Integration of multisensory information in multi-attribute decisions

Integration multisensorischer Information in multiattributiven Entscheidungssettings

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Abstract

In decisions, information is utilized differently depending on the properties provided. It has been shown repeatedly that pictorial presentation of cues promotes a holistic and complete cue integration. Textual and numerical display in contrast are found to favor the use of non-compensatory strategies (e.g. Bröder & Schiffer, 2003; Jahn, Renkewitz, & Kunze, 2007). The latter finding in fact is based upon experimental paradigms where complete options are learned and evaluative information is given afterwards. In line with unified models of decision making, a complete cue integration under any display mode is more realistic - when evaluative information is represented in memory and options are given to match evaluative criteria.

In this dissertation six studies render information use in settings where decisions had to be made between options whose evaluative criteria were learned before. In a novel experimental paradigm participants made decisions in four different cue presentation modes: pictorial, auditory, pictorial-auditory and textual. Each group was presented with forty subsequent binary decisions based upon multiple cues. Decisions were analyzed with regards to complete (compensatory) or limited (non-compensatory) information use.

The results make two important points on multimodal decision making and decision making in general. First, as a stable finding over all studies it is shown that non-compensatory strategies do not seem to be applied notably under any condition. This emphasizes the idea that matching options to previously learned evaluative criteria promotes comprehensive information integration, hinting towards unified models of decision making. Second, differences between display modes emerge. Pictorial, pictorial-auditory and textual display nearly always enable a complete cue integration. Findings for audition are similar, but less distinct. This deviation is found to stem from reduced auditory encoding capabilities rather than this group's inability to integrate cues completely and holistically.

Zusammenfassung

In Entscheidungen werden Informationen vom Kontext abhängig unterschiedlich genutzt. Wiederholt konnte gezeigt werden, dass die bildliche Darstellung von Hinweisreizen deren ganzheitliche und komplette Integration begünstigt. Im Gegensatz dazu wurde für textliche und numerische Darstellungsweisen eine vorwiegende Nutzung nicht-kompensatorischer Strategien gefunden (z.B. Bröder & Schiffer, 2003; Jahn, Renkewitz, & Kunze, 2007). Dieser Befund basiert auf Experimentalparadigmen, in denen komplette Optionen memoriert werden und evaluative Information im Anschluss präsentiert wird. Bezugnehmend auf vereinheitlichte Modelle des Entscheidens, scheint eine vollständige Integration aller Hinweisreize realistischer, unabhängig von der Darstellungsweise – wenn evaluative Information im Gedächtnis repräsentiert ist und gegebene Optionen nur mit diesen abgeglichen werden müssen.

In dieser Dissertation wird in sechs Studien dargestellt, wie Informationen in einem Kontext genutzt werden, in dem Entscheidungen zwischen Optionen, deren evaluative Kriterien zuvor gelernt wurden, getroffen werden müssen. In einem neuartigen Experimentalparadigma trafen die Versuchsteilnehmenden Entscheidungen in vier verschiedenen Darstellungsweisen: bildlich, tonlich, bildlich-tonlich und textuell. Jede Gruppe erhielt vierzig binäre Entscheidungen mit mehreren Hinweisreizen nacheinander. Die Entscheidungen wurden im Bezug darauf analysiert, ob Informationen vollständig (kompensatorisch) oder nur teilweise (nicht-kompensatorisch) genutzt wurden.

Aus den Ergebnissen lassen sich zwei wesentliche Schlüsse zum multimodalen Entscheiden und Entscheidungen im Allgemeinen ableiten: In allen Studien zeigte sich der stabile Befund, dass nicht-kompensatorische Strategien unter keiner Bedingung nennenswerte Anwendung fanden. Ein zweiter Befund liegt in Unterschieden zwischen den Darstellungsweisen. Bildlich, bildlich-tonliche und textuelle Darstellung ermöglichen fast

immer eine vollständige Integration aller Hinweisreize. Die Befundlage für die rein tonliche Darstellungsweise ist ähnlich, aber weniger eindeutig. Diese Abweichung lässt sich darauf zurückführen, dass in der tonlichen Gruppe weniger der vorhandenen Information enkodiert wurde und lässt nicht generell auf eine Unfähigkeit zur vollständigen und ganzheitlichen Integration von Hinweisreizen in dieser Gruppe schließen.

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Contents

1 Introduction

"What we learn only through the ears makes less impression upon our minds than what is presented to the trustworthy eye." (Horace, in Chabal & Marian, 2015, p. 159)

Most people have an intuitive idea of how they use information from different sources like texts, images, and sounds. For example, in the field of learning some people refer to themselves as *"more auditory"* or as a *"visual type"*. Researchers have failed to identify modality related learning styles (Kavale & Forness, 1987). Much rather it is assumed that all healthy humans share the same abilities to learn, process, and utilize information from different display modalities. Modality effects are well researched in many fields of psychology, most prominently learning (e.g. Mayer & Moreno, 1998; Rummer et al., 2008) and perception (e.g. Ernst & Bülthoff, 2004; Ghirardelli & Scharine, 2009; Giard & Peronnet, 1999; Treisman, 1996).

In other fields the role of display modality and format has hardly been examined – despite its obvious relevance in humans' perception and construction of the world. Among those fields is decision making. Some marginal evidence clearly shows that there is a good reason to evaluate decision making upon different display modalities and formats. Studies from consumer research (e.g. Burt & Strongman, 2005; Mostafa, 2012) and health communication (e.g. Ancker et. al, 2006; Garcia-Retamero & Cokely, 2013) demonstrate that the way information is presented impacts individuals' ability to utilize the information – and the judgments and choices resulting. Burt and Strongman (2005), for instance, showed that emotionally intense charity advertising images triggered higher monetary donations.

The field of judgment and decision making provides fruitful models that aim to describe how humans make decisions and how they should make them. While it has long been discussed whether individuals are provided with a single mechanism to arrive at a decision (e.g. Glöckner & Betsch, 2008b) or whether they choose from a set of strategies (e.g. Gigerenzer & Selten, 2001), more recent approaches have unified these models (e.g. Lee & Cummins, 2004; Söllner & Bröder, 2016). In particular they presume that humans basically employ a decision style where comprehensively all available decision-relevant information is considered. Simplifying strategies, however, are used under certain environmental characteristics, such as difficult information accessibility. Research findings also confirm that particular information display formats can trigger such strategy use. Bröder and Schiffer (2003b) have found participants to rely on comprehensive decision making more frequently when information is given pictorially, compared to a textual display. Their experimental paradigm, however, does have some shortcomings that are more likely to explain differences in decision making than the display format variations themselves. From a theoretical perspective, any display modality should allow for comprehensive decision making. Due to each modality's unique properties, this should be easier for specific formats though.

The main aim of this dissertation lies in identifying the differential use of decision-relevant information in different display formats. A novel paradigm was created to rule out issues of earlier studies (e.g. Bröder & Schiffer, 2003b) and applied to pictorial and textual display formats. The paradigm was additionally extended to a highly relevant but hardly researched modality: Auditory information display. Auditory input provides us with a plethora of information in daily life and does undoubtedly play a large role in decision making. The relationship between auditory display and decision making has not been subjected to research yet though. Therefore it is an important aim to investigate how information is utilized in decisions based on sounds. Next to the consideration of auditory, pictorial and textual decisions separately, information and decision strategy use in a pictorial-auditory display mode is examined. The empirical approach was designed to serve two purposes. One central aim was to test the prediction of unified models of decision making, that comprehensive decision making does occur predominantly regardless of display modality. Decisions are expected to be simplified only with increasing difficulty of the decision process, for instance when it becomes more difficult to integrate all available information into a consistent mental representation. The second aim was to examine whether external factors triggered this difficulty and the resulting decision strategy.

Six studies, designed particularly to reach these aims, are reported within this dissertation. To explain and understand inter- and intragroup differences, changes in decision structure and environment were manipulated in the course of the studies. Introductorily the theoretical framework, that the hypotheses and studies reported later are embedded in, is presented. In the final part of this dissertation an overview of all studies is given and the results and implications are discussed comprehensively.

2 Theoretical framework

2.1 Memory and information processing

The human mind has astonishing processing and storage capabilities. The number of neurons in our brain is estimated at 1000 billion with each neuron having about 10 000 connections to other neurons (Rösler, 2011). Equipped with these capabilities the human mind is enabled an outstanding performance in encoding, organizing, storing, and retrieving information.

The universal information store inside the brain is referred to as long-term memory. The short-term memory in contrast holds all information currently activated and processed – from memory or the environment (Zimbardo & Gerrig, 2008). Before entering the short-term store, information received from the environment is briefly held in a sensory store (Atkinson & Shiffrin, 1968).

A metaphor frequently used to describe how information is organized within our brain is the semantic network (Klimesch, 1994). This metaphor was introduced by Ross Quillian (1967) who tried to model a knowledge representation that could be transferred from human mind to computer systems. The *connectionist approach* (Rumelhart & McClelland, 1986) uses the semantic network metaphor to describe how information interacts within the brain: Certain pieces of knowledge (e.g. concepts or words, but also features like color) are considered nodes which are connected to related nodes. Both strength and direction of these connections are based upon associative learning and experience (Pospeschill, 2004, Rumelhart, 1989). Connections can activate (positive link) or inhibit (negative link) each other. Rumelhart (1989) emphasizes that many activation processes can take place at the same time (*parallel activation*), in order to be fast and extensive within the brain.

Behavioral psychology largely neglected the processes that enable individuals to use acquired information (input) to carry out actions (output), referring to the human mind as *black box* (Breedlove, 2015). Cognitive psychology however attempted to model this modulation of input and output and to illustrate how information is processed within the human mind, resulting in models of working memory. Cowan (1995, 1999) introduced a model which describes long-term memory as the basis where all knowledge is stored at. The information from long-term memory currently activated is held within the short-term store and within this short-term store attention can be focused actively on selected pieces of activated memory. All *voluntary processing* (Cowan, 1995) is controlled by the central executive. This notion implies that other processes are not consciously controlled and may even go unnoticed. Cowan (1999) refers to incoming information not actively attended as habituated, whereas (outgoing) actions taken without active executive control are automatic. Cowan's model of attention is depicted in a simplified version in Figure 1.

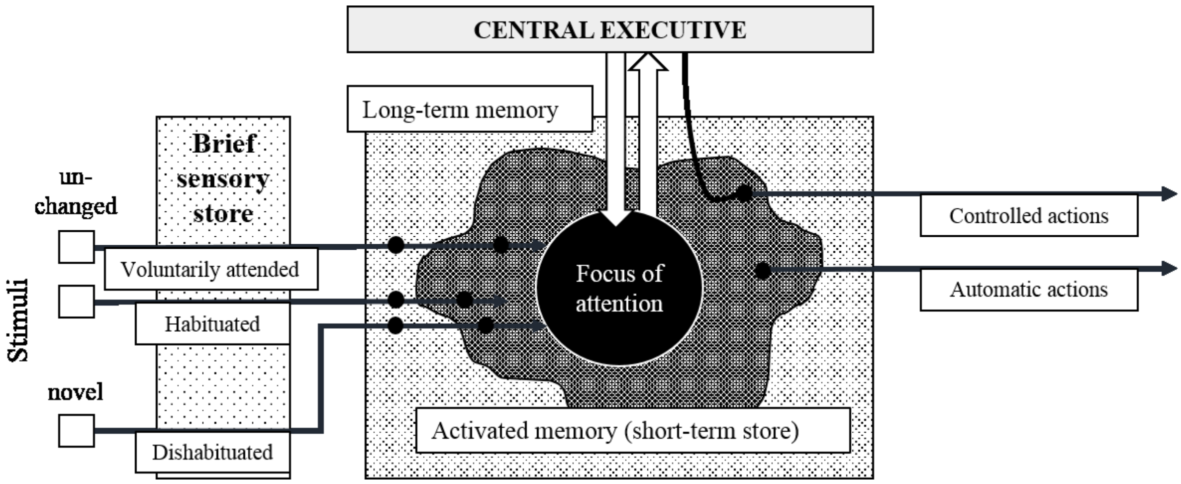

Figure 1: Simplified version of the Cowan Model of Attention (Cowan, 1995, p. 31)

Attention is thus the key element to conscious thought (Dijksterhuis & Nordgren, 2006; Shiffrin & Schneider, 1977). Conscious and automatic processes are often contrasted. Each has specific properties. Conscious processes perform a temporary controlled activation of nodes, directed by the central executive (Schneider & Chein, 2003). They can only be executed in a serial manner, as capacity and processing resources are strictly limited. Automatic processes in contrast are not bothered by these limitations and can operate in parallel. They result from learning and training until a degree is reached, where they can be carried out without conscious thought and effort (Kahneman & Frederick, 2002; Shiffrin & Schneider, 1977; Schneider & Shiffrin, 1977). The activation of automatic processes is triggered by exposure to specific input configurations and activation spreads to a sequence of associated information (Schneider & Chein, 2003; Schneider & Shiffrin, 1977). Shiffrin and Schneider (1977, p. 127) also point out an important downside of automation that it *"[...] is difficult to alter, to ignore, or to suppress once learned"*. Conscious processes are in fact important to control automatically executed processes (Kahneman & Frederick, 2002; Shiffrin & Schneider, 1977). As both take place at different levels, automatic and controlled processes can operate concurrently (Kahneman & Frederick, 2002).

Human memory and information processing is extremely powerful, as it profits from the two modes automatic and controlled processing. The first is quick and effortless, the latter deliberate and willingly executed. Our information store, long-term memory, organizes knowledge efficiently, with links between related pieces of information. Activation processes make this information available and integrate it along with information perceived from the environment.

The two types of processing modes are the cognitive basis in all areas of thinking and reasoning. They have also been a subject of discussion in the field of decision making. Intuitive "gut" decisions (e.g. Glöckner & Betsch, 2008b) are often contrasted with deliberate and conscious decision making (e.g. Beach & Mitchell, 1978). In the next section (2.2) the two types of processes are discussed in the light of decision making. Beforehand a brief introduction to the basic ideas of this discipline will be given.

2.2 Models of decision making

Making elaborated decisions is a significant ability of the human mind. It involves different processes and systems – many of which are not fully understood yet. Before discussing the "technical" properties, an understanding of decision making itself is mandatory.

Betsch et al. (2011) define decision making as a cognitive process where a choice between two or more options is made. Redish alternatively defines decision making with regards to its outcome as *"[...] the selection of an action"* (Redish, 2013, p. 8) – irrespective of the processes prior to decision making. In this dissertation decision making is assumed primarily as cognitive process which results in choice or selection of one option or action from a set of options. The process of decision making itself is considered disjoined from the actual implementation of the chosen action, which is not captured within this definition.

