas the novices gave significantly more descriptions of the Relate 200 type in comparison to the experienced subjects. In addition to the Relate 200 type of descriptions, the novices also gave an increasing number of Monza 10 type of descriptions during the experiment.

Level of abstraction
When the nature of the general descriptions is examined they can hardly be termed ‘general’. The vast majority of them are of a procedural nature. The knowledge obtained during the experiment did not evolve into a general understanding of memory retrieval, as shown by the constant low number of strategic descriptions. This could explain the absence of transfer of newly acquired knowledge on the four telephones during the experiment. Also, because subjects' experience was mainly stored as procedural information, and the operation of unfamiliar telephones required different procedures, the individual memory retrieval tasks were not facilitated. This also accounts for the knowledge of the experienced users; their knowledge, acquired prior to the experiment, remained essentially unaffected by the experience obtained.

3.3 Experiment 4, telephone memory

The aim of experiment 4 is to investigate how user’ knowledge on the operation of a product develops in time. The experience of all subjects with the telephone models used in this experiment is explicitly known and recorded by means of Experiment 3. The results of Experiment 4 are therefore to be combined with those of Experiment 3 in order to show how the experience is retained during a period of time.
To facilitate this combination Experiment 4 is designed as a repetition of experiment 3 with the same subjects.

3.3.1 Method

Subjects
All 20 subjects who participated in Experiment 3 were invited to take part in a further experiment of the same nature. Only 15 of them took part for a second time.

Materials
The same four telephones used in Experiment 3 were used in this experiment. These telephones are illustrated in Figure 3.1 and in Appendix D.

Procedure
This experiment took place 5 months after Experiment 3. The subjects were asked to perform the same tasks as in Experiment 3, in similar experimental conditions.

First they were asked to give a general description of the memory facility of telephones, then the first telephone was presented. For this telephone the subjects were asked to describe their expectations of its operation and then to operate the memory function. The subjects were allowed 5 minutes for this operation. The goal of the operation was to get in touch with an answering machine. This procedure was repeated for all four telephones. After the four telephones had been operated the subjects were once more asked to give a general description of the functioning of the memory function on telephones. Finally, the subjects were questioned about their use of the memory facility in telephones in the period between the two experiments. Each individual subject was presented with the telephones in the same order as they were presented in Experiment 3. Because only 15 of the original 20 subjects participated in this experiment the sequence groups were no longer equal in size.

3.3.2 Results

The results were analysed in a similar fashion to those of Experiment 3. In addition the results of Experiments 3 and 4 were compared per subject to see whether there were any individual changes. Besides the elapsed period of time between the two experiments, the main difference between the two experiments was the fact that in this experiment all subjects were, to a limited extent, experienced with the telephone models. Therefore, the distinction between novices and experienced, as applied in Experiment 3, is no longer used in the analysis of this experiment. Subjects indicated that their experience did not change in the period between the two experiments.

Performance

As in Experiment 3, the performance of the subjects was measured using both the success rates and the number of trials needed by the subjects to complete the operating task.

The success rates of the four telephones are given in Figure 3.9. The differences between the scores per telephone are significant (Cochran Q test, p=0.001). The overall success rates in this experiment did not differ significantly from Experiment 3 (see Figure 3.2), determined for those subjects participating in both experiments. (McNemar change test; Relate 200, p=0.50, Monza 10, p=0.15, Converse 200, p=0.19, Relate 400, p=0.06). Because of the small group size in each sequence it was not possible to determine the significance of the difference between the success rates for the different sequence groups.

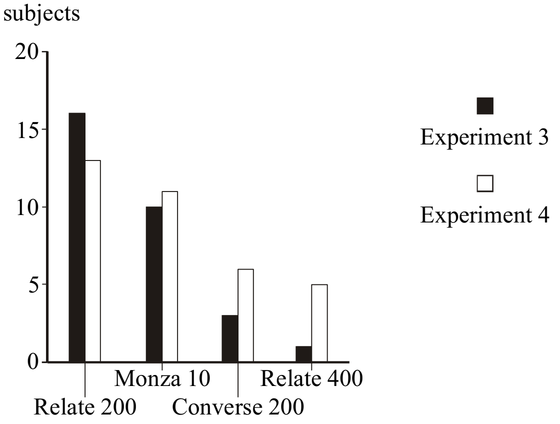


Figure 3.9
Success rate on the retrieval tasks divided over the four telephones.

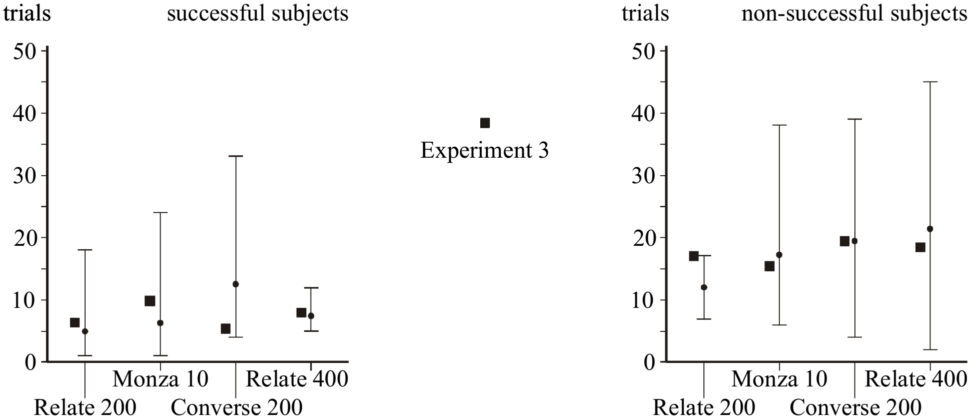


Figure 3.10
Averages and ranges of number of trials for the successful and non-successful subjects.

To see whether the different sequences in which the telephones were presented had an influence on performance, the number of trials needed to operate the telephones was analysed. A difficulty here was the difference between those subjects who were successful with the task and those who were not. The number of trials observed for those subjects who were not successful is obviously not the number of trials they needed to operate the telephone, but the number of trials they performed before the experimenter stopped them because the 5 minute time period had elapsed. Consequently, their score could have been higher if those subjects had been given more time. Nonetheless, the unsuccessful subjects were included in the analyses, otherwise the group size would have become too small to perform any kind of analyses.

In Figure 3.10 the number of trials are given for the successful and non-successful subjects. The number of trials were evaluated separately for each sequence group in order to test the influence of the different sequences. These differences were tested using the Kruskall-Wallis one-way analysis of variance by ranks (Relate 200, p=0.05, Monza 10, p=0.05, Converse 200, p=0.10, Relate 400, p=0.01). In this test the scores of both the successful and the unsuccessful subjects on each telephone were taken into account. In Figure 3.11 the averages and ranges are illustrated.

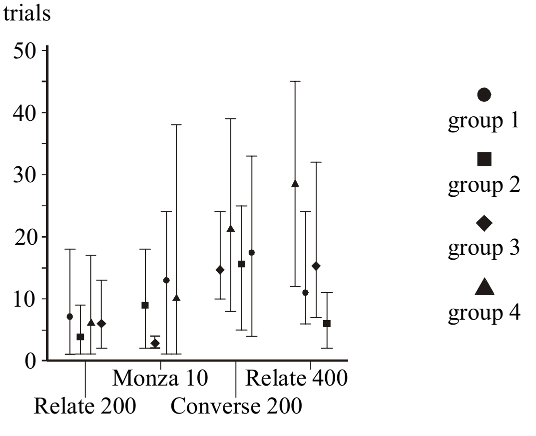


Figure 3.11
Averages and ranges of number of trials each sequence group took to operate the telephones.

The number of trials, as observed in this experiment, was compared to the corresponding number of trials as observed in Experiment 3 (see Figure 3.3) These differences are not significant (Wilcoxon signed ranks test; Relate 200, p=0.22, Monza 10, p=0.17, Converse 200, p=0.20, and Relate 400, p=0.40). The difference for all subjects who participated in both experiments was tested.

Expectations of the subjects
The number of correct expectations is illustrated in Figure 3.12. The difference between the numbers of correct expectations is significant per telephone type (Cochran Q test; p=0.001).

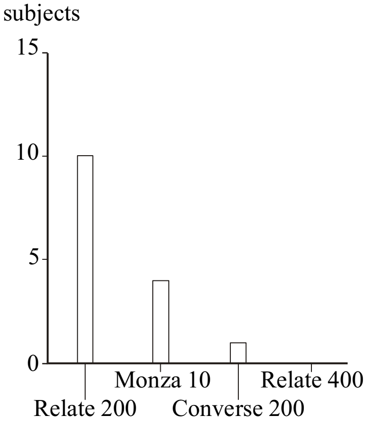


Figure 3.12
Correct expectations regarding operating procedure before the experiment.

The expectations expressed by the subjects regarding the operation of the four telephones were expected to be influenced by the experience each subject had gained during Experiment 3. However, the number of correct expectations did not differ from those recorded in Experiment 3, illustrated in Figure 3.5. In this comparison, only those subjects of Experiment 3 who also participated in Experiment 4 were included. (McNemar change test; Relate 200, p=0.34, Monza 10, p=0.66, Converse 200, p=0.50. For the Relate 400 the probability cannot be calculated since none of the subjects in both experiments had correct expectations).

General descriptions
The general descriptions, in response to the general questions on the memory retrieval function, can be categorised in a similar manner to that used in Experiment 3. The applied categorisation is based on the type of procedure described by the subjects. These procedures are labelled with the names of the telephones used in this experiment which required that specific type of procedure to operate the memory retrieval function. In Table 3.5 the response types were already described as part of Experiment 3. In Figure 3.13 the number of general descriptions recorded in each category to the first and last question during Experiment 4 is illustrated. The shift from Question 1 to Question 5 is, for reasons of clarity, indicated here as a straight line. In reality this was not proportional (see Figure 3.14).

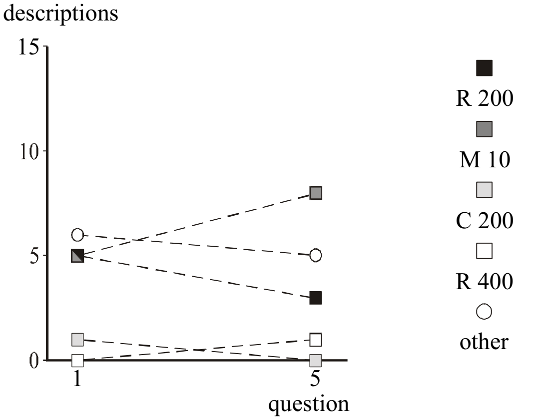


Figure 3.13
Subjects' type of response to the general question concerning the functioning of the memory function in general.

Results of Experiment 4 combined with those of Experiment 3
Since the subjects participating in Experiment 4 also participated in Experiment 3 the answers to the five general questions of both experiments may be seen as a sequence of 10 questions. The answers to these 10 questions are plotted in Figure 3.14 and by means of linear regression the trend in the data can be evaluated.

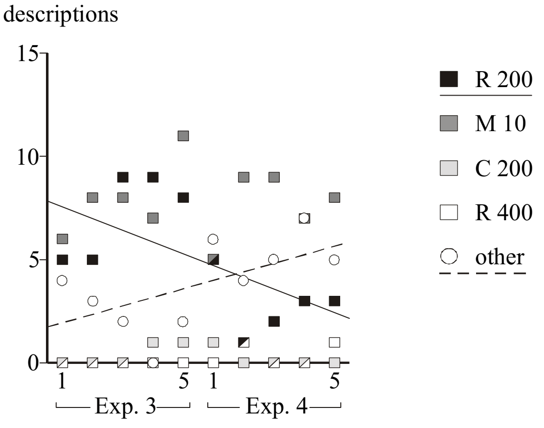


Figure 3.14
Types of descriptions found in Experiments 3 and 4 projected in sequence.

However, the explained variances of these lines are low (Relate 200, r^2=0.36, Monza 10, r^2=0.03, Converse 200, r^2=0.01, Relate 400, r^2=0.27, other, r^2=0.35).

For this combination only those subjects from Experiment 3 who also participated in Experiment 4 were taken into account. Since the explained variance of the lines is low, no conclusions can be drawn concerning the development of the type of descriptions given by the subjects over the two experiments.

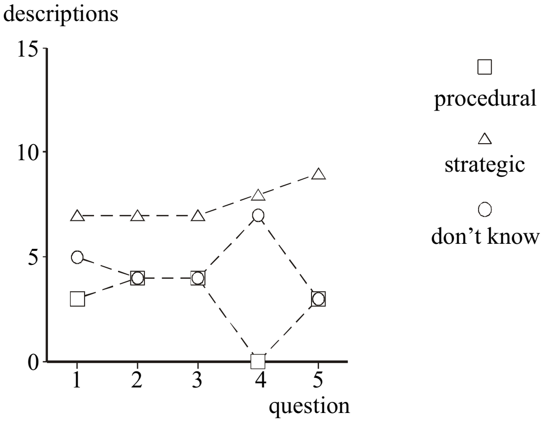


Figure 3.15
Level of abstraction in describing the memory function in general.

Level of abstraction
Another way of analysing the general descriptions is by judging them on their level of abstraction. For that purpose the same categorisation is used as in Experiment 3. Table 3.5 describes the different categories. In Figure 3.15 the number of descriptions in each category is illustrated for each of the five questions. When these figures are compared to the corresponding figures of Experiment 3 (see Figure 3.8) it shows that the number of strategic descriptions has increased, while the number of procedural descriptions has decreased. These differences are significant (extension of the McNemar change test, $p=0.001$). Again, only those subjects who participated in both experiments are considered here.

Since the subjects of Experiment 4 also participated in Experiment 3 it is possible to consider the change in the level of abstraction of the general descriptions over the two experiments sequentially. In Figure 3.16 the results of the two experiments are shown on a continuing scale and the trends are shown by lines derived by linear regression. For each category a regression line is computed (procedural type, $r^2=0.74$, strategic type, $r^2=0.89$, don't know, $r^2=0.28$). The lines show the tendency of the number of procedural descriptions to decrease during the two experiments, while the number of strategic descriptions increase. In discussing Experiment 3 it was concluded that little strategic knowledge emerged, but this had substantially increased with Experiment 4. Details of the experimental results can be found in Appendix A.

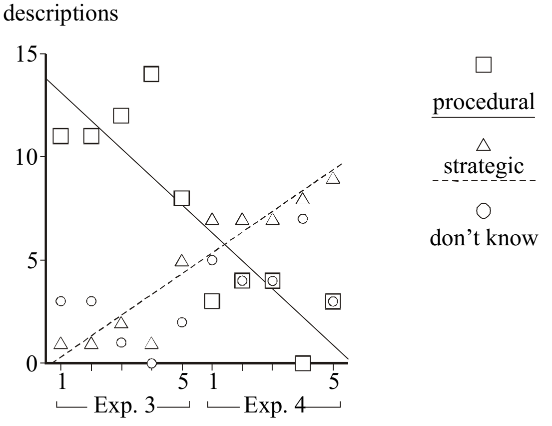


Figure 3.16
Regression lines for the level of abstraction over Experiments 3 and 4.

3.3.3 Conclusions

The aim of this experiment was to see what the influence of specific experience would be on the performance and conception of the same operating tasks outlined in Experiment 3. In Experiment 3 all subjects became acquainted with the operation of the four telephones. When the subjects did not manage to operate the telephones themselves the procedures were explained by the experimenter. This ensured that all subjects were familiar with the operating procedures, but did not affect the user's conception of the specific tasks, nor the conception of memory retrieval task in general. An important part of the analyses of this experiment, therefore, is the comparison of the obtained results with those of Experiment 3.

Performance

As in Experiment 3, performance in this experiment varied widely over the telephones, and compared to Experiment 3 the performance measured by success rate did not improve. Overall, the experience subjects gained during Experiment 3 did not facilitate operation of the same telephones in Experiment 4. The period of five months proved to be too long for retention of the acquired knowledge.
The sequence in which the telephones were operated did make a difference to the performance measured in the number of trials required. In Experiment 3 the same sequence differences had no influence on the level of performance. This indicates that subjects in Experiment 4 were able to transfer knowledge from one experiment to the other, but this effect was small, resulting in a facilitating effect

only for those subjects operating the telephones in an apparently advantageous sequence. This advantage could be the ability to transfer the knowledge gained while operating one telephone to the next telephone, whereas in other sequences the newly acquired knowledge from one model did not facilitate a procedure suitable for the next.

Expectations
The number of correct expectations still varied considerably per telephone and compared to the results of Experiment 3 no improvement was observed. If subjects were able to apply their experience of Experiment 3 during Experiment 4 this took place during the operation of the telephones, and not prior to the operating task, on the basis of recognition of product features relevant for the operation.

General descriptions
The general descriptions requested throughout the experiment provided insight into the subjects' understanding of the retrieval task in general. Both in Experiment 3 and 4 this proved to be a difficult task for the subjects. This is illustrated by the large number of subjects who had no idea how to answer the question posed. Even when a subject gave an answer to one of the questions, a subsequent question could not be answered. Users' understanding of the nature of the retrieval task did not necessarily appear to accumulate with each successive telephone. This accumulation of understanding seems likely to be inhibited by the occurrence of operating difficulties.
Throughout both experiments subjects acquired information, on the basis of which a general understanding of the retrieval task could evolve. When the two groups of five questions are plotted in chronological order, linear regression could indicate a trend in the types of descriptions given, but the explained variance of the resulting lines is too low to suppose a continuous process. The effect of the sequence in which the telephones were presented, or the perceived complexity of the telephones, might have interfered in this process.
When the general descriptions are evaluated on their level of abstraction, the distribution is different from that observed in Experiment 3. When the answers of the two experiments are plotted in sequence and a linear regression is performed for each category, the resulting lines indicate an increasing amount of strategic descriptions and a decreasing amount of procedural descriptions by subjects not knowing what to answer. Apparently, the ongoing interaction with retrieval systems has an effect on users' understanding of the task. This effect does not concern the actual type of system described, but the level of abstraction of the descriptions.
The increase of strategic understanding of the tasks in general is seen as a consequence of the subjects' experience becoming more heterogeneous.

3.4 Discussion

The aim of the experiments in this chapter was to establish the influence of experience on product operating.
Concerning the influence of experience, Experiment 3 led to four observations.