Decisions can vary extremely in their complexity, familiarity and significance (Beach & Mitchell, 1978). Thus the cognitive processes underlying decision making need to be flexible and adapted to the decision (Payne, Bettman & Johnson, 1988; Redish, 2013).

Individual decision making usually includes considering and integrating a multitude of information. Information can be retrieved from memory and/or stem from the environment (Mata, 2007). When decisions are made from multiple pieces of information it is referred to as multi-attribute decision making (Newell & Bröder, 2008). The idea of multiple pieces of information, so called cues or attributes, being used to form a decision, is somewhat trivial, but being able to structure decisions accordingly is an important premise to research on decision making.

To formally explain the concepts *of cue*, *cue dimension*, *cue validity* and *cue values* in probabilistic inference[1] decisions a tabular notation of such decisions is introduced next:

Table 1: Tabular notation of a decision

cue dimension	cue validity	Option A	Option B
1	0.9	+	-
2	0.8	-	+
3	0.7	-	+

The table provided above is a formalization of a decision between two options that are described according to cue values in the two columns on the right side. These two options differ on three cue dimensions – so-called attributes – as illustrated in the lower three rows. An option has a particular value on a dimension, for example two criminal suspects may differ on the dimension police record entry. When having to decide who is more likely to have committed a crime this information can be used to compare both options – here suspects.

Such cue values are often formalized using + and - as in the above example, with + indicating the presence of an attribute and - indicating its absence (Horstmann, 2012). A suspect may have a criminal record (+) or not (-).

Attributes differ on how validly they predict correct choice.

[1] Probabilistic inference tasks are contrasted with preferential choice tasks. The latter include individual (subjective) criteria for making a decision (e.g. color of flowers which I like), while the former are based on objectively assessable probabilistic information (e.g. chance to win in a lottery) (Söllner & Bröder, 2016)

The concept of validity is interpreted differently according to context. It is used to describe the conditional likelihood, that a cue is correct (Glöckner & Betsch, 2008a), the importance of a cue (Jahn, et al., 2007) or how discriminative cue information are (Söllner & Bröder, 2016) among others. Here validity is understood as the share of cases in which a particular cue predicts correct choice – a notion that can also be translated in terms of conditional likelihood.

In the suspect example we could assume a validity of 0.8 for the attribute criminal record. Thus in 80 percent of cases choosing the criminal with a police record over one without such would lead to a correct identification of a perpetrator. A validity of 0.5 in contrast would not discriminate between options at all and provide no predictive power (Horstmann. 2012).

The fact that different attributes inherit different validities makes clear that decision-relevant information differ with regard to their value in achieving an optimal choice. Validities can be used to weigh cues accordingly.

The cognitive processes involved in forming a decision out of this multitude of information are not easily palpable or trivial. Scientists in multiple disciplines made attempts to formalize and model decision making, most prominently psychology and economics.

In an economic approach each decision problem has a rational solution (*Rational choice theory*). The rational solution is the one with the highest expected utility. The expected utility is the factor of how likely and how useful a particular outcome for a specific option is (Baron, 2004; Briggs, 2014, August 8). In the above example an outcome could be choosing the right suspect. This outcome has a utility to the decision maker. For the mentioned example the utility of choosing the right suspect may depend on context factors. In other decisions utilities are more objectively accessible, for instance when the outcome is winning a certain amount of money in a lottery. The sum of all outcomes – weighted by probability[2] – is the expected utility of an option.

The implication of *rational choice theory* is that optimal choices can be assessed by calculation and weighting. At the same time it implies that individuals should behave according to *rational choice theory* to make the best possible decision.

Research findings have set limits to the assumption that decisions makers are perfectly rational. Humans have been observed to be susceptible to decision characteristics, sometimes leading to erroneous choices – compared to the rational solution (for an overview, see Tversky & Kahnemann, 1974). There is also another reason to question the rationality of decision makers: The amount of information that can be processed by individuals under execute control is restricted to a maximum of nine entities (Miller, 1956). In conclusion decisions incorporating more than nine pieces of information may not be made rationally as they exceed the working memory's processing capabilities.

In fact individuals are found to be competent decisions makers in the majority of cases. Different approaches render how competent decision making takes place under limited conscious processing capabilities. Herbert Simon became popular with the concept of *Bounded Rationality* (Gigerenzer & Selten, 2001). His idea was that individual decision making given the cognitive constraints of individuals was approached by *simplified approximation* (Simon, 1955). Thus decisions were not calculated as a rational approach would imply, but instead be simplified to an extent manageable by human's working memory system.

The idea of *Bounded Rationality* was seized and extended by other researchers (e.g. Beach & Mitchell, 1978; Payne et al., 1988, 1993; Riedl, Brandstätter, & Roithmayr, 2008).

[2] Probability can be derived from validities in the above example. Both concepts are strongly related, but not identical. The use of either is dependent on context and researcher.

Their approach to *simplified approximation* is to specify decision strategies that limit the amount of information taken into account within the decision.

Gigerenzer and Selten (2001; see also Gigerenzer, 2008; Gigerenzer & Goldstein, 1996) suggested an *Adaptive Toolbox* – a universal pool of heuristics that are applied to simplify the complexity of a given decision. Heuristics were characterized as *"[...] fast, frugal, and computationally cheap rather than consistent, coherent, and general. [...] these heuristics are adapted to particular environments [...]"* (Gigerenzer & Selten, 2001, p. 9).

The "fast and frugal" heuristics have been identified to lead to almost optimal decisions (Gigerenzer & Brighton, 2009). Their successful application involves controlled processing to selectively focus attention on the most important cues and to inhibit cues that are of low importance (Del Missier, Mäntylä, & Bruine de Bruin, 2010; Hilbig, Scholl, & Pohl, 2010).

A prominent example of a simplifying heuristic is called *take the best (TTB)*, which suggests that the best option according to the cue with the highest validity is chosen. Back to the work route example: The decision can be simplified by using *TTB* and thus both options are only compared to their value on the most important cue, which is distance. As route A is shorter than route B by 1.2 km, *TTB* predicts the choice of A. If the most important cue is not discriminative, options are compared on the second most valid cue and so forth (Gigerenzer & Goldstein, 1996).

Short-cut decision strategies like *TTB* are often contrasted with the more comprehensive rational approach introduced above. The algorithm used to make "rational" decisions is sometimes referred to as *weighted additive* (Glöckner, 2007; Payne, Bettman & Johnson, 1993). As described above, outcomes are evaluated with regard to their utility and weighted by probability. Even though an application of the *weighted additive rule* seems not tenable in most real-life decisions, given the cognitive limitations of humans, this idea has never been fully expulsed.

Simon (1955, p. 104) already acknowledged the possibility of processes beyond conscious consideration being part of the decision making process:

> *"The introspective evidence is certainly clear enough, but we cannot, of course, rule out the possibility that the unconscious is a better decision-maker than the conscious."*

In fact younger evidence confirms his idea. At this point it is known that information – in decisions and beyond – is to some degree encoded and structured automatically (see 2.1). Dijksterhuis and Nordgren (2006, p. 94) point out the potentials of unconscious automatic as compared to controlled conscious processing:

> *"According to the capacity principle, conscious thought is constrained by the low capacity of consciousness. Unconscious thought does not have this constraint because the unconscious has a much higher capacity. It follows that conscious thought by necessity often takes into account only a subset of the information it should take into account."*

They also point out that conscious thinking may be supported by automatic processes. So rather than opposing these two, they can be considered interrelated and collaborative. An implementation of how automatic and controlled processes interact in decision making was modelled within the *Parallel Constraint Satisfaction Model* (Glöckner & Betsch, 2008b). It transfers principles from the connectionist approach (see 2.1) to decision making and extends the network metaphor to the structure of decisions. Here options and cues are nodes within the network. Both, information from memory and the environment are integrated into this representation. These are linked inhibitory or activating, thus some cues activate options while others hinder activation. The magnitude of such (de-)activation is given by the weight of the links between nodes (Glöckner & Hodges, 2009). The term *parallel constraint satisfaction* refers to the properties of such processes: They operate in parallel as the processes leading to object identification are automatic. Thus many at a time can take place, as the unconscious is not bound to the same capacitive limitations as the conscious (Dijksterhuis & Nordgren, 2006). Such parallel processes work to form a consistent representation by *"[...] satisfaction of a very large number of mutually interacting constraints."* (Rumelhart, 1989, p. 142). The aim of decision making is to choose an option. Within the *PCS* model structuring processes in the network are assumed to minimize inconsistency and maximize consistency by spreading activation and information (weight) modification between options and option nodes. In this context, consistent means that activation clearly favors one option while other options are deactivated. Sometimes this process is not straightforward and dominance structures among option nodes not unequivocal – this is when conscious processes set in, so the individual can actively change the structure of the network (e.g. search for more information or devaluate cue attributes) (Glöckner, 2008; Glöckner & Betsch, 2008b; 2012; Glöckner & Hodges, 2009).

The empirical validity of the *PCS* model has been demonstrated repeatedly in decision tasks (e.g. Dieckmann, Dippold & Dietrich, 2009; Glöckner, 2007; Glöckner & Betsch, 2012), eye-tracking studies (e.g. Horstmann, Ahlgrimm & Glöckner, 2009; Milosavljevic, Koch & Rangel, 2011) and brain-imaging studies (e.g. Ilg et al., 2007; Lucia et al., 2012). Lee and Cummins (2004) evaluated models relying on extensive information integration (such as the *PCS*) empirically on a more global level. Their conclusions capture both, controlled and automatic processes. It is shown that decision makers are not limited in a way that forces them to simplify complex decisions. Yet when information is not easily accessible, then decisions are simplified gradually depending on the difficulty of information acquisition.

This notion will be the basis for the theoretical assumptions and hypotheses in this dissertation. Individuals are expected to be able to make comprehensive decisions including a large number of cues and to only simplify when additional information has to be searched for actively or when both automatic consistency maximizing processes and the resources necessary to reevaluate have been exhausted. Such an "exhaustion" of processing resources could attributed intuitively to the number of information that has to be processed. It has been found, however, that characteristics of the decision do influence information integration, strategy selection and "rationality". The role of format variations in decisions will be discussed in the next section (2.3), after an introduction to the concept of format itself.

2.3 The role of format in decision making

The term format can be defined as *"general plan of organization, arrangement, or choice of material [...]"* or *"a method for organizing data"* (Merriam-webster.com, 2016, November, 10). Thus on a global level, the concept format captures how data or information are organized. Here the term format will be used to particularly contrast different types of data or information organization and the role of variations in format will be emphasized. Statistical information may for instance be organized in the format of tables or graphs. Within this dissertation format variations will also be referred to as display formats or display modalities (short: display modes), e.g. a tabular or graphical display mode.

Plenty of research has been dedicated to such format variations and their impact on the quality and result of decisions. In rational decision making, choice should be invariant to display format, as the “best” option is objectively assessed. Display format turns out to be a frequent source of error though, as many examples illustrate. Tversky and Kahnemann (1974) have identified a list of biases in decision making that are sensitive to the format of a presented decision. One exemplary bias is the *insensitivity to sample size*, where objective probability assessments are found to vary mentionably with regards to sample size. Other examples include not-so-rational decision making upon probability display compared to frequency representations (e.g. Fiedler et al., 2000, Gigerenzer & Hoffrage, 1995), preference reversal as a result of varying information display (Johnson, Payne & Bettman, 1988) and overconfidence when producing probability intervals instead of values, the so-called *format-dependence* (Hansson, Juslin & Winman, 2003; Juslin & Persson, 2002).

Display format is also found in relation to the use of simplifying decision strategies. Bröder and Schiffer (2003b) conducted a series of studies where participants learned about a case of murder. During a first stage they memorized ten suspects with four discriminating attributes (e.g. hair color). In one of these studies these attributes were given to one group as images, while another group was given a textual display. After the learning phase subjects in both groups were informed about how many witnesses agreed on attributes possessed by the murderer. In paired comparisons, participants decided which of two suspects was more likely to have committed the murder. Bröder and Schiffer (2003b) were particularly interested in the use of the simplifying *Take-the-best strategy* versus a more comprehensive compensatory strategy.

The results show a clear difference between pictorial and textual display: The majority of participants that had received images used a compensatory strategy, while those who decided upon text predominantly appeared to use the non-compensatory *TTB strategy*. Despite structural equivalence of the decisions in both formats individuals who saw the attributes as images obviously tended to consider more of the given information than those who were presented with text. The authors explain this finding by different integration mechanisms: Images are perceived as a total (holistically) and thus pictorially presented cues are integrated in parallel by simultaneous feature matching mechanisms. Verbally encoded information in contrast is presumed to be perceived and thus processed sequentially (Jahn et al., 2007). As this is more effortful, the likelihood of using a simpler non-compensatory strategy increases. The higher frequency use of compensatory strategies when presenting cues as images is referred to as *format hypothesis* (Bröder & Schiffer, 2003b). This explanation has some shortcomings, which will be discussed in section 4.1.3.

Still it gives some important insights to how variations in display modality and format can affect choice. Here the given information was attended to differently when a pictorial format was compared to a textual one.

As the studies cited above illustrate, how information is presented in decisions impacts outcome and information use. In particular statistical reasoning and decisions based upon probabilities are closer to rational choice, when presented in a visual/pictorial format. Still there is not straightforward answer to the question, where these differences stem from. These studies are in addition extremely limited to specific domains. Often the representational format of statistical information is addressed. Very little is known about other formats like audition. Despite sensitivity of decisions to format variations, at this point there is no reason to assume that the application of comprehensive compensatory decision making is not the default in any type of display modality. Biases may also occur when decisions are made rationally and on the basis of automatic processes. Conclusions can only be drawn carefully from the consideration of the modalities uniquely and jointly within the next section (see 2.4). All display types relevant within the studies of this dissertation will be introduced individually and the integration of multimodal information into one consistent mental representation is described thereafter.

2.4 Processing of information in different display modalities

In the previous section (see 2.3) findings were presented that illustrate that format affects judgment and decision making. However, research from this field provides very little insight to modality effects in decisions. Within this section findings from converging research disciplines are aggregated to form a broader picture of the display modalities of interest within this dissertation. Before emphasizing the different display modalities individually, information perception, encoding and processing are described on the global level.

Information is perceived by our five senses, vision, audition, taste, smell and touch. Such sensory information is held briefly in a sensory store, before information is selectively transferred to be processed within the brain. The different sensors are assumed to not interfere with each other and not to be restricted by capacity limitations (Egeth & Sager, 1977). As far more information is perceived, than can be attended to, only a small part of sensory information is passed further to the sensory store though (Liebermann, 2012). The visual sensory store (Sperling, 1960) and the auditory sensory store (Darwin, Turvey, & Crower, 1972) have been found to be comparable in capacity (Ghirardelli & Scharine, 2009).

In a next step sensory stored information needs to be processed. Processing includes interpretation, integration and possibly storage in memory (Liebermann, 2012). This often requires the transformation of information, e.g. encoding written text (visually perceived) into a phonological format (Baddeley & Hitch, 1974) or interpreting an image in terms of meaning rather than remembering every feature (Willingham, 2015). As described earlier (see 2.1), some information is integrated automatically (Cowan, 1999), while some part is actively attended and consciously processed in working memory. Baddeley and Hitch (1974) proposed three components of working memory: The central executive, which directs attention and guides processing and two different temporary stores, the *phonological loop* and the *visual-spatial sketchpad*[3].

The *phonological loop* stores auditory information, which decays after about 2 seconds. These can, however, be refreshed and maintained in the working memory by repetition, the so-called *subvocal rehearsal* (Baddeley & Hitch, 1974; Liebermann, 2012). As a short-term store for non-verbal visual and spatial information the *visual-spatial sketchpad* was postulated. The representation enabled for working memory by this system is also expected to correspond to the representation of visual content in long-term memory (Baddeley & Hitch, 1974).

The structures in long-term memory are usually clustered into linguistic (semantic), non-linguistic (e.g. pictorial, haptic, melodic), procedural or episodic stores (Rösler, 2011). This format is, however, not necessarily equivalent to the display mode, as implied by the transformation processes addressed above.

Nickerson and Jager Adams (1979) have found their studies' participants unable to accurately recall exact visible features of a penny – a common object, which they were highly familiar to. Of course participants do have a visual representation of a penny in memory – otherwise they would not be able to recognize it. But at the same time, this representation is not exhaustive. Additionally this object – like most other objects – is represented in memory in terms of meaning. Semantic priming studies demonstrate that words are recognized faster

[3] The Baddeley and Hitch model of working memory was later expanded by an *episodic buffer* (Baddeley, 2000). As this store has been controversially discussed and is not of relevance for this dissertation, it will not be addressed further here.

when a semantically related word was presented before (Meyer & Schvaneveldt, 1971). This effect has also been replicated for words represented auditory (Holcomb & Neville, 1990) and for images (Sperber et al., 1978). Thus objects can have multiple representations in memory, but allow for fast recognition despite of presentation format. The memory representations for different formats within the brain are assumed to overlap in location, yet having unique features stored separately (Rösler, 2011; Sperber et al., 1978).

Instruction researchers showed particular interest in the capacity of memory for different display formats. Kirkpatrick (1894) tested pupils' ability to recall the names of learned objects that were either shown pictorially, presented as written text or displayed auditory. Recall was best after exposure to images – even after three days. A written display was worse, yet superior to a spoken presentation. In object recognition, a similar effect was observed: A larger share of previously shown images was recognized than written words[4] (Shepard, 1967). This advantage for pictorial representation in memory has since been studied extensively and is now referred to as *picture superiority* (e.g. Liebermann, 2012; Paivio, Rogers and Smythe, 1968; Stenberg, 2006). A widely accepted explanation is that images are stored dually, as images and conceptually (Stenberg, 2006).

In the next sections the unique properties and features of the three display formats pictures, texts and sounds[5] are addressed individually, followed by the joint consideration of these and their common integration.

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[4] It is noteworthy though, that the average magnitude of recognition was 88.4 percent out of 540 words and 96.7 percent out of 612 images.

[5] Spoken language and speech perception will not be considered in detail, as they are very specific forms of audition and do not play a role within the studies provided later on.

2.4.1 Pictorial display

When perceiving our visual environment, a wide variety of properties has to be incorporated: light, contrast, color, movements and contours (Schönhammer, 2013). This plethora of sensory information is formed to build a consistent mental visual representation. Most prominently *Gestaltpsychologie* postulated rules of how holistic percepts were formed from visual information (Rock, 2001). These rules include grouping sensory information according to common features (e.g. contrast, direction, proximity). The resulting representation is expected to be the simplest one possible (Goldstein, 2015).

Building mental representations of complete objects rather than remembering their individual features serves two functions: Recognizing objects holistically and saving cognitive storage resources. The latter has been demonstrated impressively by Luck and Vogel (1997). They displayed participants an array of objects and a trial array and asked them to indicate whether these were identical. The successful identification declined gradually when more than four stimuli were present. The authors additionally increased the number of attributes an object could differ on (size, color, orientation, presence of a gap). Even when the number of relevant attributes was enlarged from one to four, the number of correctly identified objects remained constant. Luck and Vogel (1997) concluded a visual working memory capacity of about four objects, which in turn may possess a larger number of features that are integrated within this object.

Unlike sounds, perceiving visual stimuli is not bound to a particular order in perception. The viewer can acquire visual stimuli self-directed. Yet our visual field is limited to what is within our eyes' reach, so only a selected part of the available environment can be considered at the time.

2.4.2 Auditory display

The process of hearing is a complex perceptual process. It involves to perceive frequencies, timbre, volume, spatial and temporal resolution of sounds and even very similar sounds can be distinguished. Hearing stands out by being particularly sensitive to temporal resolution (Ghirardelli & Scharine, 2009). Most sounds are determined in length and progression. They have to be heard in a predetermined sequence to be understood. Sounds are transient in nature, so they can only be maintained by memory (Ghirardelli & Scharine, 2009).

Researchers have been particularly interested in individuals' ability to attend to two different sounds at the same time, so-called *dichotic listening*. Both introspection and research (e.g. Cherry, 1953) show that two different messages cannot be processed at the same time. Yet two sounds – of which at least one is non-verbal – can be perceived simultaneously (Moray, 1959). One can, for instance, keep up a conversation and still notice the phone ringing. It is however not possible to pay attention two both a conversational partner and speak with the caller. It is assumed that sounds are – opposed to speech – processed in lower centers of the brain (Moray, 1959). Based on this idea, it can be presumed that sound recognition and processing belongs to the class of automatic processes and does not compete for attentional resources with (more) controlled processes like speech perception. This notion is also supported when considering the speed of response to auditory signals and how these are easily grouped and organized within the brain, so different sounds can be assigned to different sources without much effort (Moore, 2004). It should be noted though that speech consists of single sounds too and is perceived in the same automatic mode – yet attending to the message itself does require attentional capacities (Moray, 1959).

The automatic perception of auditory signals makes it virtually impossible to "hear away" – something easily achieved in vision. The range of auditory perception is much larger than the visual field. Humans can hear what's behind, above, beneath, in front or next to them (Ghirardelli & Scharine, 2009). This makes hearing incredibly encompassing in perceiving the auditory environment fast and easily.

2.4.3 Textual display

Language can be perceived by two different channels: Hearing spoken words or reading written text. Both ways of perceiving language are automatic (Moray, 1959; Stroop, 1935). Interpreting its content, however, requires additional attentional resources (Hugdahl, et al., 2003). Baddeley and Hitch's (1974) working memory model proposes an auditory store, the *phonological loop*, where both stimuli presented auditory and also written language that has been transformed into a phonological format are held (see 2.4; see also Atkinson & Shiffrin, 1968).

Heard and written language do, however, possess distinct features. Some "disadvantages" of hearing were presented in the section above (see 2.4.2). These included the sequentiality of sounds. Listeners are normally not able to return to previously heard sounds or skip sounds. As text is acquired visually, it profits from the holistic presentation and the self-paced acquisition that is enabled (see 2.4.1). Reading does allow for parallel processes to some degree, but is of course still bound to the pre-fixed order of texts (Rayner & Clifton, 2009).

In skilled reading, words are not identified letter-by-letter, but are often processed as units (Rayner & Clifton, 2009). The more familiar words are, the shorter they are fixated (Rayner & Duffy, 1986).

Reading is a very specific case of visual perception, because it is coded phonologically. It incorporates some advantages and disadvantages of vision and audition. Reading is also dependent on training and no “natural sensory perception” as speech is human-made. Skilled reading does, however, allow for a very accurate and fast acquisition of content with a combination of automatic and controlled processing.

2.4.4 Multimodal display

Most objects in our environment can be perceived multimodally, e.g. seeing and hearing a train approaching. The properties of vision (pictures and texts) and audition have been introduced separately in the sections above (see 2.4.1, 2.4.2, and 2.4.3).

The human mind’s capabilities enable to jointly perceive, integrate and process a multitude of information from all sensory sources at once. On the basis of this information a consistent mental representation of the environment is formed (Ernst & Bülthoff, 2004). The cues from different sources are integrated optimally according to their reliability (Ernst & Banks, 2002; Battaglia, Jacobs, & Aslin, 2002) – and that within a minimal time frame and often without conscious effort (Sheppard, Raposo & Churchland, 2013; Triesch, Ballard, & Jacobs, 2002; Wagemans et al., 2012).

Using information from multiple sensory sources of advantageous for individuals for different reasons (Gharamani, Wolpert & Jordan, 1997):

> (1) Using multiple sensory receptors decreases uncertainty by providing redundancy. Possible shortcomings (and even failing) of one receptor can partially be compensated for by another. In decision making the redundancy of multiple

sensory sources with target information is found to increase the probability for making a correct decision (Shaw, 1982).

(2) Each sensory receptor perceives unique information which cannot be retrieved by any other sensor.

(3) Sensory receptors differ with regard to their accuracy and latency. Using the sensory information follows a speed-accuracy-tradeoff, where the information from the faster or more accurate sensor can be weighted accordingly.

The optimal integration of information is assumed to follow a *Bayesian* principle (e.g. Cheng, et al., 2007; Ernst & Bülthoff, 2004; Ernst & Bülthoff, 2005). Preexisting knowledge is the basis for an *a priori* likelihood function. This idea is consistent with the postulates made by the *connectionist approach* (see 2.1): Knowledge from memory is the structural basis and incoming information is assimilated by updating structures and nodes in the semantic network. Thus sensory information from the environment is always evaluated with regards to what is already known and what can be expected. A *posterior* likelihood function incorporates both, *a priori* likelihoods and the sensual perceptions. The perceptions themselves are weighted in terms of how reliable they are (Ernst & Bülthoff, 2005). The calculations possible to render these processes shall be neglected here, for further reading see Ernst and Bülthoff (2004) and Gharamani et al. (1997).

Brain imaging studies have shown that multimodal displays activate very specific brain regions rather than only those areas that each sense would activate alone (Beauchamp et al., 2004; Ghirardelli & Scharine, 2009). Thus integrating multiple sensory input can be considered as being more than just the sum of its parts, but as a more distinct form of processing.

The optimal integration of multisensory cues is responsible for some interesting "misperceptions" of the environment. One phenomenon is known as the *McGurk effect*. In the studies conducted by McGurk and MacDonald (1976) participants watched videos of speakers saying bisyllables while another bisyllable was presented auditory. Instead of recognizing only either bisyllable, both sources were integrated "optimally" and merged. A visual "mama" and a spoken "tata" for instance, were perceived as "nana". A very common observation is the *ventriloquist effect* (Alais & Burr, 2004): Sound is assigned to the visual source it is believed to originate from, because this allows to form a consistent mental representation – even if the sound comes from somewhere else. This effect enables individuals to watch a movie for example and "hear the actors" speaking in front, while the sound is displayed from a high-end audio equipment behind.

Such sound systems can also trigger spatial perceptions. In spatial localization tasks participants were found to integrate visual and auditory cues according to their respective validity (Battaglia et al., 2002). Yet, subjects showed systematic bias towards overestimating the reliability of visual information, the so called *visual capture* (Witten & Knudsen, 2005). While the *picture superiority effect* in the memory domain (see 0) seems to be an advantage of the pictorial display mode itself, the case is not so clear for *visual capture*. In other (but very few) paradigms auditory signals were found to dominate visual ones (e.g. Egeth & Sager, 1977; Shams, Kamitani & Shimojo, 2000). These diverging findings are attributed to the so-called *Modality Precision*: When two or more senses conflict, the more reliable is used for judgment (Welch & Warren, 1986; Witten & Knudsen, 2005).

The perception of stimuli in different display modalities profits from increased working memory capacities (Giard & Peronnet, 1999; Martens, Kandula & Duncan, 2010; Mousavi, Low & Sweller, 1995; Rollins & Thibabeau, 1973). In the case of vision and audition different working memory channels are assumed (Baddeley, 1992; Mousavi, et al., 1995; see also 2.1) that possess individual storage capacities (Luck & Vogel, 1997). When visual and auditory stimuli co-occur, these capacities are combined and enlarged – possibly even additive (Frick, 1984).

2.5 Summary of the theoretical framework

The consideration of human mind within this second chapter gives important insights to how information is perceived, integrated and utilized – in decisions in particular. Our capacities to actively attend to information are limited. Yet information processing is supported by automatic mechanisms which are mainly a product of associative learning. Equipped with these capabilities individuals can perceive and integrate a multitude of information – coming in different formats and addressing different sensory channels. Vision and audition play a particularly important role in forming a consistent mental representation of the world. These are also our gateway to language in the form of written texts and spoken words.

How information is presented not trivial, as display format can systematically bias how mental representations are formed. In the field of decision making it has been demonstrated repeatedly that information utilization and the resulting choices are format sensitive. Researches in this area are particularly interested in how much of decision-relevant information can actually be considered within a decision. According to unified models of decision making individuals use all information in a compensatory manner. With increasing difficulty to do so, decisions are simplified gradually. The display format a decision is presented in does not conflict with the predictions of these models. It can be expected though that ease by which decisions can be made compensatorily differs for these display formats.

The central notions from this first chapter and their concrete relevance for this dissertation are recapped in Table 2.

Table 2: Recap of the theoretical introduction and conclusions for dissertation

Section	Central theoretical elements	Conclusions for dissertation
Memory and information processing	• Knowledge structures in memory can be modelled as networks • Information in networks in linked activatingly or exhibitory • Activation within the network is automatic • Information can be actively attended to and edited by executive control	• Information in decisions can be structured according to network metaphor • Decision making is guided by partially automatic information activation processes • Active control serves to elaborately attend to information in decisions and change existing knowledge structures
Models of decision making	• Decisions often include incorporation of multiple pieces of information • Different options have different outcomes and utilities • Rational choice includes choosing the option with the highest utility • Individuals can make comprehensive rational decisions due to automatic consistency maximizing processes • Effortful and controlled processes support decisions where consistent mental representations cannot be formed easily (e.g. when information acquisition is difficult)	• When information is readily available, individuals will employ comprehensive rational decision making • Simplifying strategies are only relevant when information is not readily accessible
The role of format in decision making	• Variations in display format can impact and bias choice • Pictorial presentation triggers compensatory strategy use	• Display format can affect decision making • Research is based on very specific and mostly visual representations • Format-specific variations in decision making do not contradict the predictions of unified models of decision making

Processing of information in different display modalities	• Each modality inherits different properties − Images are perceived holistically − Sounds are bound to progression and perceived sequentially − Texts are acquired self-pacedly, but sequentially • Input from multiple sources of information is integrated optimally	• Differences in decision making cannot be concluded from models of decision alone • However, differences can be expected when considering the different properties of the display modalities • image-based representations are often found to correspond to better memory recall and compensatory decision making when compared to textual and/or auditory representations

In the next chapter the drawn conclusions will be expanded and used to derive research hypotheses. In particular it will be addressed how decision-relevant information is utilized in decisions presented textually, auditorily, pictorially and pictorial-auditorily.