- The complexity of the (product)-models differed to such an extent that the influence of the transfer of subjects' operational knowledge from one model to another within the experiment was not traceable in the results.
- Subjects' prior experience influenced the operation of the memory function of the telephones. Such prior experience was shown to be advantageous only for the models requiring an operating procedure corresponding to this prior knowledge.
- Subjects' descriptions of the operating procedure in general and for each specific model were also influenced by prior experience.
- The descriptions of how to operate the memory function did not indicate knowledge of a general strategy: a strategy that can be applied to members of a class of products, and thus not referring to this specific model as a member of a product type. Most subjects described their operating behaviour as procedural, applicable to only one specific model. Since the operating procedures differed over all, this prohibited transfer of knowledge within the experiment.

Experiment 4 led to three further observations.

- Since the subjects in Experiment 4 also participated in Experiment 3, all subjects in this experiment were familiar with the telephone models used. This, however, did not result in a noticeable improvement of performance in comparison to Experiment 3.
- In contrast to Experiment 3, the number of general descriptions that could be labelled strategic outnumbered those descriptions labelled procedural. This availability of strategic knowledge could, in theory, facilitate the transfer of knowledge between telephone models within the experiment.
- In contrast to Experiment 3, the sequence in which the telephones were presented influenced performance. A later sequence position led to significantly less difficulties on certain models, compared to performance on the same models in an earlier sequence position. This implies the transfer of more general knowledge, acquired during the operation of one telephone model, to the operation of following models.

Interpretation
In combination these statements lead to the assumption of mechanisms involved in the acquisition and application of experience in operating products.

Causes for operating difficulties
The assumption of Norman (1988) that operating behaviour is guided by both knowledge in the head and in the world is clearly confirmed in the two experiments.
Although the experiments focussed on users' experience, the influence of the knowledge in the world, the appearance of the telephones proved to be a major influence in task performance.
Subjects confronted with a task they were complete novices at applied a trial and error strategy. This strategy, however, was not unstructured; subjects rely on whatever knowledge is available. In accordance with the recording of mainly procedural knowledge, subjects were seen to repeatedly apply procedural rules like pressing key '6', seven times in a row.
The cause of these operating difficulties lies in the absence of sufficient product information to compensate for the lack of experience of the subjects. Also**,** the level of guessability may be too low.
Subjects with more explicit knowledge of the specific task (i.e. experienced) were believed to be fixated on their knowledge, since they persisted in performing their task according to their experience, more so than those who were novices in the memory retrieval task.

Prior knowledge
Those subjects who had experience were influenced by this experience. When, again all on procedural level, this experience was in accordance with the operating task the experience gave these subjects an advantage. However, when the operating task was different from their experience this experience proved to be a disadvantage. An effect similar to the fixation effect in Experiment 1 was observed.
Prior experience was found to have the same effect on the formulation of expectation and general perceptions of the operating task.

The nature of stored knowledge
The experience subjects had in Experiment 4 proved to be insufficient to operate the telephones in this experiment. This time fixation or carry-over effect could not have prevented the application of experience, since subjects had experience with all procedures and yet facilitation through experience was rarely witnessed.
Subjects' one-time experience proved to be insufficient to smoothly repeat the telephones' operation

However, during Experiment 4 one particular influence of subjects' experience was witnessed.
The descriptions became, as requested from the beginning, more and more strategic, and a carry-over effect was witnessed. This carry-over effect indicates the transfer of knowledge from one telephone model to subsequent models. The subjects' conception of the task gradually shifted from procedural to strategic. It is assumed that this shift is related to increased experience.

4. Explaining operating difficulties

In the previous chapters an outline of the role of cognition in the use of consumer products emerged from four experiments. These experiments were necessarily explorative because of the absence of specific theoretical insight into the processes involved in the cognitive control of the operation of consumer products. The experiments provided examples of difficulties of a cognitive nature occurring during the operation of consumer products, which are thought not to be specific for the products used in the experiments. In this chapter the globally formulated general mechanisms underlying the difficulties will be further elaborated by focussing on two causes of product operating difficulties.

4.1 Mechanisms underlying operating difficulties

The operating difficulties encountered in the experiments were in the previous chapters attributed to two causes, *fixation* and *low guessability*.
Both causes concern interaction between information in the world and knowledge of the user. When operating a product the user processes information during cognitive action control, whether this control is conscious or not. Information can either be available to the user by means of knowledge in the user's memory or through information conveyed by the product design and the use context.
Usually a combination of both sources of information is processed. When the two combined information sources do not provide the user with sufficient and unambiguous information then operating difficulties may occur. A complicating factor in this process is that information available in the world is perceived and interpreted by the user before it can be applied in the action control, and this process is influenced by existing knowledge of the user. In other words, the information in the world can only contribute to the interaction with a product when it is able to activate or become appropriate knowledge in the head. The study demonstrated that users' experience is at the centre of this process.
In the experiments subjects with varying levels of experience dealt with the information in the world with varying results. Within this context, lack of experience could either mean that the operating tasks had never been encountered before or that only different but similar operating tasks had been encountered. Experimentally, the effect of information in the world was judged indirectly by its observable effect on the subjects' behaviour.

Fixation

Fixation was mentioned as an explanation when operating problems emerged in a situation in which the user had no experience with the operating task but extensive experience with a similar but different task. This cause was observed with the unfamiliar type of can-opener and to a lesser degree with the unfamiliar type of corkscrew.

Operating difficulties were explained as being caused by fixation when subjects kept trying to apply a way of operating that was not successful for the current task, but very successful for a similar familiar task with the same product function.

Fixation is explained as being the result of the combination of the existence of a *strong but wrong* rule (Reason, 1990) in memory which originates from experience, and an absence of compensating knowledge in the world.

Low guessability

Low guessability was mentioned as an explanation when observed operating problems emerged in a situation in which the user was using a product for the first time and had no prior experience with the product. This cause was found in various degrees during the operation of the telephone memory retrieval function. The term 'guessability' is used here but different terms, e.g. 'initial ease of learning' (Nielsen, 1993) are used, to indicate a similar quality of a product.

Operating difficulties were labelled as being caused by low guessability when subjects had no experience with the operation of the current product (type) and showed trial and error behaviour.

Low guessability as an attribute of the product was argued to originate from the absence of applicable knowledge in memory, combined with absence of compensating information in the world by means of *use cues* designed into the product (see section 4.2.1).

4.2 Cognitive aspects of operating difficulties

In the previous chapters the cognitive aspects of product operating were investigated and discussed. Five recurring elements were mentioned when structuring the discussion of the experimental results.

- information provided by the product
- cognitive effort
- prior knowledge
- acquisition of knowledge
- the nature of stored knowledge

These five elements will again be used to elaborate on the cognitive aspects of operating difficulties

4.2.1 Information provided by the product

The influence of information provided by the product on use actions touches upon the central problem of this thesis, since the product is provided with that information by the designer. This is the only way in which interaction with consumer products can be influenced. At the same time, it is the way in which operating difficulties are unintentionally built into a product.

Norman (1988) approaches the influence of the product at a global level. He argues that the product should primarily facilitate the formulation or activation of a proper conceptual model. In order to facilitate the formulation of such a model it is important to ensure the *visibility* of the elements that are to be operated, and that the required operation of these elements is clear. To make the required operation clear the principles of good mapping, restrictions, feedback and the use of *affordances* are mentioned. *Mapping* refers to the relationship between product parts and their function, and what action is required to activate the function in the desired way. This is also referred to as compatibility (e.g. Sanders & McCormick, 1993).
Clear *restrictions* in the possible use of product parts will limit the number of possible actions and thus simplify the discovery of the required operation. *Feedback* on the effect of performed actions will enable the user in discovering the required operation. Finally, making use of affordances, i.e. the perceived properties of a product or product-parts which communicate their use, can assist the user in executing the required operation.
Norman (op. cit.) and Gibson (1977)**,** among others, consider the product and its parts as cues for the use of the product. Aspects such as colour, texture, form and material contain information that can indicate a way of use of the product. Kanis (1993) labels these aspects literally *use-cues*; specific elements, supposedly deliberately incorporated into the product, guide the user in operating the product. Use-cues are not elements of the use instructions, but physical parts of the product. It is important to stress that the effect of these product qualities depends on their appreciation by each individual user.

Use cues not only concern product parts or design elements but also the overall appearance of a model in relation to the general appearance of the type it belongs to. The experiments show that a use-cue cannot be given a pre-defined function. Not only can the design of a use-cue be more or less effective but also its efficiency depends on its appreciation by the user.
The importance of use-cues increases when knowledge in the head is absent, contradictory or insufficient. When the user has no knowledge of how to operate a product the design should be able to supply this user with adequate cues. Absence of this ability was labelled *low guessability.*

A more complex situation arises when the user has operating knowledge that is inappropriate for the current product model. The more this knowledge has been successfully applied, the stronger the tendency of the user to re-apply this knowledge in the current situation. Then the function of the use cues is not only to indicate the proper operation but also to contradict any misconceptions about the operating procedure. In the examples of *fixation* that were found this was apparently not the case. Moreover, the appearance of the product, including any use-cues, can even stimulate misconceptions about the proper operating procedure by resembling the product for which the operating procedure was appropriate.

4.2.2 Cognitive effort

The results of the experiments demonstrate that for the execution of the operating tasks, knowledge is processed on different levels of cognitive control. The Rasmussen model (see Section 1.3.2) provides an adequate framework for explaining different types of cognitive involvement and related conscious attention during operating task execution, varying with different levels of familiarity with the operating task. The framework illustrates the tendency to perform action control with as little cognitive attention as possible, leading to a preferred application of familiar operations triggered by familiar patterns. Under certain conditions this may lead to the witnessed *fixation* effect. At the same time the design did not adequately alert the user to the necessity of applying a new operating procedure. In other words, it suffered from *low guessability*.

The amount of conscious attention required to execute a task is referred to as 'cognitive load' (e.g. Beacker & Buxton, 1987). It is generally accepted among authors that human beings have a tendency to minimise the amount of cognitive attention, the cognitive load, during the execution of tasks. (e.g. Reason, 1990). He states "*In short, human beings are furious pattern matchers. They are strongly disposed to exploit the parallel and automatic operations of specialised, pre-established processing units: schemata (-), frames (-), and memory organising packets (-). These knowledge structures are capable of simplifying the problem configuration by filling in the gaps left by missing or incomprehensible data on the basis of 'default values'.*" (p 66).
The mechanism of applying pre-learned procedures is, of course, very effective. It enables the fast and easy execution of many operating tasks.
The cognitive load resulting from task execution is subject to change over time. Both the Rasmussen framework and the Anderson ACT* model indicate that by repeated execution of a task the level of involved conscious action control decreases.

4.2.3 Knowledge in memory

The role of knowledge from memory in the occurrence of operating difficulties proved to be as important as it was intangible. In general, this knowledge was regarded as originating from experience. Knowledge from memory may concern the operation of a product function (e.g. can-opener), a type of product (e.g. "side-cutter" in Experiment 3) or specific models and/or parts.
In the experiments subjects' experience was assessed in a number of ways, directly by recording verbal descriptions, asking subjects to make a sketch or to recognise pen-drawings of product models, and indirectly by tracing task performance back to the underlying experience. However, none of these methods provided a clear view on what the (level of) experience of the users was.
A recurring problem when establishing experience was the scope of the experience to be considered. This was indicated by the term 'relevant experience'. When asked to indicate experience which was relevant to the operating task, subjects were expected to refer to their knowledge of identical or similar tasks. However, unexpected domains of experience were also reported as relevant. These reports proved to be very individual and difficult to anticipate, seemingly unaffected by task complexity.

Regardless of the difficulty of pinpointing exactly what the knowledge of the users was, users' knowledge was shown to be a key factor in product operating. It enables the execution of familiar operating tasks, with users' being hardly consciously involved, and it guides users towards successful execution of less familiar tasks through effective recognition of triggering cues. On the other hand, their knowledge led users into frustration when they made the mistake of thinking that their stored operating procedures were applicable to a unfamiliar operating task. Even feedback from their lack of success at the task could not overcome the *fixation* on pre-learned operating procedures. Although knowledge in memory concerning the execution of a task will in most cases effectively guide the execution of the same or similar tasks, this effectiveness can become a disadvantage when the application of a procedure seems appropriate because the situation corresponds to all the triggering conditions, while in fact the procedure is inappropriate because the situation is different. Human beings, when confronted with a problem, are strongly biased towards applying operations derived from familiar patterns (Rasmussen, 1990; Reason, 1990). A classic example of this 'rigidity' is found in the study of Luchins (1942). This persistence in applying the wrong rule is also referred to as *einstellung* (Luchins, 1942) or fixation (!) (Weisberg & Alba, 1981).

Different users of the same product will vary considerably in their available knowledge, ranging from complete novice to very experienced. The information a product conveys concerning its operation must be adequate to support this range of available knowledge. If not, the product will suffer from *low guessability* for at least some of its users.

4.2.4 Acquisition of knowledge

Understanding how new operating knowledge is acquired is an important step toward understanding how information should be presented in the product in order to prevent operating difficulties.
In the experiments, the acquisition of new knowledge seemed to be very limited. The subjects preferred to rely on their existing knowledge rather than searching for new information. Sein & Bostrom (1989) mention three potential sources of information that may initiate new operating knowledge.

- via use of the product
  The information in the world should then be available in the product. This source was already discussed in section 4.2.1.
- via analogy
  The operating knowledge is already in the user's memory from earlier occasions, but a connection with the current situation has to be made. Anderson (1987) refers to this source as *transfer between skills*. This transfer can either be positive or negative. Positive transfer would lead to a successful new operating procedure, negative transfer would lead to a fixation on a familiar procedure not suitable for the new operating problem. The selection of the procedure that is transferred is also based on analogy, i.e. on preference induced by *availability* or *recency*.
- via training
  Operating knowledge can be made available to the user through actual training. In the experiments subjects received instructions when they were not able to perform the operating tasks, but in the use of everyday consumer products formal training is seldom an available source of information. Moreover, the effect of training in the experiments proved to be limited. Another source of information is through use-instructions. However, use-instructions are reportedly seldom consulted by users.

The observed fixation effect is similar to what Anderson describes as negative transfer between skills. A familiar operating procedure that may seem suitable for application in a new situation is in fact not applicable. This effect can be so strong that information in the world indicating otherwise is not understood, overlooked or even ignored.
At the same time, given the occurrence of the *fixation effect* and the related awareness of the user that for a unfamiliar model a new type of operation might be required, the *guessability* should be as high as possible for a product that requires a operation that is likely to be unfamiliar.

4.2.5 The nature of knowledge from memory

The differences between users in performance of the experimental tasks were found, in part, to be related to the differences in the knowledge they report concerning the execution of the task. Throughout Chapters 2 and 3 a difference was made between novice and experienced subjects. The difference between these two categories is supposed to lie in their level of expertise. Expertise, however, is a vague measure. It is not clear which experience, and how much, makes an expert. It seems safer to use the measure ‘experienced’ only in a relative sense. Part of the confusion is caused by the fact that it is not the exposure to a situation that determines the level of expertise but the knowledge the person derives from that experience. In general though, experience is considered an important source for stored operating knowledge.

Classification on types of knowledge

Various distinctions are made within knowledge in memory or prior knowledge. Dochy (1992) mentions a number of categorisation alternatives for prior knowledge but concludes that the distinction between declarative and procedural knowledge is the most preferable.

Declarative knowledge, also referred to as conceptual knowledge, is the knowledge of facts. Procedural knowledge is the knowledge of actions and manipulations. Winograd (1975) and Anderson (1980) refer to the difference between these two types of knowledge as 'knowing what' (declarative) and 'knowing how' (procedural). Another type of knowledge worth mentioning here is strategic knowledge. Although Cohen (1983) makes no real difference between strategic and procedural knowledge, it seems a useful distinction in the context of this discussion. Both types of knowledge concern skills and plans of action. The difference lies in the fact that procedural knowledge is domain specific while strategic knowledge is not.

Homogeneous and heterogeneous experience

Successful execution of familiar tasks requires hardly any effort because users acquired the necessary knowledge prior to the operation. As experience with a task increases, a skill emerges through proceduralisation. For unfamiliar tasks no suitable skills may be available, and users tend to apply operating procedures they have available. In the experiments, relying on their experience, most subjects fixated on a familiar way of operating. However, there were subjects who were able to successfully execute the tasks and were not hampered by a fixation on their experience, although the experience with product models was identical.

This led to a new perspective on experience. With regard to product function, increment of experience may involve a repeated execution of one task requiring one operating procedure. With every successful repetition the operating procedure

is reinforced and the experience of the user becomes *homogeneous*. The type of prior knowledge thus acquired is likely to be procedural.
In contrast, the increment of experience can also concern a number of similar tasks requiring different operating procedures. The experience thus emerging consists of different procedures and can be labelled *heterogeneous*. The type of prior knowledge resulting from heterogeneous experience is not only procedural but also declarative knowledge. This declarative knowledge can be applied when a choice is to be made between different operating procedures. This may be important in the occurrence of operating difficulties.

Operating difficulties
With the distinction between two types of experience three possible causes for operating difficulties can be distinguished.

- Absence of experience leads to solving the operating problem on the basis of declarative knowledge not specifically related to the operating problem. The role of the information provided by the product is crucial and the level of guessability of the product will determine the occurrence of operating difficulties.
- Homogeneous experience leads to the solving of a problem on the basis of specific procedural knowledge. Fixation is very likely to occur when the procedural knowledge is not applicable, The effect can be worsened when the information of the product is not sufficiently alarming
- Heterogeneous experience leads first to the selection of an operating strategy, followed by the application of one specific operating procedure. The mapping via analogy mentioned earlier is only possible when heterogeneous experience is available. As experience becomes more heterogeneous, subjects become more uncertain when selecting an operating procedure, even when the required operating procedure is familiar. Heterogeneous experience allows the subject an overview of the various optional operating procedures and, more importantly, the awareness that different operating procedures are possible for a particular type of product. Fixation is less likely to occur, even when the appropriate procedure itself is not available, and use-cues are more likely to be perceived and have their effect.

4.3 Relations

On the basis of the described origins of causes for operating difficulties two relations can be formulated concerning determinants of operating difficulties. The aim of the formulation of these hypotheses is to try to evoke similar operating difficulties under different conditions.

4.3.1 The influence of product appearance.

Relation I

When a product model is of a type that functions differently from that of familiar product types, then the combination of appearance and required operation will influence the amount of operating difficulties with that model.

The information provided by the product is an important factor in determining the operation of an unfamiliar product. The unfamiliarity may concern the product function, but more commonly it will concern the product type, meaning that the user knows the purpose of the product but not how to operate it.
With innovations in product design new types of familiar product functions will emerge. The product appearance of such innovations will determine whether successful operation of the product by the user will be possible. In designing the product different strategies can be followed**,** as illustrated in the Rasmussen model outlined above. In Figure 4.1 four strategies are placed within the model.

Here, with innovation a change in the functioning of a product resulting in an unfamiliar output is meant. This can be accompanied by an alteration in the appearance, the operation and/or the internal functioning of the product.

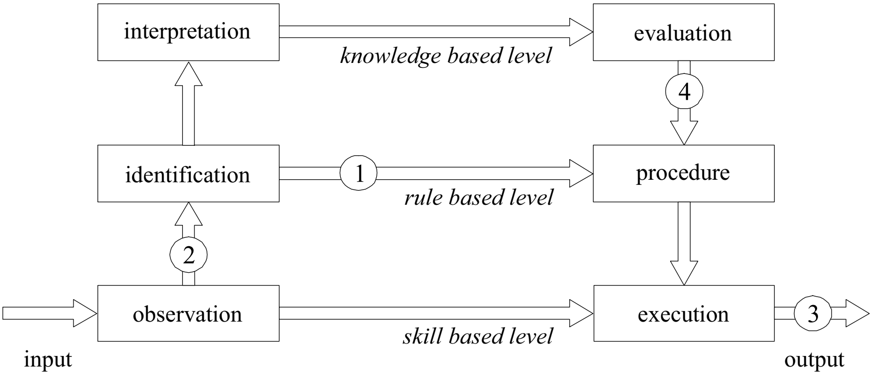


Figure 4.1
Schematic Rasmussen model in which four design strategies are indicated, implementing a new product functioning in an existing product function.

Strategy 1 Unchanged appearance, changed operation
This strategy is located in Figure 4.1 at ①. Guided by experience the user expects, on the basis of *observation* and consequent *identification,* that the learned *procedure* is applicable. However, in reality this is not the case and a new procedure has to be formed on the knowledge-based level. The result of the innovation is that a trained operating procedure triggered by the identification of

the product is replaced by a new operating procedure.
The unfamiliar type of can-opener used in Experiments 1 and 2 demonstrated this first strategy. An existing and very common link between the appearance of a 'can-opener' and the matching operating procedure is changed by the design of the side-cutter. Partly because of the setting in which it is operated, the product is positively identified as a can-opener and nothing seems to warn the user that a different operating procedure must be applied. The link between the product appearance and the operating procedure is reinforced with each use of the can-opener and it is not surprising that, given the similar product appearance, subjects fixated on the familiar operating procedure. This can result in insuperable operating difficulties, as described in Chapter 2.

Strategy 2 Changed appearance, changed operation
This strategy is located in Figure 4.1 at ➁. On the basis of *observation* the product is, during *identification,* rejected as familiar and therefore there no *procedure* is automatically executed. The innovation combines a new way of operating with a modification in product appearance, thus avoiding the user wrongly identifying the model as being a familiar type, and preventing the execution of a procedure which is linked to the familiar product.

The unfamiliar corkscrews in Experiment 2 demonstrated the second strategy. When a different operating procedure is required to reach a familiar goal, the design of the product warns the user that this is 'something different'. This opens the way for knowledge-based reasoning to produce a tailored procedure. It alerts the user that experience is possibly not sufficient. This awareness in itself is the first step towards heterogeneous experience, because the conviction that only one operating procedure is optional is abandoned.

Strategy 3 Unchanged appearance, unchanged operation
This strategy is located in Figure 4.1 at ➂. After *observation* the product is, through *identification,* positively identified as familiar and a *procedure* can be successfully applied during the *execution* phase, leading to an *output* that is different to what was expected on the basis of experience. The innovation can be implemented by making use of a familiar appearance and operation. A change in functioning can still be accomplished by a modification to the internal functioning of the product that is unobservable to the user, resulting in an unexpected output of the product.
Although not encountered in one of the experiments, the use of the Rasmussen model for the illustration leads to this alternative way of implementing a change in functioning within a familiar product type. Even when a familiar appearance and operation is maintained a different internal functioning can still lead to a different output from the product. An example of this strategy would be a can-opener that

looks like an ordinary can-opener and is operated and held like the familiar can-opener yet it still cuts through the side of the can. When the output shows a deviating and unfamiliar result the user will be surprised, but the successful application of the product function is at least secured.

Strategy 4 Changed appearance, unchanged operation

This strategy is located in Figure 4.1 at ④. After *observation* the product is not *identified* as being familiar. This can serve as a warning signal to the user, making it likely that through *interpretation* and *evaluation* a new operating *procedure* is to be produced. However, the familiar procedure is applicable and the user was misled by the unfamiliarity of the appearance into rejecting the familiar procedure. Through knowledge-based reasoning it has to be established that the familiar operating procedure was correct after all.

This situation, potentially leading to operating difficulties, was encountered in Experiment 2 when subjects had difficulties operating a familiar type of can-opener after having just used an unfamiliar type. Although the product functioning was not unfamiliar it differed from the functioning of the previous can-opener they had used. When, under these conditions, the user ignores the (unnecessary) unusual appearance and proceeds to apply the familiar way of operating no operating difficulty will emerge. Fixation would in this case prevent problems in use.

4.3.2 The influence of type of experience

Relation II

Finding the appropriate operating procedure for a product model with a familiar product function but of an unfamiliar type is helped by heterogeneous experience and hindered by homogeneous experience.

The other important factor in determining product operating is experience. The fixation effect as a cause for the observed operating difficulties was explained by relating the experience of users with model, type, function and operation of the product. From the discussion in the previous sections it became clear that a mere distinction between novices and experts is not good enough to account for the occurrence of the fixation effect. An additional distinction was introduced between homogeneous and heterogeneous experience. This distinction does not concern the quantity but the quality of the experience.

The distinction between homogeneous and heterogeneous experience is partly in correspondence with the distinction between novices and experienced users, but it differs on important elements. A cross-comparison between the two distinctions is given in Table 4.1.

Homogeneous experience can be brought about by both limited and extensive use of the product, but this extensive use would be frequent repetition of the same procedure. Heterogeneous experience can be a consequence of extended use of the product, but this experience must comprise different procedures in order to reach a particular operating goal.

Table 4.1
Cross comparison of the two distinctions within experience.

	novice	experienced
homogeneous	little use, consisting of identical procedures.	extensive use, consisting of identical procedures.
heterogeneous	little use, consisting of different procedures.	extensive use, consisting of different procedures.

It was shown to be possible to quantify experience based on the number of times a product was operated. In practice, however, the distinction between homogeneous and heterogeneous experience is not easily established. When determining the heterogeneity of experience the question of what experience is to be taken into account arises. Which experience is relevant for the operation of a certain product-function? This is important, because by definition heterogeneous experience consists of varying experience with product models or product functions. Determining a meaningful list of products to be taken into account might be feasible, but determining which products contain relevant product-function is virtually impossible. For example, the setting of an alarm on an electronic clock can be performed on a range of products varying from alarm clocks and watches to microwave ovens and VCR's.
It becomes even more difficult when the manipulations or sequence of manipulations required to operate a certain product-function are to be taken into account. The structure of the task of setting the alarm could be similar to the structure of the task of setting the channels of the television, or programming the pre-sets on a tuner. The determination of the nature of experience is undoubtedly complex. A solution to this complexity could be to simply question the user about the relevant experience and let the user decide what was relevant. However, this can only be done after the user's trial has been started. *A priori* determination of the relevance of experience is virtually impossible considering the fact that supposedly relevant experience may prove not to be so during task execution. Nor will the knowledge originating from supposedly relevant experience necessarily be applied.

5. Product appearance and types of experience

In Chapter 4 two factors that influence the use of unfamiliar products were described. a) The influence of information provided by *product appearance* on product use, and b) the influence of different types of *user experience* on product use. In this chapter the influence of both of these factors will be further investigated by means of two experiments.

I. Product appearance
In the theoretical discussion in Chapter 4 a relationship was formulated concerning the impact of product features, in particular when these features deviate from what is familiar to the user. The first relationship is based on the interpretation of the results of the explorative experiments described in Chapter 2.
Four possible design strategies were derived from the theoretical discussion in Chapter 4 describing how a new way of product functioning, unfamiliar to the user, can be accompanied by changes in product appearance and/or the required product operation. To test these strategies Experiment 5 was carried out.

II. Types of user experience
The second relationship concerns the influence of various types of experience on the use of unfamiliar products. In Chapter 4 expected differences in the influence of heterogeneous versus homogeneous experience were formulated. In Experiment 6 subjects were trained to use an unfamiliar product function in order to create different levels of experience. The influence of these levels of experience on product operation was subsequently observed.

5.1 Experiment 5, a coffee-serving machine

The aim of this experiment was to test the predictive relation I by showing how the design of a coffee distributing device influenced the operation of this device.

Relation I
When a product model is of a type that functions differently from that of familiar product types, then the combination of appearance and required operation will influence the amount of operating difficulties with that model.

Rationale
In the previous chapters it was argued that familiarity with a product leads to the execution of previously learned operating procedures. When an unfamiliar product is wrongly perceived as familiar by the user, the result may be a fixation on the previously learned operation, resulting in failure to achieve the required operation. In Chapter 4 this fixation effect was explained. It was argued that the fixation occurred when a new way of product functioning was accompanied by a familiar product appearance and an unfamiliar product operation.
When the user is unaware of the new product functioning he/she is falsely assured by the appearance of the product that a familiar way of operating can be applied, while in fact a different operating procedure is required. Following this explanation for the fixation effect, four strategies were formulated for redesigning the product appearance and the required product operation of a particular product type, given an alteration in product functioning. In Table 5.1 these strategies are indicated.

Table 5.1
Summary of the design strategies.

strategy	functioning	appearance	operation
1	changed	unchanged	changed
2	changed	changed	changed
3	changed	unchanged	unchanged
4	changed	changed	unchanged

To test the effect of all four strategies an experiment was carried out in which subjects were asked to operate different models of an identical product type. The differences between models had to be restricted to a limited number of variations in the features and operation, since the experiment is aimed at showing the influence of product features on operation.

Set up
Since it proved to be impossible to create such a situation with commercially available consumer products, a special product was assembled to meet the experimental demands. For this product it was decided to use the mapping between the direction of rotation and the control of a water tap and an electronic volume control. A water tap must be rotated anti-clockwise to increase the water flow whereas a volume control must be rotated clockwise to increase the volume. These typical combinations between type of control and direction of rotation are so strong that it seems safe to assume that, given a function and a corresponding

design, the required direction of rotation is unambiguous. In fact, the combinations are so strong that inconsistency between the two opposing directions of rotation to "increase" is seldom realised.

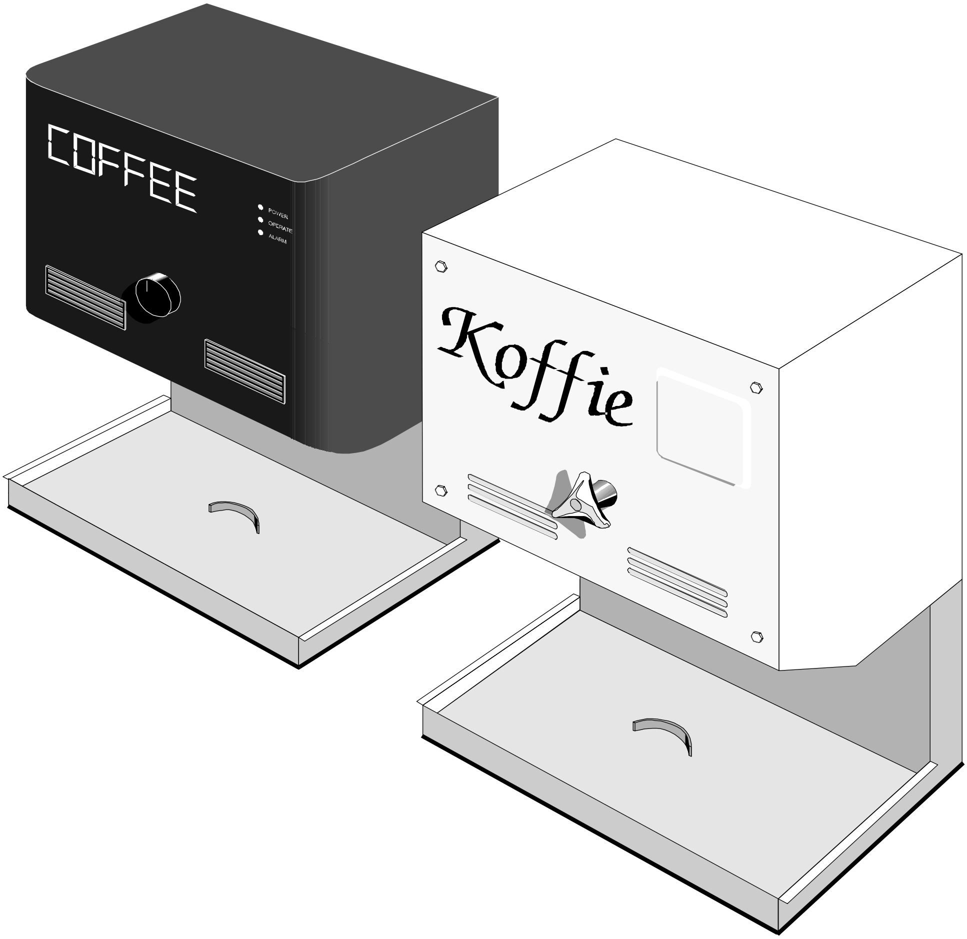


Figure 5.1
Two versions of the coffee-serving machine. Two versions are shown here with the corresponding control. The two other versions are identical, only with the controls exchanged. Right, the 'electronic' cover with volume control and left, the 'mechanical' cover with the tap head.

The function in which this contrast was applied was a coffee-serving container. For this product mechanical functioning is customary but electronic functioning could be an alternative. Different varieties of this product offered different combinations of the product features (Figure 5.1). These combinations were chosen on the basis of the formulated design strategies.

5.1.1 Method

Subjects

Subjects were 120 students from the Faculty of Industrial Design Engineering, Delft University of Technology. The subjects were randomly divided into four groups of 30 subjects each. Each group operated one version of the coffee machine. The subjects were rewarded for their participation with a cup of coffee.

Materials

For this experiment a single coffee-serving machine was developed. This device featured only one control operating the coffee valve. This ball-valve opened when rotated clockwise or anti clockwise One of two available metal covers was placed over the mechanical components. One cover suggested a mechanical operation the other suggested an electronic operation. The valve could be operated by rotating two types of controls, either a tap-head or a volume-control knob, in either a clockwise or anti-clockwise direction.
In Figure 5.1 the two covers and the two controls are illustrated. Both the covers and controls were interchangeable making four different versions possible (see Table 5.2). Each of the four versions of the coffee machine stood on a table with the control axis 135 cm from the floor. Next to the coffee machine stood cups, spoons, sugar and creamer. The four groups of subjects were observed operating one of these four versions of the coffee distributing device.
The four conditions in this experiment, the coffee machine models, provided examples of the design strategies. All models functioned when the control was rotated either anti clockwise (mechanical direction) or clockwise (electronic direction). The subjects were not aware of this. Therefore, each direction of rotation could be assumed to be appropriate or intended by the designer, which made it possible to test more than one strategy with only one model.
The strategies were applied to the models as follows.

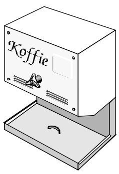
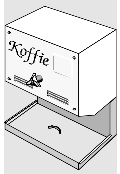
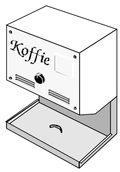
Model 1

Since the coffee machine functions mechanically, the appearance of the model featuring the tap head and the mechanical cover both correspond with the product functioning. On the basis of the conventional operation of these product parts subjects were expected to rotate the tap in an anti-clockwise direction. Because the coffee machine could successfully be operated by rotation in either direction, this model can be seen as an exponent of two strategies.

I. When it is assumed that the correct direction of rotation is clockwise while the product features indicate an anti-clockwise rotation, this model corresponds to Strategy I (see Table 5.2).

III. When it is assumed that the correct direction of rotation is anti-clockwise, the 'mechanical' direction, while in fact the functioning of the product is electronic, then this model corresponds to Strategy III. The fact that the product functions mechanically under all conditions does not change this, since this could not be perceived by the subjects; certainly not beforehand.

Table 5.2
Outline of Experiment 6, conditions, strategies and results. (d.o.r.= direction of rotation, cw = clockwise, a-cw = anti-clockwise).*

model	**1**		**1**		**2**		**3**		**4**		**4**	
												
cover	mechanical		mechanical		electronic		mechanical		electronic		electronic	
control	tap head		tap-head		tap head		volume-control		volume-control		volume-control	
expected d.o.r.*	cw		a-cw		both		both		cw		a-cw	
strategy	I		III		control		control		II		IV	
appearance	unchanged		unchanged		un/changed		un/changed		changed		changed	
operation	changed		unchanged		-		-		changed		unchanged	
results	**cw**	**a-cw**	**cw**	**a-cw**	**cw**	**a-cw**	**cw**	**a-cw**	**cw**	**a-cw**	**cw**	**a-cw**
number of subjects	8	22	8	22	7	23	24	6	22	8	22	8

Models 2 and 3
These two models (tap-head with 'electronic' cover and volume control knob with 'mechanical' cover) were believed to suggest both directions of rotation, because the product features did not correspond. Subjects were therefore expected to rotate

the control in either direction. These models do not match any of the described strategies but were used in the experiment to create control conditions. Deliberately designing an ambiguity is not considered a sensible design strategy. However, these models make it possible to monitor the relative influence of single product features.

Model 4
The model featuring the volume control knob and the electronic cover could be an alternative way of designing the product. The features indicate a clockwise rotation instead of the 'mechanical' anti- clockwise rotation. This model can also be seen as an exponent of two strategies.

II. When the clockwise rotation is assumed to be intentional by the designer, this design would follow Strategy II. The strategy was encountered in the way the deviating corkscrew was designed in Experiment 3 (see Table 5.2).