3 Hypotheses

The literature review provided above allows to formulate hypotheses for this dissertation. In particular differences in the use of non-compensatory and compensatory strategies upon pictorial, auditory, textual and auditory-visual display were emphasized. The theoretical models this dissertation is based upon (see 2.2) do not propose particular differences for different display modalities. Thus no modality specific effects on decision making can be concluded. From other domains it is known though, that different display modalities inherit substantial differences which may become apparent in decisions. Deriving research hypotheses requires a careful weighting of these different positions.

The evidence is in favor of complex and comprehensive information integration mechanisms (e.g. Glöckner & Betsch, 2008b, Lee & Cummins, 2004) within decisions. The literature reviewed in section 2.3 does not contradict these models' core assumption that compensatory decision making is the default. In turn it is expected that individuals will primarily use all of the information provided in a *compensatory* manner by default.

> *Hypothesis 1a: Compensatory strategy use is predominant regardless of display modality.*

The idea of comprehensive *compensatory* integration is often contrasted with the application of simplifying *non-compensatory* strategies (e.g. Bröder & Schiffer 2003a; Hilbig, et al., 2010). Such short-cut strategies require controlled processes and are thus costly. Therefore they are expected to be applied only under specific conditions, like difficult information accessibility (Bröder, 2000a; Lee & Cummins, 2004). In this dissertation it is not intended to provide such an environment, as the focus is put on the different display modalities. A non-compensatory strategy should not play a role in environments where all information is readily available. As stated above the mechanisms proposed in decision making are independent of display modality.

Hypothesis 1b: Non-compensatory strategy use will not be exhibited under any display modality.

The literature reviewed above hints towards differences between display modes, which are likely to be reflected in decision strategy use to some degree. The *picture superiority effect* (Liebermann, 2012; Paivio, et. al., 1968; Stenberg, 2006) and findings from Bröder and Schiffer (2003b) indicate that a pictorial presentation mode is particularly suited to build very comprehensive representations of given stimuli in memory and retrieve these with ease. As stated in hypothesis 1 compensatory strategy use is expected predominantly in any display modality, because automatic consistency maximizing processes are assumed to prevail in decision making. A pictorial presentation mode does, however, particularly favor these processes due to being perceived holistically. Compensatory strategy use is expected to be the default and within a pictorial presentation there should be no motivation for participants to deviate from this default in any case and simplify decisions – because all information can be integrated into a consistent mental representation with ease.

Hypothesis 2: Decisions upon pictorial display lead to an exclusive use of a compensatory strategy.

Compensatory strategy use based on effortless automatic processes is expected to prevail in any display format (see hypothesis 1a). Conscious control is required when information cannot be acquired easily (Lee & Cummins, 2004) or when a consistent mental representation cannot be formed with ease (Glöckner & Hodges, 2009). In these cases a pictorial-auditory display mode profits from two properties. Information acquisition is facilitated as multiple channels perceive sensory input in parallel. In addition a multimodal pictorial-auditory display, profits from enlarged working memory capacities (Frick, 1984; Luck & Vogel, 1997). A potential explanation is that both display modes use different working memory stores, the *phonological loop* and the *visual-spatial sketchpad* (Baddeley & Hitch, 1974).

In decision-making in turn, this should lead to the application of comprehensive strategies, due to fast and parallel automatic processes and – if required – enlarged capacities in sensory perception and working memory.

> *Hypothesis 3: Decisions upon pictorial-auditory display lead to an exclusive use of a compensatory strategy.*

Textual information are coded and stored phonologically, just as auditory input. These should have comparable properties with regards to storage. They do however differ in perception (see 2.4.3): Sound perception is sequential and its order is pre-determined. Reading follows an order but is self-paced and partially holistic. In addition recall from memory has been found to be better for read than for heard words (Kirkpatrick, 1894). It can be expected that the partially holistic acquisition will make it easier to build holistic representations from textual display. As holistic display has been found to engage compensatory strategy use (Bröder & Schiffer, 2003b; Jahn, et. al., 2007), this type of decision making should be observed more frequently upon textual display compared to auditory display.

Hypothesis 4: Compensatory strategy use is more frequent upon textual than auditory display.

Decision strategy use is also dependent on the decision's structure. The more consistent cues favor a particular option, the easier choices can be made. This notion is not only conclusive by face validity, but also supported by research. Glöckner & Betsch (2012) impressively demonstrated that decisions upon more cues are faster than decisions with less cues, when their structure allows to form a consistent representation with ease. In other paradigms (e.g. Kämmer, Gaissmaier, & Czienkowski, 2013; Mata, von Helversen, & Riesenkamp, 2011) strategy shifts are observed as a response to characteristics in the environment[6].

In this dissertation the majority of participants is expected to exhibit a comprehensive *compensatory* strategy already. Still small variations can be expected by structural changes. In particular it is expected that with increasing consistency the number of participants using a *compensatory strategy* increases. Within the *PCS* model it is assumed that effortful executive processes are only carried out, when a consistent mental representation cannot be reached by automatic structuring (Glöckner & Hodges, 2009). When executive control is required it will be more difficult to apply a *compensatory* strategy and more likely that simplifying strategies are applied (Hilbig et al., 2010; Lee & Cummins, 2004).

In particular two ways of increasing consistency will be considered here. The first approach is to lower the amount of information that has to be taken into account. Lowering information does not naturally increase consistency (Glöckner & Betsch, 2012). However a drop of information will make it less likely that inconsistencies arise, which require effortful

[6] Environment is used as a synonym for the decision structure. In these studies environments were compared that favored compensatory versus non-compensatory strategy application.

controlled processes. With less information, forming a mental representation from all given information should be easier – on average.

Hypothesis 5: Less decision-relevant information will increase the use of the compensatory strategy.

A second way of increasing consistency within a decision is to change the structure of this decision. *Compensatory* strategy application is the most straightforward when the decision's structure allows to form a consistent mental representation with ease. This means that the pattern of cue values is highly in favor of one option. Controlled executive processes are expected upon ambiguities that can only be resolved by actively changing the structure of decisions and searching for further information (Glöckner & Betsch, 2008b; Glöckner & Hodges, 2009; Lee & Cummins, 2004). As controlled processes will make a *compensatory* strategy application less likely (see above) this strategy should be exhibited particularly upon low inconsistency within the pattern of cue values.

Hypothesis 6: Increasing the consistency of cue pattern will enhance the use of the compensatory strategy.

To test these hypotheses a novel paradigm was developed. A variety of methodological pre-considerations was necessary to create a setting that allowed making inferences and drawing conclusions regarding the hypotheses. The empirical approach will be rendered within the next chapter.

4 Empirical approach

Within this chapter it is outlined how an experimental procedure suited to test the hypotheses formulated above (see 3) was derived. Introductorily it is discussed how decision strategies can be assessed empirically (see 4.1.1) and how strategy assessment is implemented structurally with cue patterns (see 4.1.2). It is also considered how properties of a decision can be retrieved from memory and the environment (see 4.1.3). According to these pre-considerations materials and procedures were developed, as described in 4.2 and 4.3. These were used within six studies that are described, reported and discussed individually within the sections 4.4 to 4.9. To draw some more detailed conclusions, the data from five of these studies were analyzed in aggregation in the final section (see 4.10).

4.1 Methodological preliminaries

4.1.1 Strategy classification

To arrive at a decision, individuals may use different strategies. Strategy use is both dependent on the person and the situation (Brehmer, 1994; Bröder & Schiffer, 2003a; Payne et al., 1988). Strategies differ with regard to the amount of information that is used in the decision process (Bröder, 2010b; Glöckner & Betsch, 2012; see also 2.2). Assessing strategy use among individuals has a variety of goals. These include examining the “rationality” of the decision maker (Bröder & Schiffer, 2003a), how decision makers adapt to changes in the decision environment (Payne et al., 1988) and comparing persons on the level of strategy use.

Techniques for assessing strategy use exist (e.g. Brehmer, 1994; Bröder & Schiffer, 2003a; Glöckner, 2010; Hilbig & Moshagen, 2014; Johnson et al., 1989; Riedl et al., 2008). Bröder and Schiffer (2003a) developed an outcome-based method for strategy classification.

Here the decisions made by an individual are compared to the decisions predicted by a particular strategy. Their outcome-based method makes specific assumptions:

(1) Strategy use is consistent over all decisions.

(2) Strategy use can be determined according to decision outcomes.

(3) Decisions can be structured so that different strategies predict different outcomes.

(4) People using a particular strategy sometimes deviate from the strategy and make unsystematic errors with a constant probability ε_k.

To assess strategy use, participants are presented with two (or more) options and requested to choose one. Options differ on several cue dimensions. Cue dimensions themselves have different validities. The validity is a value that indicates the relative weight of a particular cue of an option. The structure of such decisions can be formalized as cue patterns (see 4.1.2). For each decision and each strategy *k* the researcher examines, choice can be predicted.

In the studies reported here two different strategies *k* were considered. These included a compensatory strategy (*comp*) where all given cues are considered. Cues speaking for an option can compensate cues speaking against the option and vice versa. The most comprehensive form of compensatory decision making considers all relevant cues, values and validities and corresponds to the *rational approach* introduced above (see 2.2). The implementation in decisions is called *weighted additive rule* (*WADD*; Glöckner, 2007; Payne et al., 1993). Here each option is evaluated individually and finally options are compared regarding their *"overall evaluation"* (Payne et al., 1993, p. 24). An overall evaluation is the sum of cue values speaking for or against an option, with each value weighted by validity.

A milder form of compensatory strategy is called *equal weight rule* (*EQW*; Payne et al., 1993). Like in *WADD* the pros and contras are summated for every option and options are compared with regards to this value. Validities are not considered though, so that all cue dimensions are weighted equally.

In the dissertation presented here, a very general approach to strategy classification was chosen. There was no aim to draw a clear line between these two strategies but rather to compare the more general categories compensatory versus non-compensatory decision strategies. Therefore cue patterns were constructed that made equal predictions for the selection of *WADD* and *EQW*. Participants were classified globally as *comp* users.

The second strategy considered was a non-compensatory strategy (*non-comp*). In non-compensatory strategies a positive value cannot compensate for a negative value (and vice versa) within an option (Dieckmann, Dippold, & Dietrich, 2009). Options are not compared according to their overall evaluation, but compared on cue values (Hilbig et al., 2010). A highly simplifying non-compensatory strategy is *take the best* (*TTB;* Gigerenzer & Goldstein, 1996), introduced earlier (see 2.2). When individuals apply *TTB* they look for the most valid cue in each option and compare options accordingly[7]. The option with the highest value on the most valid criterion is chosen. If several options would be chosen because they possess the same value on the most valid cue, these are compared according to the second most valid cue and so forth.

In the context of this dissertation TTB will be referred to as *non-comp* and contrasted with the *compensatory* approach given above. The application of the three strategies introduced above is illustrated for an exemplary combination of cues in Figure 2.

[7] Gigerenzer and Goldstein (1996) state that *TTB* starts with a recognition principle before the actual evaluation of cues. The recognition principle is relevant in decisions made from memory, because clearly individuals have to have a memory representation of the cues used for deciding. The recognition principle will not be of further relevance in this dissertation though, as recognition in participants is ensured by learning and retrieval.

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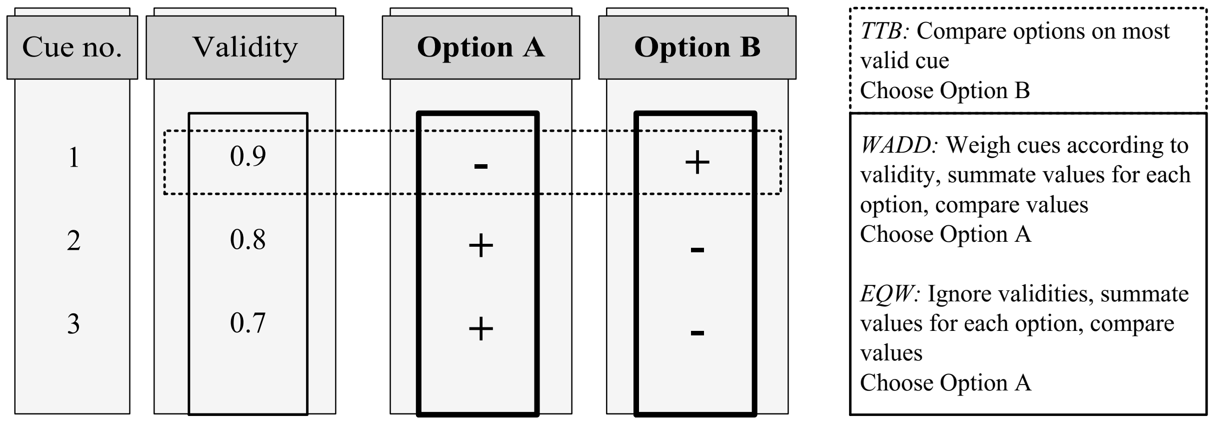

Figure 2: Application of three different strategies for decision making

To classify participants according to *comp* and *non-comp* different cue patterns were designed. Cue patterns were of two types *J*: A pattern could either make the same or different predictions for *comp* and *non-comp*. The cue patterns used in the studies reported here and their predictions are depicted in Table 4 and Table 5.