IV. When the anti-clockwise direction of rotation is assumed to be intentional by the designer then the appearance incorrectly indicates a deviation, because the familiar operation is required. This was described as Strategy IV (see Table 5.2).

Subjects were expected to be guided by the deviating appearance and to rotate the control in a clockwise direction which, for a mechanical functioning, would be an incorrect direction.

Procedure
Subjects were invited to participate in the experiment and were given an introduction explaining their task; *'We have here a prototype of a coffee machine and we would like you to pour yourself a cup of coffee'.* No further information was given on task execution or the purpose of the experiment. Care was taken that subjects could not observe other subjects operating the coffee machine. Subjects were allowed to operate the coffee machine only once and this operation was recorded on video.

5.1.2 Results
The effect of the design strategies was evaluated by interpreting the observed rotations on each of the four models. The four conditions resulted in different distributions of the clockwise and anti-clockwise rotations. The numbers of first rotations in either direction over the four conditions are depicted in Figure 5.2.

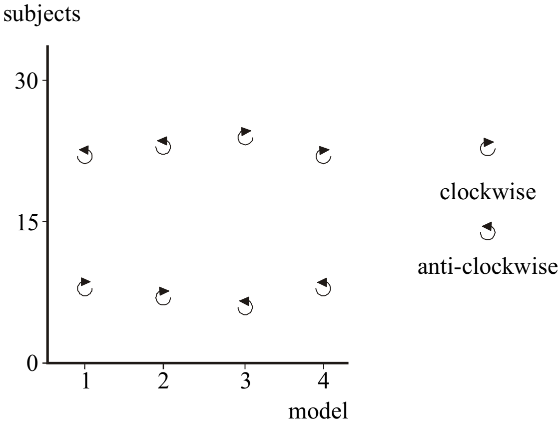


Figure 5.2
Numbers of subjects rotating in clockwise and anti-clockwise direction.

The subjects operating Models 1 and 2 rotated mainly anti-clockwise (resp. 22 out of 30 and 23 out of 30) while the subjects operating Models 3 and 4 rotated mainly clockwise (resp. 24 out of 30 and 22 out of 30). The numbers of clockwise and anti-clockwise rotations can be compared among the 4 models on the basis of one variable, either the cover or the control, using the Chi square test (between Model 1 and Model 2, p=0.000; between Model 1 and Model 3, p=0.70; between Model 2 and Model 4, p=0.50; between Model 3 and Model 4, p=0.000).
Another way of testing the results is to compare them for each model with the expected values by means of a Chi square goodness-of-fit test. The null hypothesis was that the chance of a subject rotating the control in one direction would be 50% (for Model 1, p=0.02; for Model 2, p=0.01; for Model 3, p=0.01; for Model 4, p=0.02).

5.1.3 Conclusion

The results show how product operation can be influenced by the appearance of a product. However, different features of the product can have a different impact on the user. On the basis of the results of the control conditions it can be concluded that the influence of the controls overrules the influence of the covers used in this experiment. Although the product function remains constant, subjects apply a different operation depending on the type of control.
On the basis of the results the four strategies can be evaluated.

Strategy I
The results showed that most subjects rotated the control in a clockwise direction, meaning that the subjects were misled by the appearance of the model. This result is similar to the result obtained with the unfamiliar types of can-openers in

Experiments 1 and 2.
Changing the required operation while the appearance remains unchanged led to the subjects becoming confused and attempting to operate the product in the way indicated by the appearance. This strategy should therefore be avoided.

Strategy II
The expectation that subjects would rotate the control in a clockwise direction because of the appearance of this model proved correct. Subjects were guided by the appearance of the model. This result is similar to the improvement of performance established in Experiment 2 with the corkscrews.
Changing the appearance along with the required operation led to subjects rotating the control in the appropriate direction. This strategy is therefore a good approach.

Strategy III
The results showed that most subjects did indeed rotate in an anti-clockwise direction. Not changing the appearance or the required operation, subjects also rotated the control in the appropriate direction. The different way of producing output that is part of this strategy was not simulated in the experiment. However, subjects were not aware of the type of functioning and therefore this did not influence their operating behaviour.
When possible, the application of this strategy also seems a good approach.

Strategy IV
Subjects rotated the control in a clockwise direction which, given this strategy, was wrong. Changing the appearance with the altered internal functioning without changing the required operation resulted in subjects being unnecessarily alarmed by the changed appearance and this led to a new way of operating, while in fact the familiar way of operating was required.
This strategy produced unnecessary operating difficulties and should therefore be avoided.

5.2 Experiment 6, telephone memory

The aim of this experiment was to test the predictive relation II concerning the effect of different types of experience on the ability to operate an unfamiliar product.

Relation II
Finding the appropriate operating procedure for a product model with a familiar product function but of an unfamiliar type is helped by heterogeneous experience and hindered by homogeneous experience.

Rationale
In Chapter 4 it was argued that the distinction between experienced and novice users was not sufficient to account for differences in the ability to find a hitherto unfamiliar way of operating a product function. Consequently, an additional distinction
between homogeneous and heterogeneous experience was introduced, a distinction based on the quality of the experience rather than the quantity of experience.

Homogeneous experience provides knowledge of one way to operate a product function. This one way of operating can be practised repeatedly. It is assumed that homogeneous experience can lead to fixation on one way of operation and to inhibition of a new way of operation.

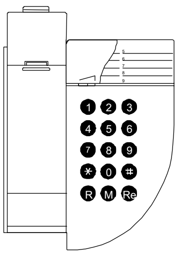
Heterogeneous experience, on the other hand, provides knowledge about the operation of different product types within the same function and, in addition, provides more general knowledge suitable for knowledge-based reasoning. It is believed to make the occurrence of fixation less likely and, if required, it makes the generation of a new operating procedure easier. These two types of experience were assumed to have these influences on the basis of the experiments described in Chapters 2 and 3. However, the empirical evidence was limited and to verify the assumed relation an experiment had to be carried out.

In this experiment groups of subjects were given different types of training in order to form the two types of experience. As in Experiments 3 and 4, the product function chosen was the memory retrieval function of domestic telephones. Subjects were asked to operate two telephone models after they had received initial training. The training was given by asking the subjects to use a number of different telephones.
The expectation was that the group with the heterogeneous training would perform better on the first target telephone than the group with the homogeneous training. On the second target telephone no such difference was expected, since both groups were familiar with its type of operation.

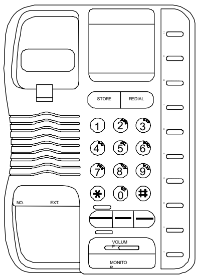
5.2.1 Method

Subjects
For Experiments 3 and 4 elderly subjects were selected. The experiments showed that this group had considerable difficulties in successfully performing the experimental tasks, even after they had become familiar with the tasks. It was therefore decided for this experiment to select younger subjects, who were expected to produce more successful task performance.
Forty students from the Faculty of Industrial Design Engineering, Delft University of Technology, participated as subjects in this experiment. The subjects were

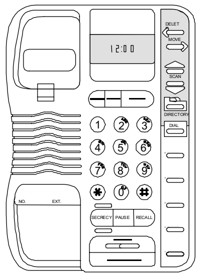
divided into four groups, each taking part in one condition in the experiment (see Table 5.3). In each condition 10 subjects participated. To which condition each subject was assigned depended on the subjects' experience with the memory retrieval function, acquired before the experiment. Subjects' experience was established by means of a brief interview. None of the subjects had participated in Experiments 3 or 4.



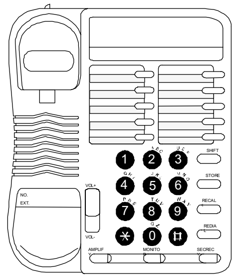
Monza 10



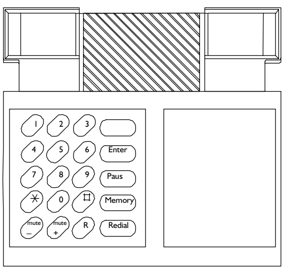
Relate 200



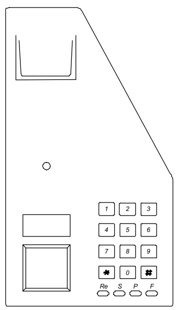
Relate 400



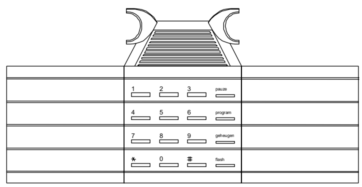
Converse 200



Beocom



Napels 10



Genova

Figure 5.3
Telephones used. The models in the top line were used in Experiments 3 and 4.

Materials
Seven telephones were used. Five were used for training the subjects and two were target telephones on which the performance ability of the subjects was investigated. Figure 5.3 represents the three telephones that were used in addition to the four telephones used in Experiment 3 and 4.
In Appendix D all seven telephones are presented on a larger scale, together with their required operating procedure.

Table 5.2
Telephones and their operating procedures.

model	purpose	procedure
Napels 10	training	Enter the memory mode through the 'Re' button and then, according to the handwritten number index, select the desired keypad retrieval number. **
Beocom 1000	training	Enter the memory mode through the 'Memory' button and then, according to the hand written number index, select the desired keypad retrieval number. **
Monza 10 *	training	Enter the memory mode through the 'M' button and then, according to the hand written number index, select the desired keypad retrieval number. **
Relate 200 *	training	Press the memory key associated with the telephone number you require.
Converse 200 *	training	Press the 'SHIFT' button and then the memory key associated with the telephone number you require.
Relate 400 *	target	Press the 'DIRECTORY' key, scan until the display reads the name and number you require, then press ' DIAL'.
Genova	target	Enter the memory mode trough the 'GEHEUGEN' button and then, according to the handwritten number index, select the desired keypad retrieval number. **

* models used in Experiments 3 and 4
** ‘memory button’ procedure

Four types of operating procedures are needed to operate the seven telephones. One of these procedures, the 'memory button' procedure, is appropriate for four telephones. The models Napels 10, Beocom 1000, and Monza 10 require this memory button procedure and these models were used to train the first experimental group in order to produce a homogeneously experienced group. In Table 5.2 the telephones used in this experiment are mentioned and the corresponding operating procedures described.

Procedure
Subjects were given a brief introduction to the experiment, in which the availability of special functions on the telephones was mentioned, specifically the memory retrieval function. To get an impression of their experience subjects were then questioned about their experience with special functions on telephones and with the memory retrieval function in particular.
Subjects were then assigned to one of the groups on the basis of their experience with the telephone memory function. Because subjects' experience could interfere with the training to be given, only subjects with either no experience or homogeneous experience could be assigned to the first experimental group. To allow for the extra variable introduced by the selection of subjects on the basis of their experience, two control groups were necessary. Subjects with either no experience or homogeneous experience were assigned to the first control group and subjects with heterogeneous experience were assigned to the second control group. In Table 5.3 the four groups with the corresponding selection criteria and training are summarised.

Table 5.3
Selection criteria and training sequences in each condition (N=40).

condition	*experience*	*training models*	*target models*
homogeneous n=9	none or homogeneous	Monza 10, Napels 10, Beocom 1000	Relate 400, Genova
control 1 n=11	none or homogeneous	none	Relate 400, Genova
heterogeneous n=10	none, homogeneous or heterogeneous	Relate 200, Converse 200, Monza 10	Relate 400, Genova
control 2 n=10	heterogeneous	none	Relate 400, Genova

After being assigned to a condition the subjects were invited to operate the three training telephones, for which written instruction were available. After completing the operation of each telephone according to the instructions the subjects were asked to repeat the operation without reference to the manual. After the completion of all three telephone operations, all three telephones were replaced on the table and the subject was again asked to explain to the experimenter the operating procedure of each telephone. This procedure was adopted to ensure that all subjects were familiar with the operation of all three training telephones. After the training, subjects were presented with two target telephones which, for all condition groups, were first the Relate 400 followed by the Genova. The first of these telephones required an operating procedure not previously encountered. The second telephone required a procedure which both experimental groups had encountered during the training.

The subjects in the control groups received no training and were presented with the target telephones immediately following the introduction. For the operation of each of the two target telephones the subjects were allowed a maximum of 5 minutes. All the actions and remarks of the subjects were recorded on video.

5.2.2 Results

The performance of the subjects was analysed using two measures, first the success rate of the subjects (Figure 5.4) and second the number of trials needed (Figure 5.5). Performance on both target telephones was analysed.

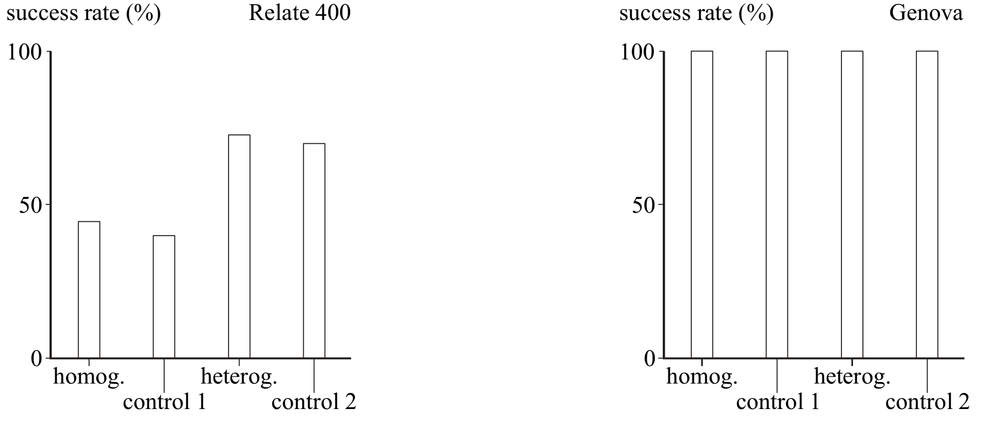


Figure 5.4
Success rates within each target group on the target telephones, given in percentages of group size.

Success rate
The success rate with the first target telephone, the Relate 400, did not differ significantly between the two experimental groups (Fisher exact probability test, p=0.204). Between the two control groups the difference in success rate was not significant either (Fisher exact probability test, p=0.184). The differences between each experimental group and the corresponding control group were not significant

(Fisher exact probability test; between homogeneous and control 1, p=0.605; between heterogeneous and control 2, p=0.632).

For the second target telephone no differences at all were observed between the groups (Fisher exact probability test; between homogeneous and heterogeneous, p=1.000; between homogeneous and control 1, p=1.000; between heterogeneous and control 2, p=1.000; between control 1 and control 2, p=1.000).

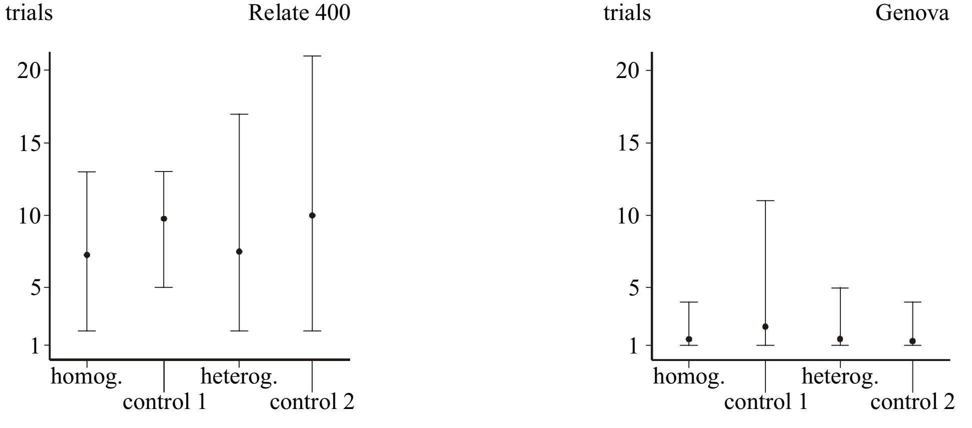


Figure 5.5
Range and average number of trials for each group on the two target telephones.

Performance
Performance, measured in number of trials needed, can be analysed using the number of trials produced by the successful subjects. In Figure 5.5 the averages and the ranges for each group are illustrated. The number of trials produced by the non-successful subjects is not included in the analyses because these numbers do not reflect the performance level of the subjects, but rather the number of trials the subjects produced in 5 minutes. The comparison between the two experimental groups, between the two control groups and between each experimental group and the corresponding control group showed no significant differences between the numbers of trials needed by the successful subjects (Wilcoxon-Mann-Whitney test; between homogeneous and heterogeneous, p=0.230; between control 1 and control 2, p=0.264; between homogeneous and control 1, p=0.200; between heterogeneous and control 2, p=0.060).
The differences between the numbers of trials on the second telephone, the Genova, between the groups was not significant either (Wilcoxon-Mann-Whitney test; between homogeneous and heterogeneous, p=0.305; between homogeneous and control 1, p=0.379; between heterogeneous and control 2, p=0.390; and

between control 1 and control 2, p=0.268). This is not surprising after having observed no difference between the success rates on the same telephone.

Finally, performances on the two target telephones were compared. Comparison between the success rates within each group showed no significant differences for any of the groups. (McNemar change test; homogeneous, p=0.100; heterogeneous, p=0.300; control 1, p=0.200; and control 2, p=0.300).
The number of trials taken within each group for each of the two target telephones was also compared. The difference per group is significant (Wilcoxon signed ranks test; homogeneous, p=0.001; heterogeneous, p=0.001; control 1, p=0.023; control 2, p=0.001).

5.2.3 Conclusion

The aim of Experiment 6 was to test the expectation that subjects with heterogeneous experience would be better able to find a way of operating an unfamiliar type of product than subjects with homogeneous experience.

The results of the experiment do not confirm these expectations. Although the observed differences in performance on the first target telephone are in the right direction, no significant results were found regarding the superior performance of the subjects with heterogeneous experience, either in the experimental group or in the control group, compared with subjects in both groups with homogeneous experience. This applies both for the success rate and performance measured in numbers of trials, although in the performance levels more differences between groups were established. The supposedly facilitating influence of heterogeneous training was not affirmed in this experiment.
The main cause for not being able to show the influence of the nature of experience is the absence of variation in performance level with the target telephones between the groups. Although in the experiment this was meant to be the criterion for deciding on the influence of type of experience, in retrospect this does not seem right.
The selection of the first target telephone was made on the basis of the results of Experiment 3. The subjects in this experiment were hardly able to operate this telephone. Therefore operating this telephone was considered a difficult task.
In fact, it was considered too difficult a task because of the absence of variation in performance levels over the experimental groups. Almost all subjects were unable to operate successfully. Therefore, in this experiment this task could only be used when subjects participated from whom a higher performance level on this task might be expected.
This intention proved to be successful, too successful actually. Again there was an absence of variation in performance levels over the groups, but this time because nearly all subjects were able to operate both target telephones with success,

regardless of the difference in experience level carefully induced in the experiment.

With hindsight, comparing the results of Experiment 3 and 4 with those of Experiment 6 would have been a better way to show the influence of the nature of experience, rather than basing it only on Experiment 6.
These results provide sufficient reason to assume that the Delft students in Experiment 6 differ from the elderly participating in Experiments 3 and 4 in the nature of their experience. Although the experience of both groups was established in a similar way, obtaining comparable results, in fact the subjects in both experiments must have differed in their type of experience.
Heterogeneous experience probably involved more than knowledge of a number of telephones. For example, knowledge of the use of all kinds of electronic appliances adds to the heterogeneous experience. This could mean that the experience concerning the experimental tasks of all the subjects in Experiment 6 was more heterogeneous than was assumed, and it was probably also more heterogeneous than most of the subjects in Experiments 3 and 4.
Although different from the way it was intended, the results of Experiment 6 combined with those of Experiments 3 and 4 do provide an indication that heterogeneous experience facilitates the ability to discover an unfamiliar operating procedure.
The analysis of performance on the two target telephones, within each group, shows no difference in success rate within the groups, but significant differences in number of trials taken for the two models. Because this difference concerns all groups there is no reason to assume that it originates from subjects' knowledge or type of experience. More likely the Genova is simply easier to operate than the Relate 400. Experiment 3 showed the Monza 10 type procedure, identical to the procedure required for the operation of the Genova, was easier to find than the Relate 400 type procedure.
Besides, the required operating procedure is adopted on most of the telephones available in the Netherlands, so that most of the experience subjects assigned to the control groups were familiar with that procedure.

5.3 Discussion

Experiments 5 and 6 were conducted to test the assumed relations derived from the theoretical discussion in Chapter 4. Experiment 5 dealt with the influence of information provided by the product and Experiment 6 dealt with the influence of different types of experience.

5.3.1 Experiment 5

The aim of Experiment 5 was to show how different ways of (re-)designing an existing product type will affect the operating behaviour of users. Provided that a very familiar product functioning is modified, four strategies were formulated and their effectiveness evaluated.

Successful strategies

Two of the strategies proved to be successful. Strategy I involves changing nothing or as little as possible and letting the modified functioning take place without the awareness of the user. In contrast, Strategy III involves changing all aspects, functioning, appearance and operation, so that the user is fully aware that the functioning has been modified.

Unsuccessful strategies

The remaining two strategies proved to lead to operating behaviour other than that intended by the designer. These strategies are therefore prone to operating difficulties.
With Strategy II the user is not alerted by the appearance of the product that a different operation is required to activate a modified functioning. The resulting operating difficulties were encountered not only in this experiment but also in Experiment 1 when the unfamiliar can-opener was used.
With Strategy IV, in contrast, the user is alerted by the appearance but without reason since the modified functioning is activated by the traditional operation.

Strong link between appearance and operation

This experiment also showed that the operating behaviour evoked by the appearance of the product could be changed dramatically by replacing just one product part. Obviously, the appearance of this product part, the control, has a very strong link with its operation.

5.3.2 Experiment 6

The aim of Experiment 6 was to show the effect of different types of experience on performance with an unfamiliar type of product.
Unfortunately, this effect could not be shown in the way it was intended, within the experiment. Additional research is required in which the nature of subjects' experience should be operationalised in a more refined way. In the introduction to Chapter 3 two ways of establishing experience were indicated, based on content and based on the level of abstraction. This experiment obviously dealt with the level of abstraction of experience (heterogeneous vs. homogeneous) whereas experience was controlled by means of its content (training with telephone models and types). This resulted in the superior ability of the subjects going unrecognised.

The results of Experiment 6, combined with the results of Experiment 3 and 4, can be interpreted as a strong indication that heterogeneous experience does have a facilitating effect on discovering an unfamiliar way of operating.
The technical students (Experiment 6) had fewer problems in discovering the unfamiliar operations than the elderly had (Experiment 3 and 4). For the students this was not due to their knowledge of telephones as this was controlled in the experiment. Their ability must have originated from another source of knowledge.

Knowledge based reasoning
Sein and Bostrom (1989) mention three sources of operating knowledge;
- hands-on experience (mapping via usage)
- transfer from another domain (mapping via analogy)
- application of general knowledge (mapping via training)

For the successful formulation of a new operating procedure reasoning at knowledge based level (Rasmussen) is essential. Discovering by accident through hands-on experience is not necessarily initiated by knowledge based reasoning. Deriving a new operating procedure, either through transfer of knowledge or through the application of general knowledge, requires at knowledge based level insight into how and when to apply available knowledge.
It is this type of insight that was labelled *strategic knowledge* in Experiment 3 and which in Experiment 6 was assumed to originate from heterogeneous experience. Obviously, heterogeneous experience must be defined as going beyond the boundaries of the domain e.g. telephone memory retrieval.

6. General discussion

6.1 Result of the study

6.1.1 Cognition and the use of products

The aim of this study was to gain insight into the role of the cognitive factors that determine the unsuccessful use of consumer products. It explores the nature of cognition involved in the use of products and searches for the causal mechanisms underlying unsuccessful product use. The resulting insight involves understanding how unsuccessful product use is related to the interaction between design features and cognitive activities. Cognitive involvement during evoked operating difficulties was traced by analysing use actions, and factors and mechanisms underlying the occurrence of these difficulties were explored.
Throughout the study a recurring theme has been the interaction between user knowledge and information provided through the product, what Norman (1989) labelled *knowledge in the world* and *knowledge in the head.* The success of this interaction proved not to depend simply, as supposed at the outset of the study, on whether or not the two sources of knowledge are complementary.
A complicating factor in the interaction is the dilemma mentioned on Chapter 1. While the use actions of the user determine the success of the individual man-product interaction, a product designer cannot influence these actions directly, except by arranging the knowledge in the world, the product features, in such a manner that the user is guided towards a successful operation. The effect of the knowledge in the world on usage depends on existing knowledge in the head. Whether the information provided by the product is perceived and, if so, how it is processed and combined with the users' prior knowledge determines whether or not the user will encounter operating difficulties.

Other sources of operating difficulties.
The study is based on the collection of operating difficulties encountered in the experiments. To illustrate the general nature of consumer product related operating difficulties, two internet collections of *bad designs* by de Waard (2000) and Darnell (2000) can be mentioned. Their collections comprise examples of designs that are claimed to be prone to operating difficulties. Darnell's collection includes the unfamiliar can-opener used in Experiments 1 and 2. (Section 2.3, model A) and an example on opposite directions of rotation required for operating faucet handles. The authors provide explanations for difficulties, and in some cases

formulate guidelines to prevent the difficulties. More than half of the examples include cognitive elements
and are clustered in categories such as.'*Things that don't work the way you expect, Controls with conflicting cues'*, or *'Displays that look like controls*'. The other examples, involving physical rather than cognitive factors, deal with '*Things that are hard to see'*, '*Things that don't fit you*' or '*Controls that are easy to activate accidentally'*.
When identifying causes for cognition related examples the authors describe problems that arise when a product does not supply suitable information and users are confused, not able to understand, or forget to perform essential actions. This absence of information, resulting in confusion and misunderstanding for the users, is addressed in the causal mechanisms identified in this study. The remaining cause i.e. forgetting to perform an important action, is not likely to occur when operating an unfamiliar product

Explanations for the operating difficulties in the study
Within the conditions provided by the experimental designs a number of operating difficulties were encountered. It was argued that these operating difficulties could be explained in general by two causal mechanisms, *fixation* and *low guessability.* These two mechanisms share a number of common elements, but the starting points of their causal explanation are very different.
Fixation refers to a condition in which a users' cognitive action control cannot provide a successful operating solution on the basis of the available experience, while information provided by the product is contradictory or not sufficient to guide the user to the proper operation.
Low guessability refers in general to the absence of any self-explanatory quality in the product. The information provided by the product is insufficient to lead the user to a successful operation, or confuses the user. However, the same product may prove to be self-explanatory for another user due to differences in knowledge between users.

In dealing with the possible occurrence of these two causal mechanisms a designer cannot solve fixation of the user directly, it can only be compensated for with information provided through the design. In contrast, low guessability is a quality of the design and can be directly influenced by the designer.

6.1.3 Operating difficulties and users' knowledge

The experimental work in this thesis demonstrated that operating difficulties can depend on the knowledge of the user.
The ability of users to discover the operation of a product that has not been used before was found to depend on the knowledge the user has available for the specific task. Experience is an important source for this knowledge, but experience

is not a simple entity. Experience and its influence proved to be difficult to assess. It is hard to determine to what extent the user is experienced and also what knowledge relevant to the operation is available on the basis of the users' experience.
At first users' experience was assessed by determining with which similar *product models* the user had experience, but this method was discarded as too simple (Experiment 1, can-openers and corkscrews). The next alternative, determining with which *types* the user has experience, had to be rejected on the basis of the experimental results because the content of relevant experience seems to stretch beyond the boundaries of the domain in which the operating task is located. Unfortunately, this makes it impossible to assess the relevant experience of a user.

To explain the differences found in product operating ability in the experiments related to differences in knowledge on the basis of available experience, a distinction between homogeneous experience and heterogeneous experience was introduced. This was thought necessary because experience proved not to mean expertise. Homogeneous experience provides knowledge about one or two product models, including the operation required, while heterogeneous experience was defined as also containing more abstract insight, as well as knowledge of two or more models and types. However, when put to the test in Experiment 6, the product-type related heterogeneous experience alone proved not sufficient to explain the differences in ability between users. It seems that the definition of heterogeneous experience should be extended to include insights that are not domain-specific, and general abilities. Unfortunately, this further complicates the assessment of experience that is relevant for the operation of products.

6.1.4 Operating difficulties and product information

The second main factor in the occurrence of operating difficulties, in the study, is the information proved through the product. As stressed earlier, in contrast to the knowledge of the user, the information conveyed by the design is the only available option the designer can use to influence the occurrence of operating difficulties. The study showed that this information has three types of function in the prevention of cognition related operating problems.

- It provides missing operating information in an unfamiliar situation.
- It triggers an awareness of unfamiliarity in an apparently familiar situation.
- It provides missing, correct operating information in an apparently familiar situation.

These functions should work both directly during interaction between user and product and also indirectly by forming a functional internal representation for future usage. These three functions are required simultaneously in one product design when the variation within the user population is taken into account. The use

cues that are included in the design should be aimed at actively achieving each of these functions, so that users are guided towards successful operation. If not 'designed' into the product itself, then these messages can be indirectly presented to the users through written use instructions.
However, information in written use instructions is generally aimed at influencing the user on a rational, knowledge-based level. This does not agree with the lower level of control at which most product operating actions are controlled, as found in the experiments. Preferably, the information should function passively by avoiding associations with products requiring a 'wrong' operation and providing consistency between appearance and the operation.

6.2 Generalisability

The underlying question in this study was whether the insight gained into the causes of operating difficulties in the experiments can add to the prevention of operating difficulties in general. This presumes the generalisability of the findings of the study. Whether it is allowable to generalise the results obtained from the experiments can be discussed from different viewpoints.

Type of problems
The operating difficulties encountered in the experiments are not unique to this study. Norman describes similar problems and corresponding causes for many different products. The collections of "bad designs", (mentioned in 6.1), also describe similar difficulties. There seems to be sufficient reason to expect similar cognition related operating difficulties in a wide variety of interactions between users and products.
However, one restriction must be made. The observed problems are related to the unfamiliar use of products. Operating difficulties caused by low guessability, and certainly by fixation, are likely to be overcome when the user gains experience in the use of a particular product. When the operation of a product becomes truly familiar, meaning that the appearance of the product triggers a successful operating procedure, the persistence of a fixation effect on an unsuccessful operation is not likely. Similarly, the absence of guiding product information does not make it impossible for a persistent user to overcome the shortcomings of the design and find a successful operation; and once the successful operation is familiar, supporting product information becomes less important.

Reaching an adequate level of expertise on an operating task, however, can be seriously hindered by initial operating problems and consequently may be never reached.

Type of product
Relatively simple products were used in the experiments. The reason for choosing simple function products, apart from the common use of these products, was that the use of a product depends not only on the characteristics of the product but also on the characteristics of the user and the context of use. (see Section 1.1). In order to identify the causal mechanisms underlying the operating behaviour an initial reduction of influencing variables was required. If it is not possible to identify such mechanisms for the operation of simple products then it is pointless to attempt this for more complex products.
Regarding the operating difficulties encountered in this study, it is argued that the origin of these difficulties lies in the way users combine different sources of knowledge and/or information. The use of a product becomes difficult when the information available to the user is wrong, contradictory or too limited. The operation of more complex products will involve increased complexity in combining the required knowledge and information, and therefore similar or more numerous difficulties can be expected.
The repeated recording of the operating problems with a range of products, and the derived explanation for the difficulties that is not product specific, make the generalising of the results to more complex products justified and possible.
For example, there is no reason to assume that the same mechanisms that cause operating difficulties with 'simple' consumer products will not cause operating difficulties in human-computer interaction as well. The formulated explanations are not product specific, as was the case with many explanations for operating difficulties formulated within the field of HCI (see section 1.3.2)

Individual differences
Only a limited range of users acted as subjects in the experiments in the study, yet even with this limited range, under identical experimental conditions, differences in the occurrence of operating difficulties between subjects were observed.
In correspondence with the formulated explanation for the observed operating problems, variation in the knowledge and experience of users leads to users having no difficulties in using a product, while others might face serious operating difficulties with the same product. Regardless of the complexity of the operating task, there will always be users who are able to solve the operating riddle. For example, most PC users of today would have faced unsolvable operating problems with the generation of computers featuring punch card storage.
Nonetheless, although the occurrence of operating difficulties is individually determined, the underlying mechanisms are common enough to allow generalisation.

In Chapter 1 the individual differences were primarily brought up in relation to the designer of a product. He/she can be regarded as proficient in the use of the products under development and will not encounter the type of operating problems described in this study. As a consequence the designer will have difficulty imagining the operating problems novice users of the product will face.

Context of use

The context in which the products in the experiments were used was not varied and consequently was not included in the explanation for the observed difficulties. Within each experiment the physical context was standardised and was equally new to all subjects, whereas the presence of the experimenter formed the social context.

In real-life the context of use provides an additional influence on the occurrence of operating problems. Users facing operating difficulty can use additional sources of information to easily solve the problem, which were not available during the experiments (e.g. ask for help, read the instructions). On the other hand, the absence of the experimental situations allows the user free choice in selecting an alternative product, avoiding use of the product or simply giving up. The operating problem is then not solved, although the user's problem is.

6.3 Design related implications

This study aimed at generating insights that can be applied to product design. The study of the causes of operating difficulties provides a number of lessons. The implementation of these lessons should lie in an understanding of the mechanisms underlying operating difficulties and subsequent translation into individual designs, rather than in translation into general design guidelines.

Cognition in product use

In general, users prefer to rely on stored procedures for the operation of unfamiliar product models. They may persist in this even when the procedure does not lead to success. A possible explanation for this persistence was provided, and alternative strategies on how to implement a new operating procedure into the appearance of the product in order to prevent the observed difficulties were proposed, in Section 5.1.

When a new product is designed, implementing a new way of functioning, a choice must be made as to whether this has consequences for the way the product is to be operated. Either the required operation is adjusted to the new way of functioning, making it unfamiliar to the user, or an existing way of operating is chosen which is familiar to the user.

If a new type of operation is chosen, then the product should alert the user. Ideally, the design of the product itself should communicate the information.

An unfamiliar product function may be linked to a familiar product appearance, but only if the operating procedures associated with that appearance actually achieve the (unfamiliar) function. If a new operating procedure is required to achieve a given function, then the appearance should not refer to another, familiar, function.
In any event, the appearance of the product should not prompt a familiar operating procedure which is not appropriate. Relying on the knowledge-based reasoning of the user for the generation of a new operating procedure is less desirable than relying on the selection of an operating procedure available on rule-based level. Operating a product by doing what first comes to mind (stored rules that are triggered) is obviously easier than having to come up with an alternative for what first comes to mind.

Varying experience
Future users will vary from complete novices to heterogeneous experienced, and information provided by the product must suffice to provide adequate knowledge to users with any level of experience. It is important to note here that future users are, by definition, inexperienced with the operation of the product under design, but may well be experienced with similar products, products with the same function but of a different type. This experience may lead them, at least, to consider familiar, potentially unsuccessful ways of operating.

Prevention of fixation
When the new product is associated with a product that requires a different operation, fixation may occur. Depending on the product, the confusing associations and resulting fixation may concern the overall function of a product, or only a single component that is to be operated as part of the task at hand. Prevention of fixation lies in keying the appearance of the product (parts) to the operation, or vice versa. In principle, the level of agreement between appearance and operation is individually determined. However, the individual knowledge is, at least to some extent, based on generally available products and is likely to share common elements between individuals.
The agreement between appearance and required operation can therefore be judged on what is customary. Although in general this may be a vague statement, it is not in the case of specific products. In the case of the products used in the experiments, the most familiar product type corresponds to the type on the market which sells most or has been available the longest.