The options actually chosen by participants were compared to the choice predictions of *comp* and *non-comp*. As stated above, the outcome-based strategy classification method (Bröder & Schiffer, 2003a) takes into account that people applying a particular strategy might unsystematically deviate from a consistent strategy use. For each individual and each strategy *k* the relative frequency of erroneous choices according to *k* (ε_k) is estimated by the following equation (see Bröder & Schiffer, 2003a, p. 201):

$$\hat{\varepsilon}_k = \left[\sum_{j=1}^{J} (n_j - n_{jk})\right] \div \left[\sum_{j=1}^{J} n_j\right]$$

In this equation, n_j is the total number of items of type *J*. The individual's number of strategy-conform decisions for strategy *k* in item type *J* is denoted as n_{jk}. Thus $\hat{\varepsilon}_k$ approximates the probability for making errors in applying strategy *k*. The higher the error, the less likely the individual has used strategy *k*. As making a single decision would neither be very informative nor discriminative, decisions structured according to cue pattern *J* are presented repeatedly[8]. Now it can be calculated how likely it is that this person has used *k* according to the observed response pattern by the equation given beneath (see Bröder & Schiffer, 2003a, p. 201):

$$L_k = p(n_{jk} | k, \varepsilon_k) = \prod_{j=1}^{2} \binom{n_j}{n_{jk}} \times (1-\varepsilon_k)^{n_{jk}} \times \varepsilon_k^{(n_j - n_{jk})}$$

To actually classify individuals as users of a particular strategy *k*, two conditions need to be fulfilled:

(1) The estimated error probability $\hat{\varepsilon}_k$ does not exceed a prefixed value. In the studies reported in this dissertation, a maximum error probability of $\hat{\varepsilon}_k = 0.3$ was set as a limit in order to classify a participant as user of strategy *k*.

(2) The likelihood for the use of strategy *k* is larger than for any other strategy considered, hence possessing *likelihood ratios*[9] larger than 1.

Thus the outcome-based strategy classification method is based upon likelihood functions and the assumption that when the conditions above are fulfilled, strategy *k* is most likely to underlie an individual's response pattern. If a person cannot be classified according to the strategies considered – either because the errors are too high or the likelihoods for two or more strategies are identical – then he or she will remain unclassified.

[8] The number of repetitions (trials) is defined by the researcher.
[9] The likelihood ratio is derived by dividing the likelihood of the use of strategy *k* by the likelihood of the strategy to be compared.

Bröder and Schiffer (2003a) point out that their outcome-based strategy classification method has been validated empirically and highlight its usefulness in assessing the relationship between data from decisions and theoretical decision models. It is a powerful method and has been proved useful in many research paradigms (e.g. Bröder & Schiffer, 2003b; Jahn et al., 2007; Lindow, 2014). Yet it does face some limitations, which will be discussed in section 5.3. Bröder (2010b, p. 67) points out the usefulness of this method and its robustness to the different types of formats decisions can come in:

> *"Although the display format might influence strategy selection, the only thing that matters for choice-based strategy classification is the formal structure of cue patterns that allow to discriminate strategies."*

This presupposition is fundamental to the experimental paradigm introduced in this dissertation. It can be concluded that differences in strategy use upon display format variability do arise from the manipulation itself and are not a result of the classification method used.

After discussing the possibilities and technical properties of decision strategy classification according to the outcome-based method (Bröder & Schiffer, 2003a), the concept of cue patterns – fundamental within this method – will be introduced next.

4.1.2 Cue patterns

Cue patterns respond to the structural composition of cues and validities in a decision, artificially arranged by the experimenter. The outcome-based method for classifying strategy use in decision making (Bröder & Schiffer, 2003a, see 4.1.1) requires specific structural properties, such cue patterns, within the decision provided. For an example see Table 3.

Table 3: An example for cue patterns and strategy predictions

cue dimension	cue validity	Option A	Option B
1	0.9	+	-
2	0.8	-	+
3	0.7	-	+
Strategy Prediction	non-compensatory	Choose option A	
	compensatory	Choose option B	

Cue patterns also serve as denotation for the structure of probabilistic inference decisions. The notation given above (see Table 3) is the standard to oppose a finite number of options within the columns. The cues belonging to these options are listed in the rows beneath. In the first column the validity for each cue is denoted. The cue values for each option for each cue dimension are given within the cells. These values carry the information, whether an option is preferable or unfavorable with regards of the cue dimension. The relative importance of cues is only interpretable when simultaneously considering cue validity. In this dissertation cue values can be either positive (+) or negative (-), speaking for or against an option. It is possible to differentiate between these two extremes more fine-grainedly (e.g. using ++, +, o, -, --), but for the aim of this dissertation the former notation is sufficient.

Table 4 and Table 5 depict the cue patterns used in studies one to four and in studies five and six. The cue patterns were varied from study four to study five with regards to structure and number of trials. In the first four studies one out of four cue patterns (25 percent of trials) differentiated between the two strategies examined. The number of differentiating patterns was enhanced to two in the later studies, with an increased number of trials (75 percent of trials were differentiating). The reason for the shift in cue patterns is discussed in 4.8.

Table 4: Cue patterns and strategy predictions for Studies 1 to 4

Cue pattern		**1**		**2**		**3**		**4**	
cue no.	cue validity	A	B	A	B	A	B	A	B
1	0.9	+	-	-	+	-	+	+	-
2	0.8	+	-	+	-	-	+	-	+
3	0.8	+	-	+	-	+	-	+	-
4	0.7	-	+	-	-	+	-	-	+
Number of trials		10		10		10		10	
Strategy Prediction	non-compensatory	A		B		B		A	
	compensatory	A		A		B		A	

Table 5: Cue patterns and strategy predictions for Studies 5 and 6

Cue pattern		**1**		**2**		**3**		**4**	
cue no.	cue validity	A	B	A	B	A	B	A	B
1	0.9	+	-	-	+	+	-	-	+
2	0.8	+	-	-	+	-	+	+	-
3	0.8	+	-	-	+	-	+	+	-
4	0.7	-	+	-	+	+	+	-	-
Number of trials		5		5		15		15	
Strategy Prediction	non-compensatory	A		B		A		B	
	compensatory	A		B		B		A	

Implementing these cue patterns allowed to classify participants according to the two types of strategy *comp* and *non-comp* by the outcome-based strategy classification method (Bröder & Schiffer, 2003a; see 4.1.1).

Examining how decisions are made based on these patterns is straightforward when the notation given within the tables is used. For other display formats, such as images and sounds, additional considerations are necessary. In particular the implementation of the numerical validity expression and the symbolic cue values revealed some issues. To overcome these, a learning procedure was developed, which enabled a representation of cue values and validities in memory in the respective format. The major goal of this procedure was to make both features readily available within the decision and for participants to evaluate options with ease by inference from memory.

4.1.3 Representing cues in memory

The goal of this dissertation is to compare decision making in different formats including pictures, sounds and texts. The concrete implementation of the different formats is described in the next section (see 4.2). In advance some preliminary considerations regarding memory representation are indispensable.

Implementing cue patterns as symbols like shown above (see 4.1.2) is possible when a textual display is used. In a merely pictorial or auditory display mode this format needs to be reconsidered and adapted. To resolve this problem, representations had to be chosen that are equivalent to the cue patterns provided. Bröder and Schiffer (2003b) handled this issue by letting participants learn ten complete options (cue patterns) in the respective format (pictorial or textual) within their studies. An option was constructed of four different cues belonging to a suspect in a murder case. The cue validity hierarchy was disclosed after the learning but before the decision phase by telling participants how many witnesses agreed on a particular cue. Afterwards binary choices between two suspects were presented and participants had to indicate who was more likely to be the murderer (see also 2.3).

This approach may be suitable and reasonable for that particular experimental paradigm. For this dissertation a different approach was chosen. The paradigm introduced by Bröder and Schiffer (2003b) does something very atypical for decisions made from memory: Specific options are represented in memory without their respective weights (validities). These are introduced later. Neuroscientific research indicates that information, and their connections and relative weights are updated in memory by incoming information (Gerstner, 2016). However there are no insights into how participants integrated them in the studies from Bröder and Schiffer (2003b). The authors argue that most participants used the simplifying *TTB* heuristic, because cognitive costs for memory retrieval are high. While the notion of high cognitive costs, leading to simplifying decision strategies, is supported by other findings (e.g. Payne et al., 1988), it cannot offhandedly be attributed to costly memory retrieval.

Alternatively one could hypothesize that it is costly to update validities in this fashion (Bröder, Newell & Platzer, 2010). Participants may have evaded the – cognitively straining – matching of each suspect's cues with the new validity information by only focusing on the most informative validities and the related cues. Alternatively participants may have dropped validity information altogether. Both explanations correspond to the two most frequent strategies found in Bröder and Schiffer's (2003b) studies and give an alternative explanation for these findings. A later study (Bröder & Platzer, 2012) exhibits another weakness by showing that cue salience could completely account for the results rather than format, as proposed in the original study. Since cue salience is likely reflected within the network nodes' weights, it becomes obvious that the validities presented to participants did not accurately reflect the weight given to each cue (Shah & Oppenheimer, 2009).

The problems of this paradigm can be illustrated by the following analogy: Imagine you work at an HR department and your boss asks you to memorize the curriculum vitae of ten job candidates. After memorizing these cues he tells you which of them are important in choosing a candidate and asks you to choose the best one. Such decisions are not unrealistic, but seem very unlikely. Much rather one would expect to learn which cues exist and their relative importance (validity) for choice jointly. With this in mind, options are compared to the "categorization" stored by the individual (e.g. matching learned cues important for a job to a given CV). Categorization can be considered a particular case or part of decision making (Bröder et al., 2010; Seger & Peterson, 2013). Individuals acquire categories by a learning process of perceiving and receiving cause-effect interactions and build these categories to easily apply them to novel stimuli matching the criteria initially learned (Newell & Bröder, 2008). The application of categories (categorization) is known to be automatic, thus cognitively of low effort and hardly requiring attentional capacity (Newell & Bröder, 2008; Rosch, 1978; Waldschmidt & Ashby, 2011). In addition active and controlled search in the environment is supported and improved by categorization (Shiffrin & Schneider, 1977).

With this in mind, it can be expected that evaluating options according to cues and categories stored in memory is far less demanding than evaluating options stored in memory according to criteria that are given. This argumentation is also in line with hypothesis 1 of this dissertation (see 3), where the predominant use of *WADD* is expected due to partially automaticity-based processing. According to these pre-considerations a paradigm was constructed as presented in the studies herein. The main aim was to have participants learning optimal and suboptimal cues that they could match options to during the decision phase.

Within the next section it will be described how the corresponding materials for the studies presented in this dissertation were generated and tested before introducing the experimental method and paradigm.

4.2 Selection and pretest of stimulus material

For the studies of this dissertation a travel scenario with multiple travel-related cues was chosen, as brought up by Jahn et al. (2007). The different cue dimensions and respective cue values used herein (see 4.1.2) were chosen for pragmatic reasons. On the one hand cues were required to be comparable between the different display conditions. On the other hand materials were selected that participants could relate to and made the decision task intuitive, so it would not conflict with participants' preexisting knowledge structures and categories. This notion is an important one, because decisions are assumed to be – at least partially – structured automatically based on knowledge from the environment and from memory (Glöckner & Betsch, 2008b). When cues in an experimental paradigm massively conflict with information from memory the decision becomes counterintuitive and it is difficult to determine how information is integrated with regards to pre-existing knowledge structures. Cues in line with these structures and categories should in turn strengthen the association between nodes and simplify the formation of a consistent mental representation.

For the studies of this dissertation stimulus material was chosen that would be in line with the actual preference structure revealed by the majority of subjects. Even though the actual decisions in the main studies were not preferential, but probabilistic inference decisions, making intuitive judgments is expected to aid rational choice.

Stimulus materials were chosen that would allow for a textual, pictorial and auditory display. In total five travel cue dimensions with two respective cue values were generated. Dimensions and their two cue values were selected as follows:

- Type of hotel: Wellness / Family
- Crowdedness: High / Low
- Bathroom equipment: Bathtub / Shower
- Transportation: Bus / Plane
- Location: Nature / Street

For every cue value a matching image and sound were selected. Images were retrieved via Google image search (Google, 2014). Sounds were selected from FreeSound.org (Universitat Pompeu Fabra Barcelona, 2014). Within a pretest participants were asked for their travel preferences and rated the match between sound and image. This own preference was used for the main studies where own preferences did not play a role, but only the preferences revealed by fictitious customers. The latter were constructed from these pretest results.

Procedure. An online-survey was constructed to assess participants' inherent weights and values for five dimensions chosen beforehand. During a first task subjects were to indicate the importance of these dimensions by marking a point on a continuous rating scale. Items were presented in a randomized order. In a second task two opposing values were presented as endpoints of a continuous scale (e.g. bathtub versus shower). Again participants' own preference was to be indicated by marking the respective point on the scale.

To particularly assess how well images and sounds matched, subsequently each of the ten sounds was presented and participants indicated for every image on a continuous scale, how well it fitted this sound. The pretest materials are given within Attachment A-1: Pretest instructions and material

Participants. The survey was run on the online-survey platform SoSci Survey (2014) from January to February 2014. *63* subjects (*26* female, *11* not specified; $M_{age} = 32.4$ years) participated.

Results and consequences. On all dimensions one cue value could be identified as significantly favored over the others (e.g. bathtub was significantly preferred over shower). In the main studies the cue value of higher preference was treated as impacting an option positively (+) and the lower preference cue value as devaluating an option (-).

How strongly a positive or negative cue value impacts choice is indicated by this cue's validity. For all cue dimensions and the respective pair of cues, importance was assessed for each cue dimension. In the main studies the order of validities assigned to these cue dimensions was in line with the order provided by the pretest, the most important remained the most important, etc. The actual validity value however was generated artificially in order to structure decisions in accordance to the cue pattern given above (see 4.1.2).

When analyzing how well a sound was captured by the corresponding image compared to all other images, the corresponding image was always rated highest – with two exceptions. The plane sound had a higher rating on the image bus ($M = 58.6$, $SD = 36.8$ versus $M = 59.4$, $SD = 32.5$). Thus a more appropriate sound was derived from FreeSound.org (Universitat Pompeu Fabra Barcelona, 2014) for the main studies. The sound for low crowdedness had a very high match ($M = 79.2$, $SD = 25.2$) with the image for high crowdedness, in contrast to little match with the actually corresponding image ($M = 33.9$, $SD = 30.1$). Thus the cue dimension crowdedness was dropped for the main studies. The complete results are appended in Attachment B-1: Pretest results

The material generated for and tested within the pretest was transferred to the six main studies reported in this dissertation. Within the next section (see 4.3) the paradigm used and its implementation with regards to method and the used materials will be described.

4.3 Introduction to the paradigm, method and material

The six main studies reported in this dissertation all included three stages:

(1) Learning phase
(2) Decision phase
(3) Retrieval phase

The concrete implementation of these stages partially varied between the studies. Here a global introduction to the approach will be given. The concrete procedure within each study will be described in more detail within the study descriptions.