Guessability through standardisation
Although most users may eventually learn any new operating procedure, the most powerful way to ensure adequate operating behaviour is by falling back on what users already know. Triggering available, proceduralised operating knowledge of

the user makes the laborious process of training and the replacement of existing knowledge unnecessary. For example, if the classic can-opener appearance were to be combined with only one type of required operation the difficulties observed in the experiments would not have occurred.
The most effective way to achieve this is through standardisation. This standardisation would concern the combination of appearance and operation and be aimed at the prevention of contradictory appearances and operations (fixation prevention) or guiding the user towards the correct operating procedure (guessability).
Norman (1988) mentions standardisation as a way of preventing operating difficulties, but only as a last resort. When all other methods fail standardisation can ensure an absence of confusion or misunderstanding about the proper operating procedure. He mentions as an example the standardisation of the pedals of a car.
This study shows that standardisation should not be seen simply as a last resort solution. Fixation can be seen as a negative side effect of the normally very successful strategy of users scanning an unfamiliar product appearance for familiar patterns and then executing associated operations. A familiar pattern in a products' appearance and the associated operation is, at least for the individual user, a case of standardisation.
Standardisation does not mean that only one type of functioning may exist for each product function. Alternatives may exist next to each other as long as the relation between appearance and operation is not mixed up.
With the rejection of standardisation because it would prohibit innovation or advancement in product design, also the possibility of using and creating strong relationships between appearance and operation is rejected. This can be effective at the rule based level without the process of proceduralisation.
How standardisation can be applied, both effectively and ineffectively, is illustrated by two examples. Two commercially available product designs feature retro-appearance while they function using modern technology.
The Profoon telephone (www.profoon.nl) in Figure 6.1 obviously resembles telephone models of the previous century that required dialling for number selection. The telephone shown requires the pressing of buttons. In this way the relation between appearance and operation is deliberately violated and standardisation is applied ineffectively. This design is in accordance with Strategy 1 as described in Chapter 4 and rejected in Chapter 5.
The Bosch refrigerator (www.bosch-huishoudelijke-apparaten.nl) in Figure 6.2 also resembles models of the previous century. These models required a specific operation of the door handle for opening and this handle mechanism is maintained in the Bosch. By doing so the relationship between appearance and operation is honoured and standardisation is applied effectively. This design corresponds to Strategy 3 described in Chapter 4.

Figure 6.1
Operation not in correspondence with appearance. Push buttons in a dialling configuration (Profoon TX 280TN).

Figure 6.2
Operation in correspondence with appearance. Operation of the door handle as can be expected. (Bosch KDL 1955).

Written use instructions
Given the demonstrated preference of users to control operating behaviour with as little cognitive involvement as possible it seems that, rather than regarding standardisation as a last resort in preventing operating difficulties, written use instructions should be seen as such. Written instructions typically contain a description of the product followed by step-by-step procedures to operate the function(s) of the product.
In general written instructions are renowned for being seldom read. Carrol and Rosson (1987) explain their observation that users never read manuals but start using the software immediately with *the paradox of the active user*. This paradox states that users act irrationally when they reject an opportunity to learn how to perform a task but instead immediately start to execute the task. With learning, however, performance would have been better. Acquiring new operating knowledge is a knowledge-based activity and the study showed that in discovering an alternative operating procedure, reasoning at the knowledge-based level is seldom successful (Experiments 1 and 2). Users prefer to rely on their knowledge in the head in combination with the (expected) self-explanatory quality of the product.
The supposed facilitating effect of strategic knowledge in discovering an unfamiliar operating procedure (Experiment 3) would suggest that the type of information provided in the instructions should not only be procedural but also strategic, not only explaining what to do but also why.

6.4 Research related implications

6.4.1 'User trials' methods

The term 'user trials' refers to design related research into the use of artefacts by users. These artefacts can vary from a functioning product to a collection of sketches. The purpose of user trials is to gain insight into the possible future use of a new product. Since the use of products is theoretically unpredictable, user trials are regarded as a means to gain insight into the use of a new design (Kanis, 2000). Besides the physical use of a product, user trials can also provide insight into the cognitive aspects of user actions. The experiments in this study provide examples of this. To achieve insight into the mental processes during product use, three approaches were explored, the traditional approach of *verbalisation* and two less traditional approaches a) drawing mental models and b) deriving cognitive involvement from the interpretation of use actions under controlled conditions.

Verbalisations

Usually cognitive processes constituting action control are monitored in user trials, through elicitation techniques involving verbalisations. In this study two common techniques were considered; *think aloud* and *retrospective self reports*. The relevant difference between these two types of techniques in this context is that the *think aloud* method is used to monitor the ongoing cognitive action control almost instantly, while the *retrospective techniques* are used to register the cognitive processes after the event. Both approaches have disadvantages (Ericsson & Simon, 1984), but for the observation of cognitive processing during the use of familiar products the 'think aloud' method is preferred over the retrospective self reports, since trained task execution involves, to a large extent**,** automated behaviour which requires only limited cognitive involvement. This means that not all considerations during product use are rational and logic and should be recorded as soon as possible. The use of retrospective reports is likely to elicit different kinds of (prior) knowledge and not all applied knowledge is reported (Christiaans, 1992).

Sketching mental representations

Besides verbalisations in this study, an initial attempt was made to elucidate the contents of subjects' mental representations by asking them to sketch their associated view of the product type. The resulting sketches are illustrative and information rich and provide data of a qualitative nature. The sketches proved the assumptions of Norman (1988), concerning mental representations, to be correct. However, some negative aspects emerged as well.

- Subjects complained about the task being too difficult,
- The results added little to the understanding of the mechanisms underlying the operating behaviour demonstrated with the product type concerned.

- The method can only provide insight into the contents of subjects' experience based knowledge within a specific domain.

For these reasons the sketching method was not deployed in subsequent experiments.

Interpreting use actions

Interpretation of the operating behaviour (recorded on video) was used to provide insight into the cognitive action control. The combination of the physical behaviour and assessed experience of the subject was interpreted and thus mechanisms underlying the occurrence of unsuccessful product operation were found. The major advantage of this approach is that cognitive involvement is investigated by analysing only the operating behaviour itself, without introducing potentially interfering additional behaviour (verbalising).
Moreover, since it was found that the cognitive involvement can be limited, it seems safer to consider the operating behaviour itself.

Combining methods

Although very fruitful in explaining the origins of operating difficulties, the approach of interpreting use actions cannot provide actual insight into the contents of user knowledge. The establishment of experience, acquired both prior to and during the experiment, gives only an indication of the content of knowledge, in as far as is thought relevant by the subject.
For more detailed insight into the content of user knowledge, therefore, the think-aloud method was used as well. Despite the obvious shortcomings it remains the only method that provides at least some insight into the contents of user's knowledge.

6.4.2 Choice of subjects

To obtain meaningful results in a user trial it is of vital importance to select the appropriate subjects. In this study the experience of subjects proved to be a key variable.
However, the generally made distinction between novices and experienced users seems to fall short when it comes to explaining the results of the experiments. A better operationalisation of experience than is presently available is desirable. The proposed distinction between homogeneous versus heterogeneous experience provides a qualitative measure, in addition to the existing quantitative measure. Moreover, in determining heterogeneous experience non-domain specific knowledge should also be taken into account.
When selecting subjects for user trials aimed at finding operating difficulties, the range of the subjects' experience should be as wide as possible, since different experience levels were shown to cause operating difficulties in different ways. The status of both novice users and users with homogeneous experience with respect to

a certain operating task can be defined, but what makes a subject heterogeneously experienced has not been successfully defined in this study.

6.4.3 Internal representations

The concept of internal representations was initially included in the study because it seemed a useful concept in investigating the knowledge influencing use and its structuring

In Norman's view (1988) mental models, as the conceptual representations built to guide the interaction with the product, concern both the way to operate the product and insights into the functioning of the product. These insights are used to find an unfamiliar way of operating. Rasmussen (1990) reserves the term 'mental model' only for a collection of general knowledge, representations of the relational structure of the causal environment and work content. This knowledge is used when cognitive control at the knowledge-based level is required. Procedural knowledge is not incorporated in his conception of the mental model, but is stored as rules in memory.

The different meaning given to the concept of internal representations makes it difficult to identify the use of the concept as an explanation for the observed operating behaviour. The discussion on the nature of internal representation is likely to be ongoing (e.g. Marcus, 2000).

Type of knowledge included in mental models

When a mental model includes both declarative and procedural knowledge the explanatory quality of the concept is limited. The decision for a certain way of operating is then solely based on the mental model, and every eventual operating failure is consequently due to an inadequate mental model. The mental model concept then functions as a homunculus in determining the way a product is used, and it becomes impossible to falsify a mental model. Moreover, it adds little to the understanding of operating behaviour.

When the information stored in mental models is limited to general 'knowledge based' information, then mental models can not be seen as the knowledge source for operating behaviour, since only a limited amount of the required action control involves processing at the knowledge based level, as most behaviour is controlled at the skill- and rule based levels.

Range of knowledge included in a mental model

The concept of a mental model only makes sense if there is more than one mental model. Users draw on some mental models, depending on their knowledge or experience and the task at hand.

This study showed that knowledge relevant for product operation can be retrieved from any associated experience in which domain barriers proved not to be relevant.

Using the mental model concept to approximate users knowledge, therefore, requires either a very broad definition of a mental model (one big mental model) or many mental models forming a well-connected network.
Neither of these offer much possibility for the mental model concept to establish specific knowledge users apply during product use.

6.5 Future research

The cognitive processes involved in the use of consumer products provide an important, yet extensive, area for research. Future research should be aimed at different views on the cognitive aspects of human consumer-product interaction.

6.5.1 User related

With regard to the user, studies are needed on individual differences, such as age, cultural background, intellectual abilities and education, and the effect of these on cognitive processes taking place during the use of products, since diversity of users will lead to diversity in use and operating difficulties.

Learning how to use a product
New knowledge is constantly acquired. People in a changing environment are constantly learning to operate new products and consequently adjusting their body of knowledge. The practicalities of these processes as they occur during the learning process of product use is not well understood. In this study the main focus was on the process of discovering a procedure to operate a product. This procedure had to be found on the basis of knowledge in the head and knowledge in the world. However, besides the procedural knowledge that is derived on the spot during the guessability phase of product use, users can learn how to use a product during the following learnability phase. During this phase users learn which procedure is required to operate a product. Several ways in which such procedural knowledge is established are available to the user. Instructions can be seen as a source of declarative knowledge, and through proceduralisation declarative can be converted into procedural knowledge. Training provides procedural knowledge and transfer of skill is a third source of knowledge of how to operate a product. Learning processes in product use are an important area of future research.
Not only the practical side of learning but also more fundamental questions were raised in this study, i.e. how to explain the co-existence of the process of proceduralisation which leads to fixation, and the emergence of strategic insights which prevent fixation, both of which arise from frequent use.
Another topic is the relation between knowledge and experience. The distinction made between homogeneous versus heterogeneous experience was not shown to make a substantial difference in product operating. Nonetheless, experience as

such proved to be a major influence throughout the study. Whether the distinction proposed in this study can be useful in strengthening the grasp on the rather vague notion of experience is yet to be demonstrated. Perhaps other ways of dealing with users' experience should be considered.

6.5.2 Product related

Product design seems to involve an increasing number of functionalities, incorporated into one product. Mechanical functioning is more and more being replaced by miniaturised electronic functioning, introducing modes and menus. In this study the products used were still relatively simple, but increased complexity of product will yield increased complexity in cognitive involvement.
In the midst of all this, product features are an important source of information for the user in determining the way to operate these products (use cues). The ability to design appropriate use cues into a product is therefore of vital importance. However, determining the influence of every thinkable product element, and the influence of combinations of product elements, is not possible. Research could lead to a practical way of investigating the influence of product information on the behaviour of the user. Such research should be closely related to studies into the effect of aesthetics.

6.5.3 Final remarks

To sum up, the study of the cognitive aspects of the use of products should start with the use actions it considers. This statement is less obvious than it may seem. It has been a tradition in both Ergonomics and Psychology to try to predict future behaviour by gathering information on the actor. Modelling the cognitive system of humans, and the formation of large anthropometric databases, without a clear idea as to how this information is related to the actual behaviour, is only postponing addressing the actual problem, which is the anticipation of user behaviour.

While it is clear that experience is a factor in determining the successful use of products, lack of experience in users must never be used as an excuse for non-successful product use.

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Appendix A

Details of experimental results

Survey study **Can-openers**
N=200

model	*marked drawings (%)* daily	occasional	total
I.1	43.5	54.5	98
I.2	49.5	32	81.5
II.1	9	15	24
II.2	11	14	25
III.1	5.5	26.5	32
III.2	4.5	17	21.5
III.3	1	11.5	12.5
III.4	4	9.5	13.5
III.5	2.5	12.5	15
III.6	1.5	8.5	10
III.7	2.5	41	43.5
III.8	2.5	18.5	21

Experiment 1 **Can-openers**
N=23

group	model	*trials* average	range	*top-cutter positions (%)* average	range
1	own	1	1 - 1	100	100 - 100
	B	6.4	1 - 11	73.4	0 - 90.9
	A	3.4	1 - 8	95.8	50 - 100
	C	3.2	1 - 10	30.7	0 - 87.5

Experiment 2 **Can-openers**

N=28

group	model	trials average	range	top-cutter positions (%) average	range
1 (n=5)	A	1.6	1 - 4	100	100 - 100
	B	7.2	1 - 15	52.2	0 - 93
	C	6.8	1 - 15	47.1	0 - 80
	B	1.2	1 - 2	10	0 - 50
2 (n=4)	A	2.5	1 - 4	100	100 - 100
	C	8.8	4 - 14	82.3	75 - 90
	B	1.3	1 - 2	12.5	0 - 50
	C	1.3	1 - 2	0	0 - 0
3 (n=10)	B	9.4	1 - 15	73.9	0 - 91
	C	2.6	1 - 11	14.5	0 - 67
	A	2.1	1 - 5	100	100 - 100
	B	1.2	1 - 2	5	0 - 50
4 (n=9)	C	12.1	5 - 30	83.4	67 - 94
	B	1.3	1 - 2	11.1	0 - 50
	A	4.4	1 - 8	85.6	43 - 100
	C	1	1 - 1	0	0 - 0

Corkscrews

group	model	trials average	range	centre positions (%) average	range
1 (n=5)	A	1	1 - 1	100	100 - 100
	B	4	2 - 7	40.6	0 - 67
	C	2.2	1 - 4	0	0 - 0
	B	1.3	1 - 2	0	0 - 0
2 (n=4)	A	1	1 - 1	100	100 - 100
	C	2	2 - 2	37.5	0 - 50
	B	2.8	1 - 4	6.3	0 - 25
	C	1.5	1 - 3	0	0 - 0
3 (n=10)	B	4.4	1 - 8	27	0 - 71
	C	2.6	1 - 6	16	0 - 75
	A	1.1	1 - 2	100	100 - 100
	B	1.3	1 - 2	0	0 - 0
4 (n=9)	C	4.7	2 - 9	34.4	0 - 75
	B	1.7	1 - 3	3.7	0 - 33
	A	1.2	1 - 2	100	100 - 100
	C	1.2	1 - 3	0	0 - 0

Experiment 3 **Telephone memory retrieval**

N=20

Performance

group	model	successful subjects	*trials* average	range	non-successful subjects	*trials* average	range
1 (n=5)	R 200	5	7.6	1 - 20	0	-	-
	R 400	0	-	-	5	19.0	8 - 26
	M 10	2	13.5	2 - 25	3	14.0	4 - 28
	C 200	1	6.0	6 - 6	4	22.5	7 - 43
2 (n=5)	M 10	3	10.7	7 - 17	2	22.5	18 - 27
	R 200	4	6.7	1 - 20	1	19.0	19 - 19
	C 200	2	5	3 - 7	3	21.7	8 - 32
	R 400	0	-	-	5	17.4	3 - 31
3 (n=5)	C 200	0	-	-	5	19.6	7 - 57
	M 10	3	11.0	1 - 31	2	8.0	3 - 13
	R 400	1	8.0	8 - 8	4	17.8	3 - 48
	R 200	4	8.3	1 - 29	1	8.0	8 - 8
4 (n=5)	R 400	0	-	-	5	19.2	5 - 42
	C 200	0	-	-	5	15.2	7 - 31
	R 200	3	1.0	1 - 1	2	20.5	17 - 24
	M 10	2	3.0	1 - 5	3	17.0	9 - 25

Success rate and initial ideas related to experience
Number of subjects (between brackets is de total number of subjects with the indicated level of experience on each model)

group	model	success		initial idea	
novice	R 200	15	(19)	9	(19)
	M 10	4	(12)	1	(12)
	C 200	3	(20)	1	(20)
	R 400	1	(20)	0	(20)
experienced	R 200	1	(1)	1	(1)
	M 10	6	(8)	5	(8)
	C 200	0	(0)	0	(0)
	R 400	0	(0)	0	(0)

General descriptions

Number of subjects (between brackets first the number of novices, then the number of experienced)

type	*question* 1		2		3		4		5	
R 200	6	(6,0)	6	(5,1)	10	(10,0)	10	(10,0)	9	(8,1)
M 10	9	(8,1)	9	(7,2)	10	(6,3)	9	(7,2)	14	(7,7)
C 200	0	(0,0)	0	(0,0)	0	(0,0)	1	(1,0)	1	(1,0)
other	5	(5,0)	5	(5,0)	3	(1,2)	2	(1,1)	3	(2,1)
procedural	15	(8,7)	15	(8,7)	15	(10,5)	17	(11,6)	12	(7,5)
strategic	1	(0,1)	1	(0,1)	2	(0,2)	1	(0,1)	5	(3,2)
don't know	4	(4,0)	4	(4,0)	3	(1,2)	2	(1,1)	3	(2,1)

Experiment 4 **Repeated telephone memory retrieval**

N=15

Performance

group	model	successful subjects	*trials* average	range	non-successful subjects	*trials* average	range
1 (n=4)	R 200	3	7	1 - 18	1	7	7 - 7
	R 400	2	6.5	6 - 7	2	15.5	7 - 24
	M 10	3	15.3	1 - 24	1	6	6 - 6
	C 200	2	16.5	4 - 29	2	18.5	4 - 33
2 (n=3)	M 10	1	2	2 - 2	2	12.5	7 - 18
	R 200	3	3.7	1 - 9	0	-	-
	C 200	1	5	5 - 5	2	21	17 - 25
	R 400	1	5	5 - 5	2	6.5	2 - 11
3 (n=3)	C 200	1	10	10 - 10	2	17	10 - 24
	M 10	3	2.7	2 - 4	0	-	-
	R 400	1	7	7 - 7	2	19.5	7 - 32
	R 200	3	6	2 - 13	0	-	-
4 (n=5)	R 400	1	12	12 - 12	4	32.8	15 - 45
	C 200	2	11.5	8 - 39	3	28	18 - 39
	R 200	4	3.5	1 - 17	1	17	17 - 17
	M 10	4	3.3	1 - 38	1	38	38 - 38

Initial ideas

Number of subjects in each sequence group giving a correct description.

group	model	correct initial idea
1	R 200	3
n=4	R 400	0
	M 10	1
	C 200	0
2	M 10	1
n=3	R 200	2
	C 200	0
	R 400	0
3	C 200	1
n=3	M 10	0
	R 400	0
	R 200	1
4	R 400	0
n=5	C 200	0
	R 200	4
	M 10	2

General descriptions

Number of subjects

	question				
type	1	2	3	4	5
R 200	5	1	2	3	3
M 10	5	9	9	7	8
C 200	1	0	0	0	0
R 400	0	1	0	0	1
other	6	4	5	7	5
procedural	3	4	4	0	3
strategic	7	7	7	8	9
don't know	5	4	4	7	3

Experiment 5 **Rotating controls**

N=120

group	*model* control	cover	*rotation* clockwise	anti-clockwise
1 (n=30)	tap-head	mechanical	8	22
2 (n=30)	tap-head	electronic	7	23
3 (n=30)	volume control	mechanical	24	6
4 (n=30)	volume control	electronic	22	8

Experiment 6 **Trained telephone memory retrieval**

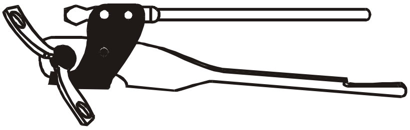
N=40

group	model	success rate	*trials* average	range
homogeneous	Monza 10	training	-	-
(n=9)	Napels 10	training	-	-
	Beocom 1000	training	-	-
	Relate 400	4	7.3	2 - 13
	Genova	9	1.4	1 - 4
control 1	Relate 400	4	7.5	2 - 17
(n=10)	Genova	10	2.3	1 - 11
heterogeneous	Relate 200	training	-	-
(n=11)	Converse 200	training	-	-
	Monza 10	training	-	-
	Relate 400	8	9.7	5 - 13
	Genova	11	1.5	1 - 5
control 2	Relate 400	7	10	2 - 21
(n=10)	Genova	10	1.3	1 - 4

Appendix B

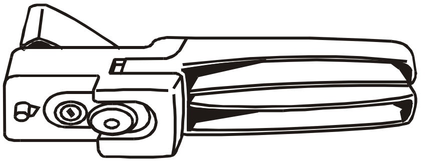
Pictorial checklist used in the survey study.