In the first stage participants were introduced to a scenario, where they had to make decisions as a purchaser of a travel agency. In order to do a good job, they would be given the chance to learn all attributes that customers would prefer. They were informed that vacation trips could differ on four different dimensions: Location, transportation, bathroom equipment and type of hotel. On each dimension a vacation trip could have one out of two possible values (e.g. bathtub or shower in dimension bathroom equipment). Additional information made it possible to evaluate each dimension according to these values: The share of customers who prefer a particular value (validity). In the dimension bathroom, for example, 80 percent of preferences were in accordance with bathtub, whereas only 20 percent favored the shower. With these properties, decisions could be structured so that options would correspond to the cue pattern provided above (see Table 4 and Table 5). The four dimensions represent the four numbered cues. Validity is indicated by the share of preference. Finally the positive (+) and negative (-) cues are represented by the values – as either is preferred by the majority of customers (e.g. bathtub), which in turn means that the other value is rejected by this majority (e.g. shower).

All cue dimensions and their respective values are depicted in Table 6.

Table 6: Vacation trip dimensions and their values and validities

cue no.	dimension	validity	+	–
1	location	0.9	nature	street
2	transportation	0.8	plane	bus
3	bathroom equipment	0.8	bathtub	shower
4	type of hotel	0.7	wellness	family

In this learning phase, cue dimensions, cue values and validities were learned. This was to ensure that these categories were represented in memory and could be easily applied to particular options presented in the decision phase. Concrete options did not occur until the decision phase.

In the six studies of this dissertation two different learning procedures were used. Within the first three studies, participants acquired the cue information by self-directed learning. This learning phase was implemented using MS PowerPoint. For each cue dimension a slide was shown where all relevant information regarding this dimension was presented, as illustrated in Figure 3.

Figure 3: Slide of learning procedure for studies 1-3 for dimension bathroom equipment

Participants saw the name of the cue dimension (e.g. bathroom equipment) and the two cue values a hotel could possibly possess on that dimension. One of these cue values was preferred by the percentage of fictitious customers expressed in the numerical validity value (e.g. 0.8, which equals 80 percent).

In this learning procedure participants learned about the cues in all display formats. They saw the name and an image of each cue value on the screen. By clicking a loudspeaker symbol the respective sound was played. In the decision phase, the format was varied between subjects, so only part of the learned information was required then.

After learning about each cue dimension, participants were asked about the cues previously learned. At first they were shown each cue image and name in the center of the screen. Then they were asked whether this cue value was preferred or rejected by the majority of customers (indicated by a happy or sad face). After answering correctly, participants were asked to choose the validity of this cue out of three options (0.7, 0.8 and 0.9). Upon a correct answer, all images from all cue dimensions and their names were displayed on the screen. Participants were asked to click the image of the other cue value from the same cue dimension (e.g. bathtub – shower). In the final part of the learning phase, a screen was presented where all images from all cue dimensions and their respective names were displayed. This time the goal was to indicate through mouse-clicking which image belonged to the sound that was played. Sounds could be repeated by clicking a loudspeaker symbol on the same slide.

All questions were repeated until they had been answered correctly. Thus the study continued only when 100 percent of the learning test had been mastered successfully. Screenshots for this learning procedure are provided in Attachment A-2: Instructions and stimulus materials for studies 1-6

The learning procedure introduced above revealed some methodological and theoretical limitations. These are discussed in detail in sections 4.6, 4.7 and 5. Thus a different learning procedure was used in studies 4 to 6.

Within the new learning procedure participants only learned about the travels in the display modality that they would later be given within the decision phase. Now learning was not self-paced, but based on sampling from a series of ten consumer preferences given on the screen as text, image and/or played as sound (e.g. bathtub-bathtub-shower-bathtub-…). This adapted learning phase was implemented in Processing (Fry & Reas, 2016). The number of repetitions of each cue value was equivalent to the preference indicated by this cue dimension's validity (e.g. 8 repetitions "bathtub" and 2 repetitions of "shower" in the cue dimension bathroom equipment with a validity of 0.8). The name of the respective cue dimension was displayed prior to each sequence. An exemplary sequence is shown in Attachment A-2: Instructions and stimulus materials for studies 1-6.

After each sequence, participants were given a slide and asked to choose which of the two cue values was preferred by a larger number of customers and received feedback about the correctness of this response. Then the sequence was shown once again. On the next slide they were to click on the percentage of customers showing this particular preference (options were 0%, 10%, 20%,…, 100%) and were informed whether they had guessed correctly. The exactly correct percentage was never disclosed and correct answers were not required in order to continue. After receiving feedback for their guess, the next sequence for the next cue dimension was displayed analogously. This procedure was repeated until the two sequences and the corresponding questions had been presented four times per cue dimension. On a final screen participants saw which of their guesses regarding percentage had been correct.

After successful completion of the learning phase, the second experimental phase was started. The decision phase was implemented in the open access experiment builder tool OpenSesame (Mathôt, Schreij, & Theeuwes, 2012). Participants were presented with 40 subsequent decision trials. Decisions were structured according to the cue patterns described above (see 4.1.2).

In the decision phase participants s aw a fixation dot in the center of the screen for 1000ms. Then the first option was presented on the left for 1500ms, disappeared and the second option was displayed on the right for 1500ms and disappeared. Afterwards two dots were presented on either side of the screen representing the options' initial position. By pressing the LEFT or RIGHT arrow keys on the keyboard the corresponding option was chosen and the next trial was started and displayed analogously. The sequence of each decision trial is given in Figure 4: Implementation of the decision phase in the pictorial display modality. Three practice trials were given at the beginning of the second stage, followed by the 40 decision trials.

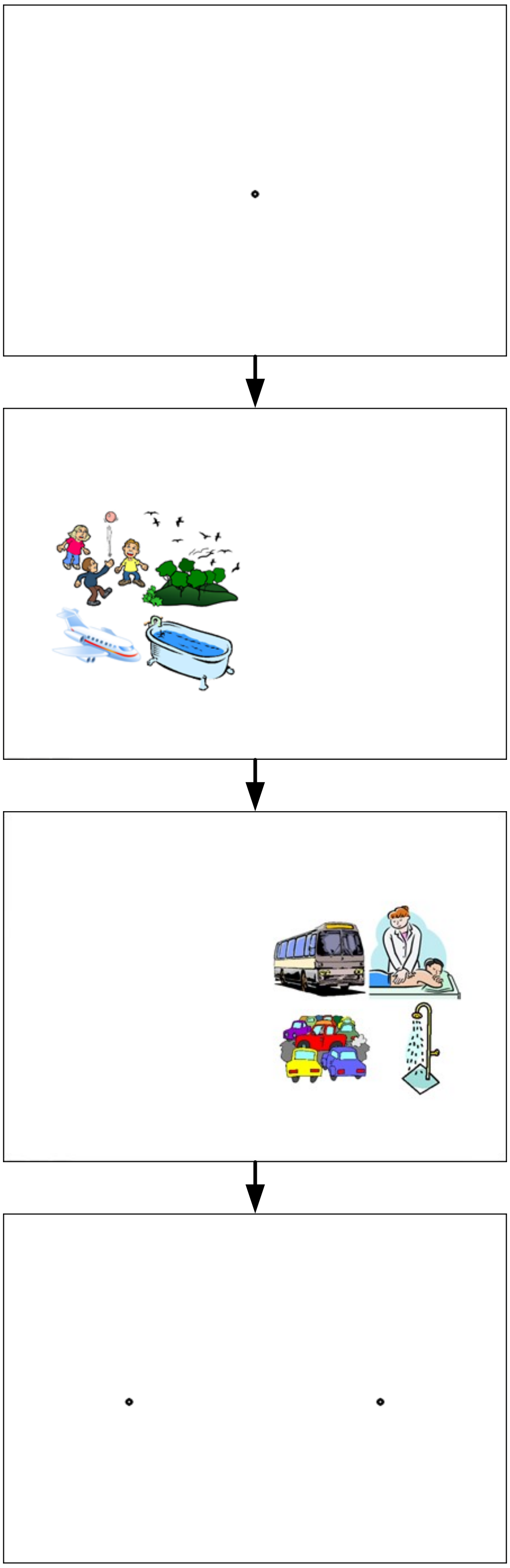

Figure 4: Implementation of the decision phase in the pictorial display modality

As display format was varied between subjects, participants received decisions in one of the four variants:

Pictorial. The sequence of the pictorial decision phase is illustrated in Figure 4: Implementation of the decision phase in the pictorial display modality. Participants were given the first option's image on the left screen side, followed by the presentation of the second option on the right screen side. Finally two dots were shown and participants indicated their decision with a keypress.

Auditory. The single sounds representing the cues of an option were merged into one sound file for each option. They were presented in a sequence, but did overlap slightly (i.e. sound of second cue was started before sound of the first cue ended, and so on). The auditory presentation of the first option was accompanied by a single dot on the left half of the screen, while the second option was played as a dot appeared on the right half of the screen. These were representative of the two dots displayed on the subsequent slide, where a LEFT versus RIGHT decision was required.

Pictorial-auditory: The pictorial-auditory version of the decision phase was a combination of the pictorial and auditory variants. Half of the cues per option were presented pictorially and the other half auditorily. For studies 3 and 6 that included only 3 cues per option, it was randomly varied whether two sounds and one image were presented or the other way around. In the pictorial-auditory decision phase, images for the first option were presented on the left half of the screen accompanied by the respective sound played simultaneously. The same was repeated on the right side for the second option, followed by the two dots that indicated choice.

Textual. The textual version of the decision phase was analogous to the pictorial variant, only with a textual presentation of cues. The textual presentation was arranged in a table which included the cue dimensions' names in the first column and the cue values in the second column (see

Lage:	Natur
Badausstattung:	Wanne
Hotelart:	Familie
Transportmittel:	**Bus**

Figure 5: Textual presentation of an exemplary option in the decision phase

Figure 5).

In all of the different display formats the order of cues was varied randomly. Cues were not ordered according to validity or any other criterion.

The final stage served to check memory retrieval. This test was implemented in the online-survey platform SoSci Survey (2014) for the studies 1 to 4 and in a paper-pencil format for studies 5 and 6.

In the online version participants listened to the sound file of each cue value and indicated with a mouse click which image corresponded to the played sound. In the next part every cue dimension's name was displayed and the validity was to be indicated by choosing from a dropdown selection. Again the eight cue images were displayed simultaneously and participants were asked to select the image that represented this category's positive value. The same was repeated for the negative cue value. Only participants who made at least 70 percent correct responses in the retrieval phase were submitted to the analyses. For studies 1 to 3 preference was also assessed: Participants could choose for each dimension which of the two cue values they preferred themselves.

In the paper-pencil measure used in studies 5 and 6 the retrieval phase was simplified substantially. Now questions and answers were only given textually and no sounds or images were presented. Participants indicated for each dimension which of the two cue values presented textually was preferred and how many customers showed this preference with a crossmark.

In both versions, online and the paper-pencil, gender and age needed to be specified. The materials used in the third experimental stage are given in Attachment A-2: Instructions and stimulus materials for studies 1-6

The above introduction is a general outline of the paradigm and measures used within the six studies presented subsequently. Variations and specifics for each study are disclosed within the study descriptions.

4.4 Study 1: Display-format-induced differences in decision strategy use

Study 1 was mainly of a pilot character in assessing differences in decision strategy use depending on display format. It addressed the first four hypotheses formulated above (see 3). To summarize, compensatory strategy use was expected to be predominant in all experimental conditions. For the pictorial and pictorial-auditory groups this compensatory strategy use was expected exclusively. For the textual and auditory group compensatory strategy use was hypothesized to be prevalent, yet more frequent in the textual as compared to the auditory condition.

4.4.1 Method

Design and measures. Decision strategy choice served as dependent variable and was assessed in a one-factorial design. The independent variable display format was varied between subjects in the groups pictorial, pictorial-auditory, auditory and textual display. Decision strategy was assessed from the decisions made by participants according to the outcome-based strategy classification method (Bröder & Schiffer, 2003a; see 4.1.1). Strategies examined were a compensatory (*comp*) and non-compensatory (*non-comp*) strategy, respectively. If no classification was possible regarding the criteria outline above (see 4.1.1), participants remained unclassified.

Participants. *89* subjects (*77* women, M_{age} = *22.8* years) recruited via ORSEE (Greiner, 2004) from the University of Erfurt's subject pool participated. Participation was credited as course fulfillment.

Procedure. Study 1 was conducted according to the method described introductorily (see 4.3). It was run in June and July 2014 in the Hermann-Ebbinghaus laboratories of the University of Erfurt. Upon arrival participants were welcomed and requested to fill out a consent form. Afterwards they were randomly assigned to one of the four experimental groups and seated in a cabin of the laboratory's PC pool. Initially they were required to read the copy of the instructions located on the desk and then start the experiment according to the instructions. Within the instructions participants were asked to put on the headphones placed on the desk. On the PC the learning phase was already opened in MS PowerPoint. Participants were informed that their aim was to acquire knowledge about the travel dimensions and to be able to reproduce this knowledge in the later decision phase. After learning about each travel dimension on single PowerPoint slides, a test of the learned material followed. Only when all questions had been answered correctly, the next phase of the study was started manually by the experimenter in OpenSesame (Mathôt et al., 2012) in the display format assigned initially (e.g. auditory cues in decision for auditory group). Participants at first learned about the structure of a decision and took three practice trials, followed by 40 measured trials. After finishing the decision phase, the retrieval phase implemented in the online survey tool SoSci Survey (2014) was started manually by the experimenter in Internet Explorer. Participants were asked questions regarding the previously learned travel dimensions and cues that had to be answered by mouse-clicking within a set of answers on each page. On the last page, age and gender were recorded and participants' own travel preferences assessed.

Finally participants returned to the experimenter, were thanked, debriefed and received a certificate for partial course credit.

4.4.2 Results

Preliminary analyses. One dataset was removed as no output had been produced during the decision phase. Another two participants were excluded from the analyses due to a larger error rate than *30* percent in the retrieval phase. The remaining sample consisted of *86* subjects (*74* women, $M_{age} = 22.8$ years).

Main analyses. The distribution of strategy users within the four experimental groups is given in Table 7 and illustrated in Figure 6. In total *54.7* percent of participants could not be classified according to the outcome-based strategy classification method (Bröder & Schiffer, 2003a). One third (*34.9* percent) was found to rely on *comp*, the remaining *10.5* percent were identified as users of *non-comp*. This distribution differs for the four experimental groups. In the pictorial-auditory, auditory and textual groups the highest fraction of participants could not be classified, with a share as high as *76.2* percent in the auditory group. Only the pictorial group exhibits a predominant share of *comp* users (*63.6* percent).