The drawings are all on the same scale and the indicated sheet was originally A4 size. The numbers were not included on the original sheets.

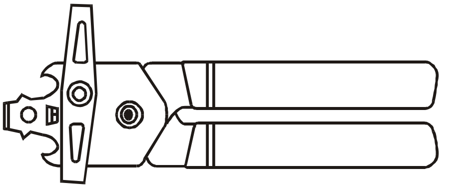


I.1

III 2



II.2



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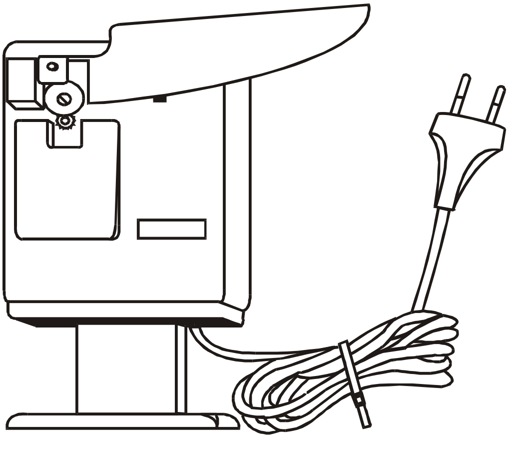
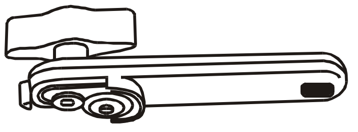
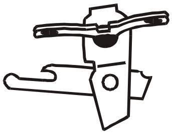


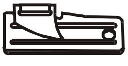
III.8



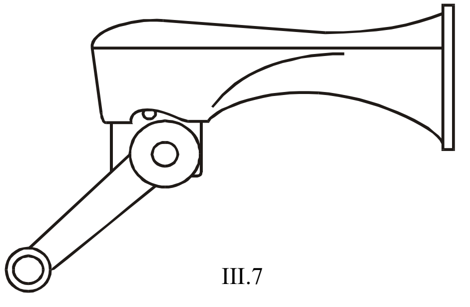
II.1



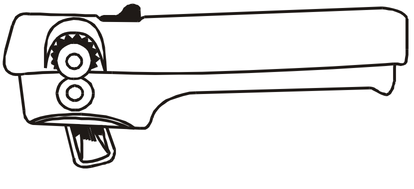
III.5



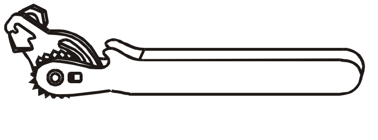
III.1



III.7



III.4



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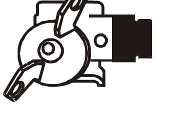
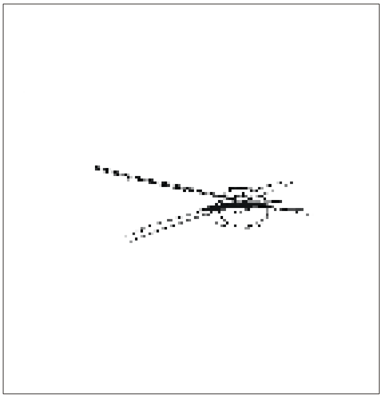
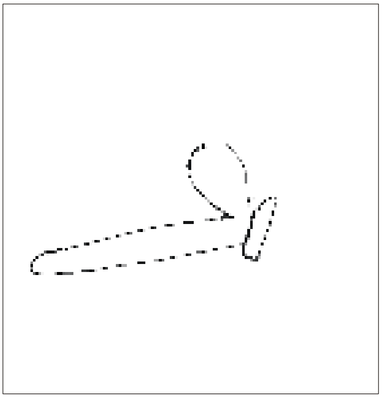


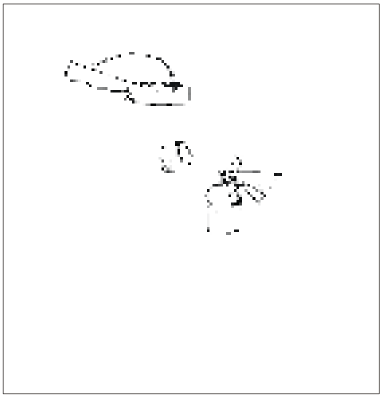
III.6

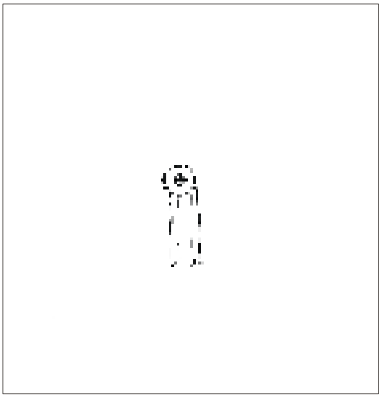
Appendix C

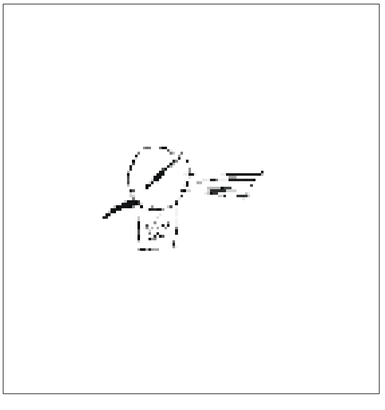
Drawings made by the subjects in Experiment 1.

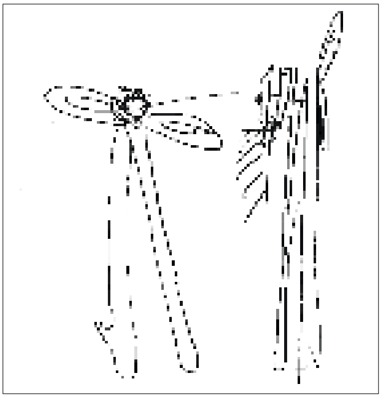


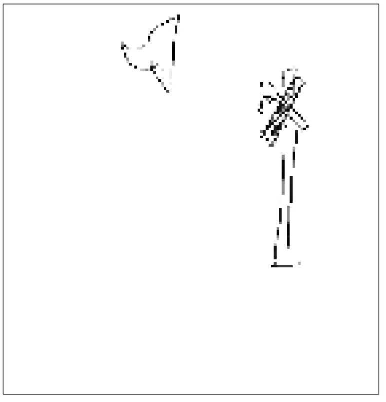
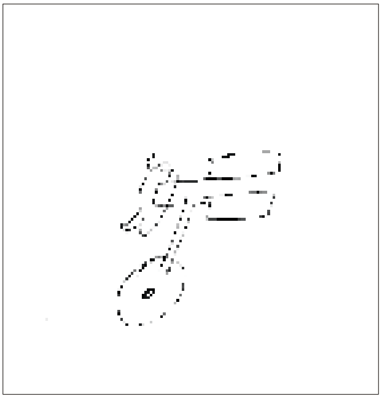
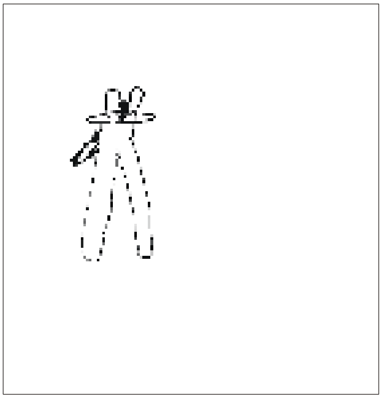
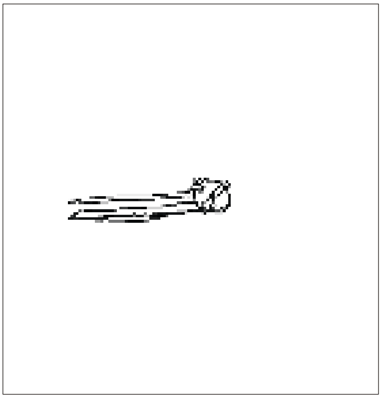
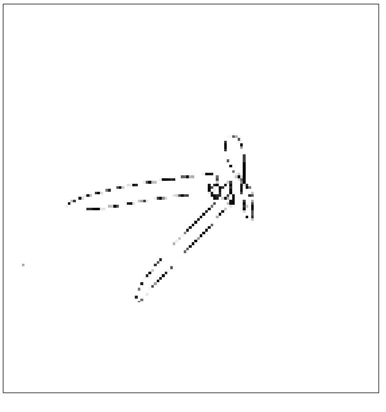
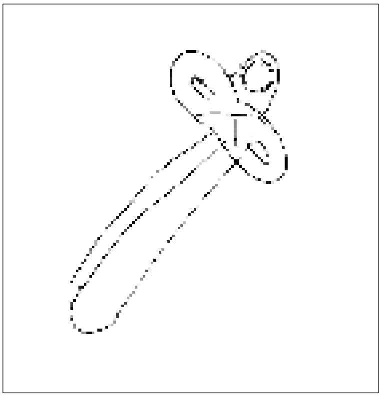


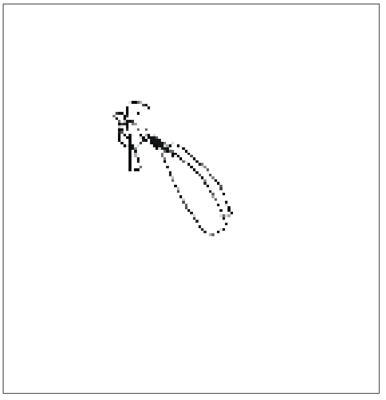


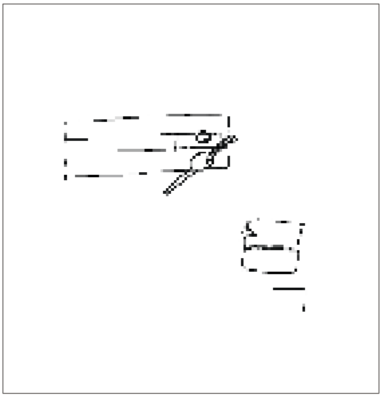


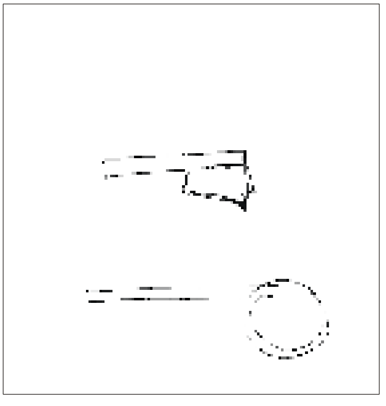


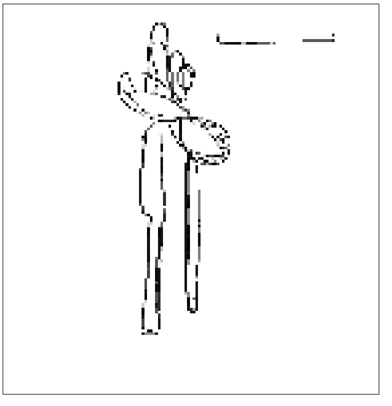


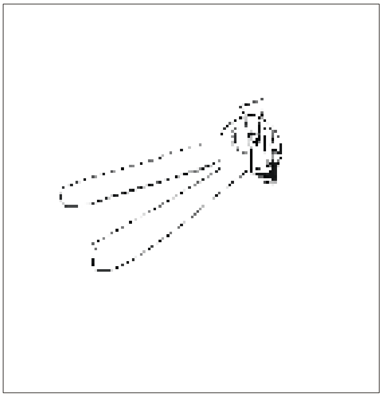







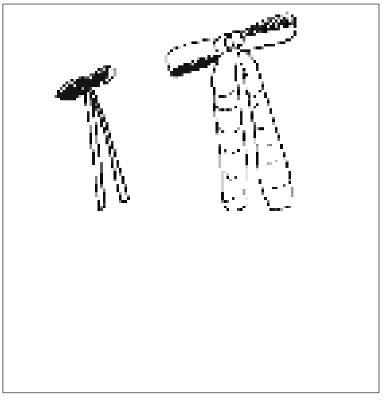


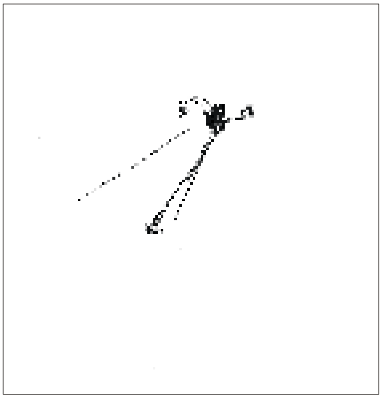


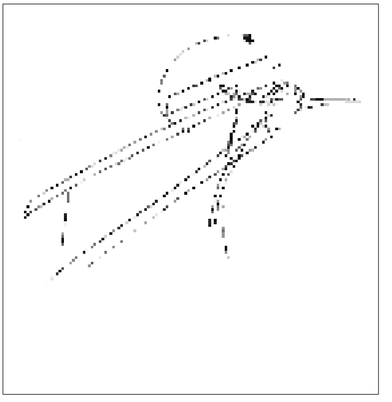


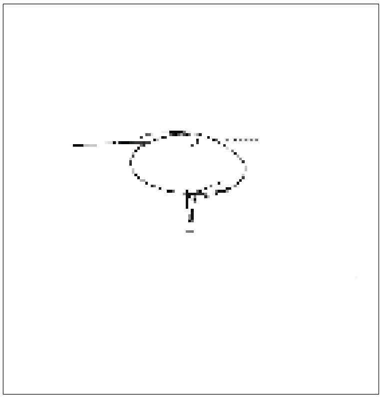


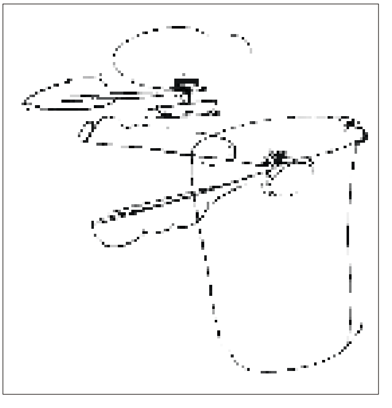


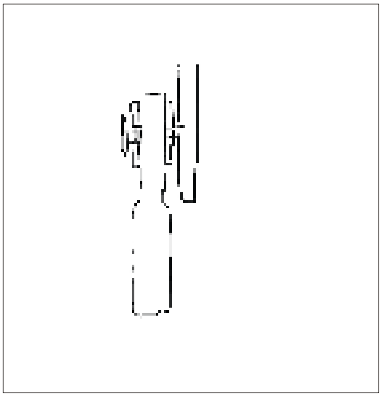












Appendix D

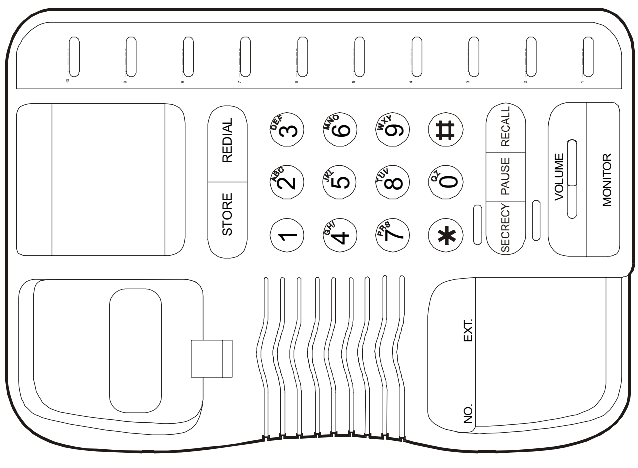
Telephones used in Experiments 3, 4, and 6.

The handsets are not included in the drawings.

Telephones used in Experiment 3, 4, and 6.

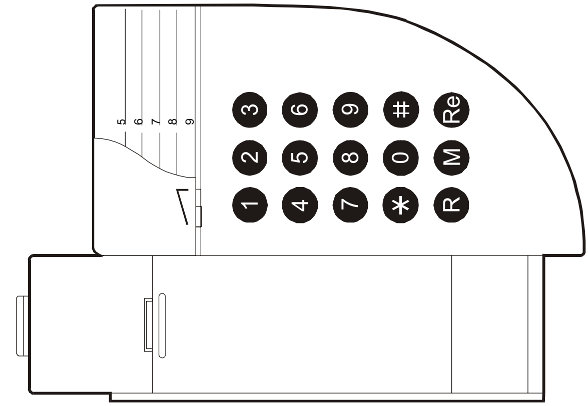
BT's Relate 200

One key to press for direct selection of the required telephone number



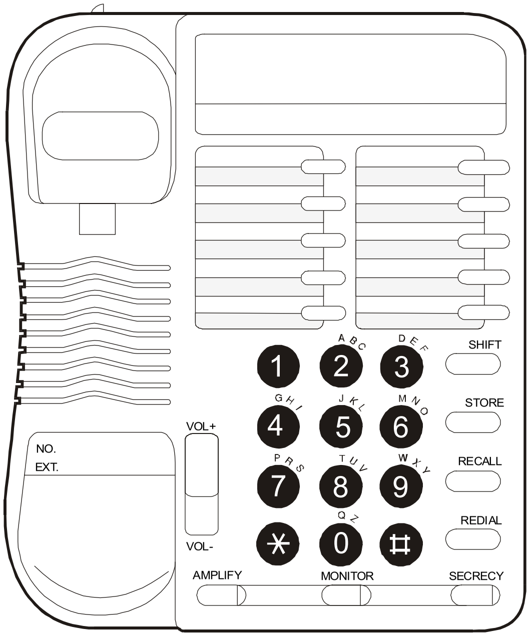
KPN's Monza 10

First a key to enter the memory mode (M) and then a keypad number for the selection of the required telephone number.



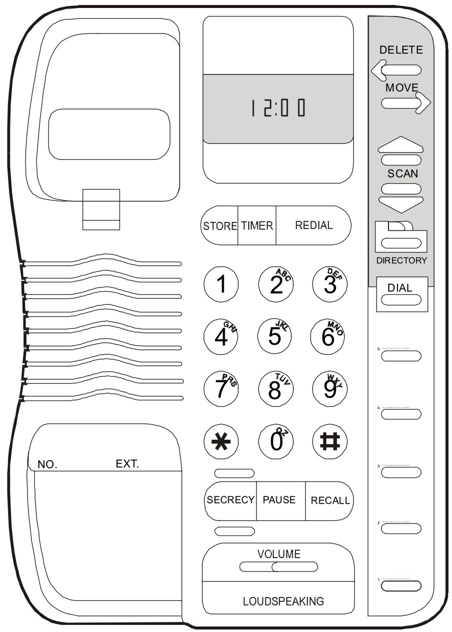
BT's Converse 200

Double functioned memory buttons that require the SHIFT-key to be pressed if the second telephone number associated with that button is required.



BT's Relate 400

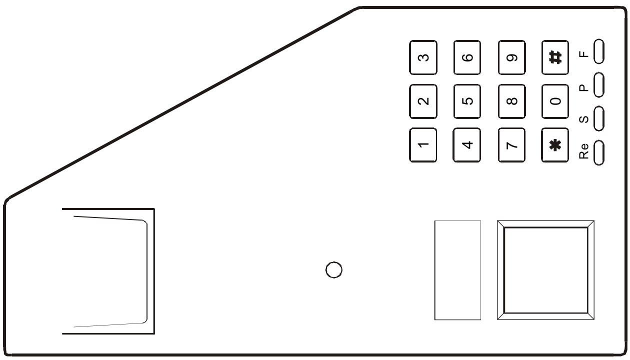
Memorized telephone numbers directory system with display feedback. Requires DIRECTORY activation, scanning and finally selection of the required telephone number by pressing the DIAL key.



Additional telephones used only in Experiment 6.

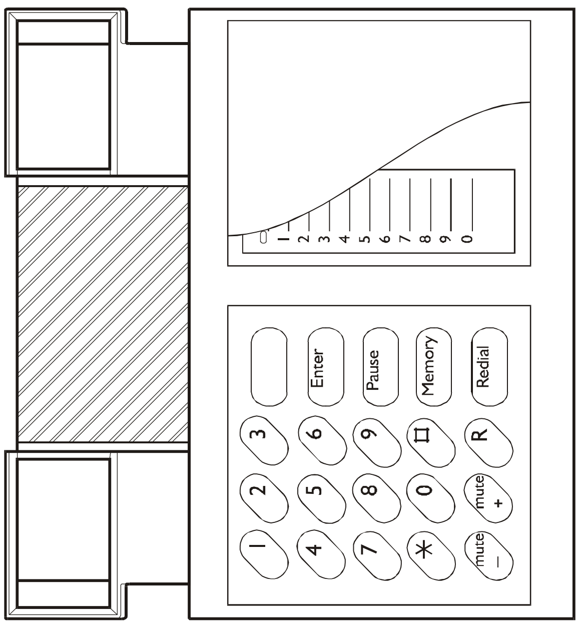
KPN's Napels 10

First a key to enter the memory mode (Re) and then a keypad number for selection of of the required telephone number.
The built-in index on this model is attached to the handset



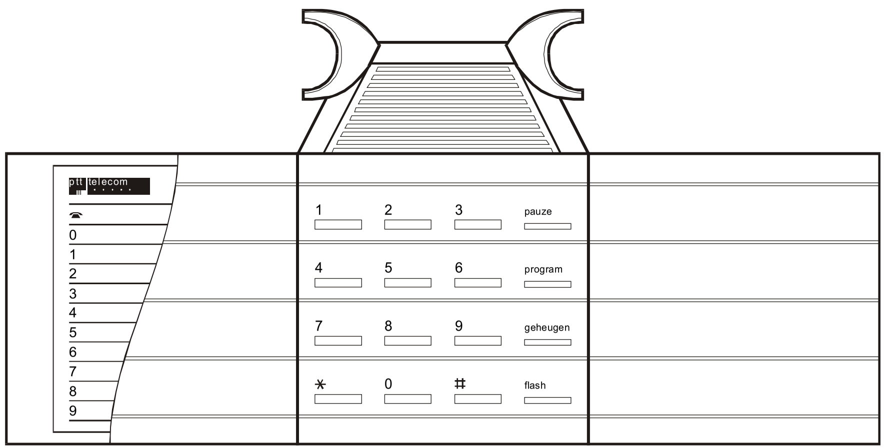
B&O's Beocom

First a key to enter the memory mode (Memory) and then a keypad number for selection of the required telephone number.



KPN's Genova

First a key to enter the memory mode (geheugen) and then a keypad number for selection of the required telephone number.



Gebruikers cognitie in product bediening

Samenvatting

G.J. Gelderblom

Inleiding

Consumentenproducten worden dagelijks gebruikt. Een enorme verscheidenheid aan producten wordt elke dag gebruikt door vele gebruikers. Met het ontwerpen van een product creëert de ontwerper bepaalde mogelijkheden voor het gebruik ervan. Toch kan het gebruik van een product en het effect van gebruik aanzienlijk variëren, zowel tussen gebruikers als bij herhaald gebruik. Een van de oorzaken voor de variatie ligt in de invloed van de cognitieve kenmerken van de individuele gebruiker, zoals kennis, ervaring en verwachting.
Variatie in gebruik is in principe geen probleem, zelfs niet wanneer het gebruik anders is als door de ontwerper voorzien, zolang als het gebruik het gewenste resultaat heeft. Het kan echter een probleem worden wanneer bepaald gebruik leidt tot suboptimaal of zelfs afwezigheid van product functioneren.
Voor de gebruiker kan het resultaat van het ongewild uitblijven van product functioneren variëren van eenvoudige irritatie tot gevaarlijke situaties. Helaas is het geheel of gedeeltelijk mislukken van productgebruik veel voorkomend bij alledaags product gebruik.
Ondanks deze frequentie van voorkomen zijn de oorzaken voor het mislukken van gebruik van consumenten producten niet bekend en worden ze zelden bestudeerd. Het doel van deze studie is het leveren van een bijdrage aan het begrijpen van het veelvuldig mislukken van mens-product interacties. Daarbij zal vooral worden ingegaan op de cognitieve aspecten van falend product gebruik. Hoewel menselijk falen al is bestudeerd in gerelateerde domeinen en de rol van cognities bij het menselijk handelen in het algemeen uitgebreid is onderzocht en beschreven blijken slecht weinig van de beschikbare inzichten toepasbaar te zijn op het falen van alledaags product gebruik. Daarom bestaat de studie uit een reeks van zes exploratieve experimenten waarin de onderliggende factoren en mechanismen aan falend product gebruik worden onderzocht. De eerste experimenten zijn daarbij gericht op bedieningsproblemen in het algemeen terwijl de laatste twee experimenten specifiek gericht zijn.

Het gebruik van producten met een bekende functie

De eerste twee experimenten zijn gericht op het verkrijgen van inzicht in de invloed van de combinatie van twee factoren, ontwerp en ervaring, op het voorkomen van bedieningsproblemen tijdens het gebruik van blikopeners en kurkentrekkers. In de experimenten worden verschillende modellen met variërende bekendheid door proefpersonen gebruikt. De experimenten laten zien dat het gebruik met zo min mogelijk cognitieve moeite plaatsvindt, zelfs wanneer proefpersonen geconfronteerd worden met hun onvermogen om zeer bekende taken met onbekende modellen tot het gewenste eindresultaat te brengen. Dat het mogelijk is om met zeer lage cognitieve investering alledaagse producten succesvol te gebruiken is zeer effectief in het dagelijks leven maar het kan het oplossen van bedieningsproblemen in de weg zitten.

De invloed van ervaring
Experimenten 3 en 4 gaan meer specifiek in op de invloed van ervaring op het voorkomen van bedieningsproblemen. Varianten van een onbekende productfunctie met variërende complexiteit, m.n. het oproepen van nummers in het telefoon geheugen, worden bij proefpersonen geïntroduceerd. Het initiële, onervaren gebruik van de proefpersonen wordt vergeleken met een tweede keer gebruik van dezelfde productfunctie nadat de gebruikers ervaring hebben opgedaan met verschillende modellen. De experimenten laten zien dat het faciliterend effect van ervaring afhangt van de complexiteit van het ontwerp. Sommige modellen kunnen de proefpersonen succesvol gebruiken op basis van de opgedane ervaring terwijl dit voor andere modellen onmogelijk blijkt.

Het verklaren van de bedieningsproblemen
In Hoofdstuk 4 worden de experimentele resultaten geëvalueerd tegen de achtergrond van een reeks van theoretische inzichten in de rol van cognities in het menselijk handelen. Dit leidt tot het formuleren van twee verklarende mechanismen die aan bedieningsproblemen ten grondslag liggen. Het eerste mechanisme, *lage raadbaarheid*, betreft de afwezigheid of het misleidende karakter van informatie die het product de gebruiker verschaft over het gebruik ervan. Met het tweede mechanisme, *fixatie,* wordt de neiging van gebruikers aangegeven om de keuze van mogelijke bedieningswijzen te beperken op basis van sterke maar onjuiste verwachtingen. Deze onbedoelde uitsluiting van onbekende bedieningswijzen kan leiden tot de onmogelijkheid een product succesvol te gebruiken.

De uiterlijke kenmerken van een product en typen ervaring
Experiment 5 gaat in op het effect van uiterlijke kenmerken van een product op het gebruik ervan. Proefpersonen bedienen vier versies van een voor het experiment geconstrueerde koffie serveer ketel. Het bedienen hiervan beperkt zich tot het draaien van een enkele knop. De invloed van het uiterlijk van de serveerketel op de gekozen draairichting wordt geanalyseerd. De resultaten laten zien dat sommige combinaties van uiterlijk en bedieningswijze tot bedieningproblemen kunnen leiden terwijl er ook betere combinaties zijn.

In Experiment 6 wordt de invloed van verschillende typen ervaring onderzocht op het gebruik van dezelfde oproeptaak van nummers uit het telefoongeheugen als in de Experimenten 3 en 4 toegepast. Om verschillende typen ervaring te bewerkstelligen worden de proefpersonen op verschillende wijzen geoefend met een aantal telefoons. Het verschil in prestatie tussen de ervaringsgroepen is echter te klein om het veronderstelde effect van type ervaring te bevestigen. Vergelijking van de resultaten met die van de Experimenten 3 en 4 bevestigen de relevantie van het onderscheiden van typen ervaring.

Discussie

Gelet op de aard van de conclusies die getrokken worden uit de resultaten van de experimenten is het aannemelijk dat de generaliseerbaarheid van de conclusies de in de experimenten gebruikte producttypen overstijgt. De relatief complexe mechanismen die tot bedieningsproblemen leiden bij 'simpele' producten zullen ook een rol spelen bij meer complexere producten. De betekenis van deze studie voor het ontwerpen van producten moet niet gezocht worden in het opstellen van richtlijnen voor ontwerpen maar eerder in een bewustwording van het type processen dat een rol speelt wanneer een gebruiker producten met verschillende niveaus van bekendheid gebruikt.

Het type onderzoek in deze studie, is gekozen omdat de cognitieve activiteiten van gebruikers niet direct bestudeerd kunnen worden. Bedieningsgedrag werd bestudeerd onder zo gewoon mogelijke omstandigheden terwijl de condities het tegelijkertijd toelieten dat het geobserveerde bedieningsgedrag inzage verschaften in de cognitieve processen van de gebruikers. De studie laat zien dat dit mogelijk is met dit type onderzoek, hoewel er ook valkuilen op het pad bleken te liggen. De studie wordt afgesloten met aanbevelingen voor verder onderzoek.

User cognition in product operation

Summary

G.J. Gelderblom

Introduction
Consumer products are used on a daily basis. A wide variety of these products are used every day by large numbers of people. In designing a product the designer creates possibilities for its use. However, the actual use and the effect of this usage can vary considerably, both between users and in time. Part of the reason for this variation lies in the influence of the individual cognitive characteristics of the user, such as knowledge, experience and expectations.
Variation in product use is in principle not a problem, even when use is different from what the designer anticipated, as long as use of the product leads to the wanted result. However, it does become a problem when the use of a product fails, i.e. usage results in sub-optimal or non-existent product performance. For the user the result of unsuccessful product performance can range from mere irritation to unsafe situations. Unfortunately, failure in product use is very common in everyday product operation. Yet in spite of its frequent occurrence, the origin of failing consumer product use is poorly understood and seldom studied.
This study aims to contribute to an understanding of the countless failures of daily human-product interactions. In doing so, the focus will be on the cognitive aspects of failed product use. Although human error has been studied in related domains, and the general cognition underlying human action has been studied extensively, few of the insights are applicable to failure in the use of consumer products. Therefore, the study consists of a series of six explorative experiments in which the factors and underlying mechanisms leading to failure in product use are investigated. Starting with experiments that focus on operating difficulties in general, the series moves on to the last two experiments in which two presumed failure mechanisms are tested.

The use of products with a familiar function
The first two experiments are aimed at reaching a global understanding of the influence of the combination of two factors, design and experience, in the occurrence of operating difficulties during the use of can-openers and corkscrews. In the experiments different product models with varying degrees of familiarity were operated. The experiments show that products are used with as little cognitive effort as possible, even when users are confronted by their inability to

perform very familiar tasks with unfamiliar models. The ability to operate products with limited cognitive involvement is very effective in everyday life, but it can hamper recovery from operating difficulties.

The influence of experience

Experiments 3 and 4 deal more specifically with the influence of experience on the occurrence of operating problems. An unfamiliar product function of varying complexity, i.e. telephone memory retrieval, is introduced. The users first inexperienced performance is compared with a second performance with the same product function, carried out after users have become familiar with the task. The experiments show that the facilitating effect of experience depends on the complexity of the design. The operation of some models could be mastered on the basis of the experience gained within the experiment, while for other models this was impossible.

Explaining operating difficulties

In Chapter 4, evaluating the experimental results against the background of a range of theoretical insights leads to the formulation of two causal mechanisms which underly operating difficulties. One mechanism is labelled *low guessability*, indicating that the information provided by the product on its use is either absent or misleading. The second mechanism is labelled *fixation*, indicating the tendency of users to restrict operating possibilities on the basis of strong but wrong expectations. This unwitting exclusion of an unfamiliar but appropriate type of operation results in an inability to operate a product successfully.

Product appearance and types of experience

Experiment 5 focuses on the effect of product information. In the experiment users operated four variants of a purpose built coffee serving machine. The operating tasks required only the rotating of a single control. With reference to common operating rules, the influence of device design on direction of rotation was studied. The results show that some types of combinations of product appearance and required operation lead to operating difficulties and that better alternative combinations are available.

In Experiment 6 the effect of different types of experience on the occurrence of fixation is investigated, using the same telephone memory retrieval tasks as those used earlier in Experiments 3 and 4. In order to establish different types of experience, users were trained in different ways. Unfortunately, the variation in performance between the different experience groups was too small to allow confirmation of the presumed effects of different types of experience. Comparison with the results of Experiments 3 and 4, however, affirm the relevance of distinguishing between different types of experience.

Discussion

In light of the type of conclusions drawn, it can be argued that the generalisabilty of the results of this study is wider than the type of consumer products used in the experiments. The complex mechanisms underlying the (failed) use of 'simple' products such as a can-opener is not likely to differ from the causes underlying the use of more complex products.

The implications of this study for the design of products should not simply be to improve design guidelines but rather to heighten awareness of the types of processes that emerge when a user tries to use products with different levels of familiarity.

The type of experimentation adopted in this study was chosen because human cognitive involvement cannot be studied directly. Operating behaviour was observed under conditions resembling actual use, while at the same time the conditions were such that the type of operating behaviour would provide information on the cognition involved. The study showed that this type of experimenting does provide insight into cognitive processes, although in the process some pitfalls were encountered. The study concludes with recommendations for future research.

Dankwoord

Aan het tot stand komen van dit proefschrift hebben een aantal mensen bijdragen geleverd waarvoor ik hen dankbaar ben.
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Curriculum Vitae

Gerhard Jan Gelderblom was born on 24 July 1963 in The Hague. He attended V.W.O. at S.G. de Vlietschans in Leiden, studied Psychology at Leiden University and graduated in Experimental Psychology in 1988 with a thesis on diagnosing by car mechanics.
He worked as a research assistant at Delft University of Technology at the department of Product and Systems Ergonomics at the Faculty of Industrial Design Engineering on the cognitive aspects of consumer product operating behaviour, the work resulting in this thesis.
Since 1997 he works as researcher at iRv, Institute for Rehabilitation Research in Hoensbroek on projects concerning the use, usability and effects of Assistive Technology.