Table 7: Study 1 - Distribution of strategy users in the four experimental groups

Strategy	compensatory	non-compensatory	unclassified	Total
pictorial	14 (63.6)	1 (4.5)	7 (31.8)	22 (100.0)
auditory	3 (14.3)	2 (9.5)	16 (76.2)	21 (100.0)
pictorial-auditory	6 (28.6)	4 (19.0)	11 (52.4)	21 (100.0)
textual	7 (31.8)	2 (9.1)	13 (59.1)	22 (100.0)
Total	30 (34.9)	9 (10.5)	47 (54.7)	86 (100.0)

Note. Numbers depict absolute number of classified participants, percentage of strategy users per experimental condition in parentheses.

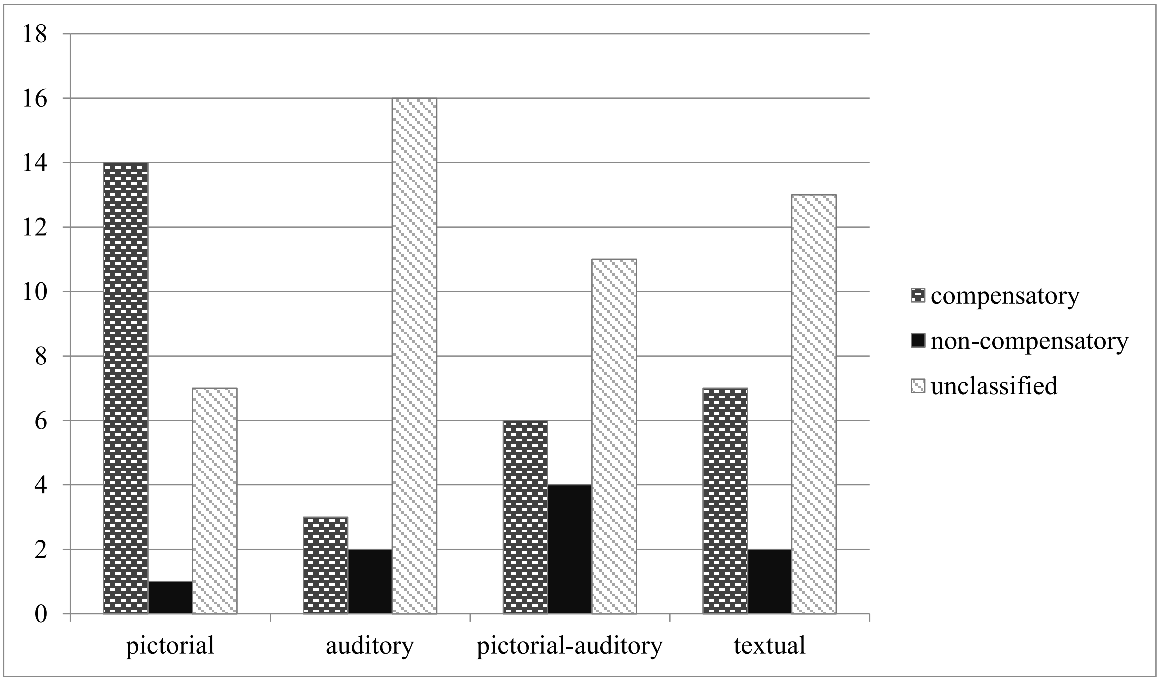

Figure 6: Study 1 - Number of classified participants for the 3 strategies in the four experimental groups

This difference between groups is significant ($p < .05$, Fisher's Exact Test[10], $V_{Cramer} = .29$). The hypothesized difference in strategy use for the auditory and textual group, however, remained non-significant ($p = .28$, Fisher's Exact Test, $V_{Cramer} = .20$).

[10] A chi-square statistic would have been adequate for the given data, but was not applicable, as part of the expected cell values was below the minimum of 5. In the following sections chi-square will be reported whenever possible, otherwise the Fisher's exact test is reported.

Additional Analyses. Participants were instructed to make their choices based on the customer preferences learned. Still it cannot be ruled out that pre-existing preferences biased choice within the decision task. Therefore the match between learned and own preference was calculated for every participant. On average match was *71.76* percent ($SD = 21.75$ percent). In addition it was tested whether this fit was associated with a more precise use of the compensatory strategy. The percentage of preference match did, however, hardly correlate with the error probability for the compensatory strategy ($r = -.08, p = .45$). Thus a high match between the own preferences and the learned customer preferences did not correspond with a more accurate *comp* use.

Group differences are also likely to affect decision times. An analysis of variance did not reveal any decision time differences between the four experimental groups ($F(3) = 1.79, p = .16$) and neither did the Bonferroni-corrected post-hoc test (all *p-values* > *.31*). Also when comparing between the different strategy users no group differences emerge within the ANOVA ($F(2) = .80, p = .45$) or Bonferroni-corrected post-hoc tests (all *p-values* > *.45*). Hence decision times were not considered further within this dissertation.

4.4.3 Discussion

Study 1 was supposed to give a first idea of display format specific differences in decision strategy use. It forms a solid basis for further investigation and a general idea of existent group differences.

The findings do not support any of the four hypotheses addressed within this study strictly, as they all predicted a predominant or even exclusive *comp* use for all four groups. There is however an indication for a less stringent version of hypothesis 2, where an exclusive use of *comp* was predicted for the pictorial group. In this group almost two thirds of participants were identified as *comp* users, which makes this type of strategy predominant at least within the pictorial display mode.

The four experimental groups differ significantly with regards to strategy use, which most likely stems from the deviating distribution of strategy users in the pictorial group. The hypothesized higher share of *comp* users in the textual group as opposed to the auditory group was not supported by the results.

Non-comp was expected to be non-present and only found in a small number of cases. This group may be of low relevance, but is not negligible though.

In study 1 it was also tested whether participants' own preferences interfered with applying a compensatory strategy. In that case, those participants whose preferences strongly deviated from the ones learned in the study were expected to have a higher error probability in applying a compensatory strategy. This idea is not supported by the data. It can be concluded that learning did successfully induce the cue values and made them readily available even for those participants whose own preferences deviated highly.

An additional analysis was conducted to check whether display modality and the strategy used had an impact on the speed of decision making. Such a difference was in fact not found. Neither did any display mode encourage fast choices, nor were participants who used a particular strategy faster. The non-compensatory *TTB* strategy is often referred to as "fast and frugal" and described as especially efficient in decision making (Gigerenzer & Goldstein, 1996). Here, evidence is not in favor of *TTB* being particularly fast. It should be noted though that with only nine participants classified as non-compensatory strategy users, conclusions have to be drawn carefully.

The fact that most participants could not be classified is difficult to interpret. It is possible that the two strategies *comp* and *non-comp* that were tested are not suitable to capture the shown decision behavior adequately. Alternatively, participants may have not decided systematically at all – possibly some were just guessing. Another explanation is that the cue patterns used to assess strategy use (see 4.1.2) were not suited perfectly to discriminate between strategies. Yet the indisputably high share of *comp* users in the pictorial group likely results from the unique features of this type of format and is apparently not random.

It has been discussed earlier that vision and audition mainly differ with regards to the way this information is displayed. Images can be presented holistically thus allowing for a self-directed information acquisition. The auditory display mode was always predetermined in its order, cues had to be retrieved sequentially. Textual and pictorial-auditory display possess some features of both, self-directed and predetermined acquisition. This might explain why these two groups are somewhere in-between the distributions of the pictorial and auditory groups.

If sequentiality led to the small share of *comp* users and large share of unclassified participants in the auditory group, then displaying images as a sequence should trigger the same distribution of strategy users. Study 2 was designed to address this question and will be described in detail in the next section.

4.5 Study 2: Strategy use in sequential and simultaneous pictorial decisions

The aim of the second study was to compare decision making, particularly strategy use, between a group that would see images simultaneously and a second group perceiving them in sequence. This assumption is derived from the group differences in study 1 of this dissertation, but also the core of the format hypothesis introduced by Bröder and Schiffer (2003b). The latter find an increased non-compensatory strategy use in a sequential display modality. As their paradigm has some weaknesses (see 4.1.3) and *non-comp* use is hardly present in study 1, here no increased *non-comp* use is expected. Yet a more frequent use of *comp* is likely in a simultaneous display mode, compared to sequential display.

Hypothesis 7: Displaying cues of an option simultaneously will lead to a higher compensatory strategy use than sequential display mode.

In order to test this hypothesis, study 2 was constructed analogously to study 1 with the comparison of the two pictorial groups.

4.5.1 Method

Design and measures. In study 2 the two groups sequential versus simultaneous pictorial display were compared in a one-factorial between-subjects design. Again the two strategies *comp*, *non-comp* and unclassifiable participants were assessed as dependent measure. As in study 1 groups were compared according to frequencies of strategy use.

Participants. 65 subjects (*58* women, M_{age} = *21.4* years) participated. They were recruited via ORSEE (Greiner, 2004) from the University of Erfurt's subject pool, receiving either 2 Euro or course credit.

Procedure. The second study was run in October 2014 at the University of Erfurt's Hermann-Ebbinghaus laboratories. Participants entering the lab were welcomed and filled out a consent form. Each participant was randomly assigned to either experimental condition and seated in a cabin of the PC pool. They were asked to read the instructions laid out and start with the learning phase on the PC. The learning phase in MS PowerPoint was constructed as described above (see 4.3). As the second study was focused on two versions of pictorial display, all auditory learning elements were removed. Thus the questions within the learning phase only required retrieval of cue values and validities, not sound-image affiliation.

After successful completion of the learning phase, the decision phase was started by the experimenter in OpenSesame (Mathôt et al., 2012). In the simultaneous condition, options where all four cues were given at the same time appeared on the screen for 1500ms, followed by the second option for 1500ms. Both disappeared and two dots, left and right, were presented in exchange. In the sequential condition, each cue of an option was presented separately and subsequently on the screen for 400ms. Between both options an empty screen was presented for 400ms. After all eight cues had been presented, again a screen with a left and right dot was shown and a decision required. The progression of cue display in both conditions is depicted in Figure 7.

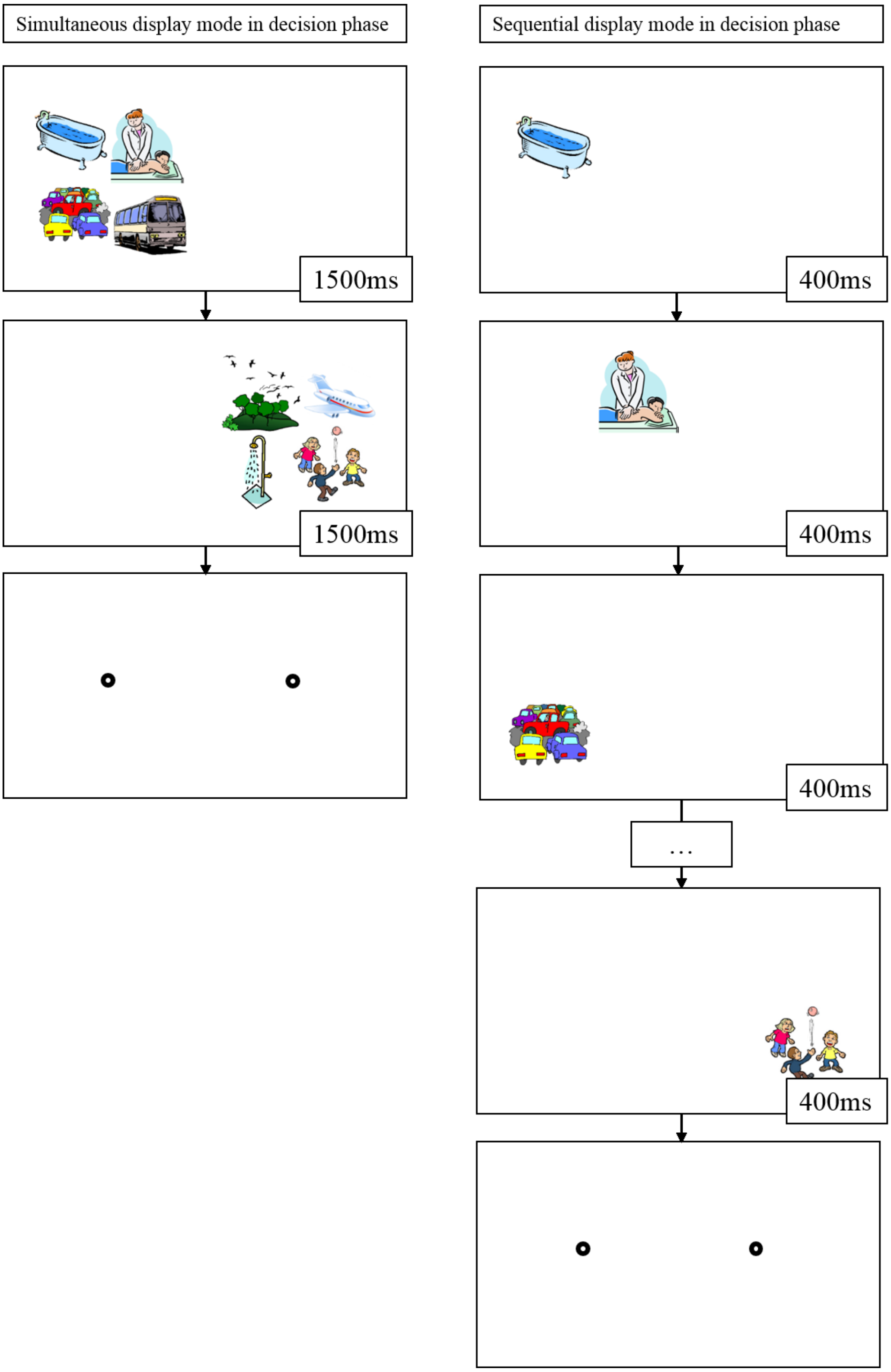

Figure 7: Simultaneous versus sequential display of the decision phase in Study 2

Again the decision phase was initiated with 3 practice trials, followed by 40 measured decisions. After finishing the decision phase, the retrieval phase was started on the PC as described for Study 1 (see 4.4.1). As no sounds had been learned, no questions and measures regarding sound were taken in this phase.

Finally participants returned to the experimenter, were thanked, debriefed and received a certificate for partial course credit or 2 Euro, respectively.

4.5.2 Results

Preliminary analyses. One dataset was removed as the wrong keyboard buttons were used during the decision phase. Another eight participants were excluded from the analyses due to a larger error rate than 30 percent in the retrieval phase. The remaining sample consisted of *56* subjects (*52* women, M_{age} = *21.2* years).

Main analyses. The examination of strategy users in the two experimental groups shows only slight differences (see Table 8 and Figure 8).

Table 8: Study 2 - Distribution of strategy users in the two pictorial groups

Strategy	compensatory	non-compensatory	unclassified	Total
simultaneous	19 (70.4)	1 (3.7)	7 (25.9)	27 (100.0)
sequential	21 (72.4)	3 (10.3)	5 (17.2)	29 (100.0)
Total	40 (71.4)	4 (7.1)	12 (21.4)	56 (100.0)

Note. Numbers depict absolute number of classified participants, percentage of strategy users per experimental condition in parentheses.

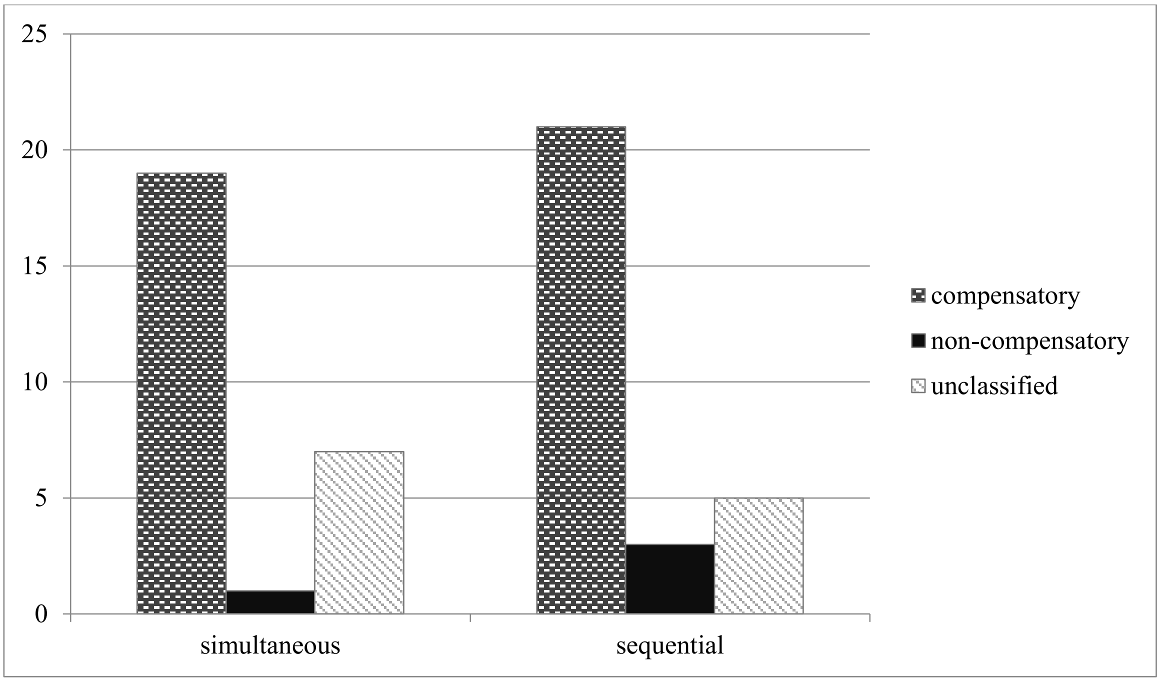

Figure 8: Study 2 - Number of classified participants for the 3 strategies in the two experimental groups

The differences of strategy use in the two groups are not statistically significant ($p = .61$, Fisher's Exact Test, $V_{Cramer} = .15$). In particular it was tested whether the two experimental groups differed with regards to the use of *comp*, which did not turn out to be true ($\chi^2(1) = .03, p = .87$).

Additional analyses. The match between own and learned preference was high ($M = 74.6$ percent, $SD = 20.7$ percent), yet not correlated with the error probability for *comp* ($r = -.04, p = .78$). Thus an own preference in line with the learned customer preference did not make the application of *comp* more precise.

4.5.3 Discussion

In study 2 it was compared whether a simultaneous display format of images enhanced *comp* use as opposed to sequential display. For the simultaneous cue display mode, the results from study 1 could be replicated. Again compensatory use was found in the vast majority of participants and the share of *non-comp* users was almost negligible. Contrary to the expectation that a sequential display would be associated with a lower application of *comp*, this group exhibited an almost identical distribution of strategy users. Particularly the use of *comp* did not differ significantly between the two experimental groups. This finding is very surprising, given that sequential display is expected to hinder holistic processing and therefore compensatory strategy use (Glöckner & Betsch, 2008a). The format hypothesis (Bröder & Schiffer, 2003b) additionally predicts the use of *non-comp* in sequential display modes. This idea is not supported by study 2 at all, as *non-comp* does, again, not play a large role.

Sequentiality cannot account for the group differences from study 1 as expected. The high share of *comp* users in the pictorial group is more likely an effect of this format itself. Compensatory decision making corresponds to the integration of all given information. It appears to be easier to use all decision-relevant information when given as images – for both sequential and simultaneous display. In turn the low share of *comp* users in the other experimental groups indicates that using all information is more effortful to them. According to this idea and the pre-considerations for hypothesis 5, lowering the amount of decision-relevant information should enhance *comp* use in all groups. Particularly, fewer cues are associated with a higher consistency in most cases. This should favor the automatic formation of a consistent mental representation. Even if more effortful deliberate thinking processes are involved, using all decision-relevant information should be easier due to the decreased number of cues.

4.6 Study 3: Display-format-induced differences in strategy use in decisions with reduced complexity

In study 3, the aim was to provide an environment that encouraged compensatory strategy use in all groups. The idea behind this notion is to see whether the expected “default” *comp* use can be found in any display modality, as expected from the unified models of decision making. If particular formats make it virtually impossible to use information in a compensatory manner, it would contradict the predictions of these models and partially falsify them.

As discussed in the hypotheses section (see 3), presenting less decision-relevant information is expected to enhance *comp* use for two reasons: Here, less information will increase consistency within the cue pattern and make it easier to form a consistent mental representation. This process is assumed to be based on effortless automatic processes and may be supported by additional cognitively effortful controlled processes. Even if executive control is guiding the decision process, less information should be integrated more comprehensively. Trivially, less information requires less cognitive resources and in either case more participants should rely on *comp* in any experimental condition, as it becomes easier to consider all information in the decision.

To particularly test hypothesis 5, study 3 was conducted analogously to study 1. Additionally, the first four hypotheses were examined again within this study.

4.6.1 Method

Design and measures. Study 3 was identical to study 1 regarding all variables and design.

Participants. 90 subjects (*79* women, M_{age} = *22.1* years) recruited via ORSEE (Greiner, 2004) from the University of Erfurt's subject pool participated. Participation was credited as course fulfillment or rewarded with 2 Euro.

Procedure. The study was run in November 2014 at the University of Erfurt's Hermann-Ebbinghaus laboratories. The procedure was identical to the procedure described for study 1. The materials were changed in that the least valid cue dimension (type of hotel) was removed in all three phases. This practice did not change the strategy predictions of the cue pattern (see 4.1.2). It did, however, lower the number of cues by 25 percent.

4.6.2 Results

Preliminary analyses. No datasets had to be excluded from the analyses.

Main analyses. The distribution of strategy users, given in Table 8 and illustrated in Figure 9, shows a prevalent use of *comp* in all groups. The total share of *comp* users is *75.6* percent. In this study only *12.2* percent were classified as *non-comp* users or not classified at all, respectively. On the descriptive level, the distributions are very similar for all groups, except the auditory group. In this group only *54.5* percent was identified as *comp* users, while *27.3* percent still remained unclassified.

Table 9: Study 3 - Distribution of strategy users in the four experimental groups

Strategy	compensatory	non-compensatory	unclassified	Total
pictorial	19 (82.6)	3 (13.0)	1 (4.3)	23 (100.0)
auditory	12 (54.5)	4 (18.2)	6 (27.3)	22 (100.0)
pictorial-auditory	19 (82.6)	2 (8.7)	2 (8.7)	23 (100.0)
textual	18 (81.8)	2 (9.1)	2 (9.1)	22 (100.0)
Total	68 (75.6)	11 (12.2)	11 (12.2)	90 (100.0)

Note. Numbers depict absolute number of classified participants, percentage of strategy users per experimental condition in parentheses.

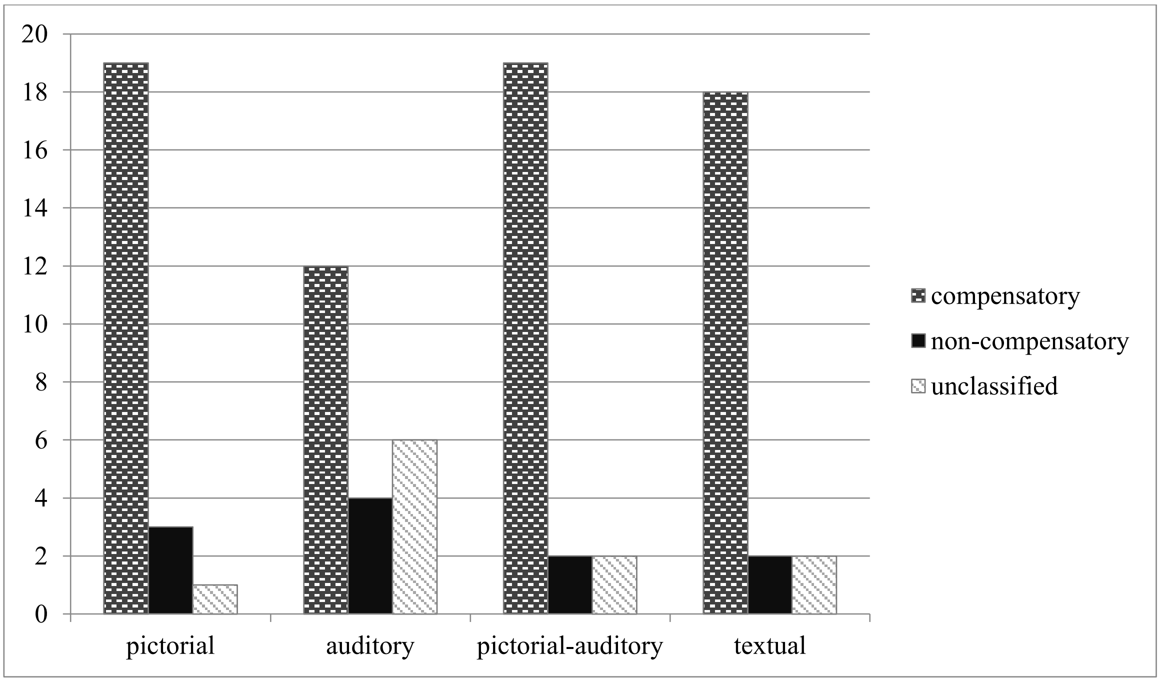

Figure 9: Study 3 - Number of classified participants for the 3 strategies in the four experimental groups

The difference between all groups is not significant ($p = .28$, Fisher's Exact Test, $V_{Cramer} = .22$). When separately testing the auditory group against all other groups though, they do differ significantly ($p < .05$, Fisher's Exact Test, $V_{Cramer} = .30$).

In particular it was again examined whether the use of *comp* was more frequent upon textual display compared to auditory display. The difference between these groups is evident on the descriptive level (*54.5* percent *comp* use in the auditory versus *81.8* percent in the textual group) and marginally significant ($\chi^2(1) = 3.77$ $p = .05$).

Additional analyses. In this study the match between own and learned preference was medium ($M = 55.0$ percent, $SD = 15.5$ percent), but not correlated with the error probability for *comp* ($r = -.04$, $p = .73$). Again it can be concluded that having a preference similar to the learned customer preference did not decrease the error probability for *comp*.

4.6.3 Discussion

In the third study the aim was to evaluate the use of decision strategies in different display formats when information was dropped by 25 percent compared to study 1. It was hypothesized that less information would lead to an increased *comp* use. The share of compensatory strategy users more than doubled from *34.9* percent in study 1 to *75.6* percent in study 3, which indisputably confirms the fifth hypothesis[11]. Even though the pictorial and pictorial-auditory group exhibit the highest share of *comp* users (each *82.6* percent), the hypothesized exclusive use of this strategy in these groups is not confirmed. The results do, however, correspond with the weaker prediction of predominant *comp* use in all groups formulated within hypothesis 1.

The increase in *comp* use from study 1 to study 3 was observable within all groups. This finding is an indicator for the validity of unified models. It is possible to integrate all of the given information compensatorily in any display mode. Even though no conclusions can be drawn on the process level, these findings are generally in line with the idea that decisions are based on effortless automatic processes and supported by controlled processes, if triggered by

[11] Despite the clear evidence on the descriptive level, in addition a statistical test was conducted within the overall analyses (see 4.10).

environmental characteristics, such as decreased consistency or difficult information acquisition. The latter is more likely the more information has to be considered.

When looking at the distribution of strategy users again, the pictorial-auditory and textual group are found to assimilate towards the mere pictorial group. The auditory group however still exhibited a significantly different distribution of strategy users, which manifested itself in a smaller number of *comp* users and higher share of unclassifieds. It becomes apparent that a mentionable share of the auditory group fails to incorporate all information in a compensatory manner within the decision at some point.

From a learning perspective, a fast and partially automatic cue integration is enabled by comprehensive previous learning. It cannot be ruled out that the learning phase prior to the decision phase was not suited equally well for all groups. Within the learning phase each cue dimension with the corresponding cue values and names was presented on a slide. Sounds were acquired self-directedly by clicking a small loudspeaker. The images and names in contrast were visible throughout and thus their exposure duration was longer. Therefore, the responding memory representations may have been corroborated more strongly, resulting in an easier and faster retrieval from memory.

The learning phase also shows another weakness: Validities were presented as numbers. It is unclear, if and how participants used the validity information in their decisions. If validities were not used sufficiently or even ignored, then it could also be explained why there was no use of *non-comp* – which is based on the most valid cue alone.

To rule out these issues, a new learning procedure based upon sampling was constructed. The approach will be outlined within the next section.

4.7 Study 4: Display-format-induced strategy use differences in decisions based on cue sampling

In the fourth study the learning procedure prior to the decision phase was changed markedly. The procedure has been described in detail in section 4.3. In summary, learning was now modality specific. Participants only learned cues in the display format that they would later make decisions in. The chosen approach was based upon sampling. Participants saw a sequence of ten individual customer travel preferences representative of all customers. This procedure had two major advantages: The exposure duration during learning was comparable for all formats. Later differences in information and strategy use during decision making were precluded to result from differences in learning. The second advantage lies in the natural assessment of validities given as absolute frequencies. This representation corresponds more strongly to the way validities are perceived in natural environments (Shah & Oppenheimer, 2009). In consequence these are expected to manifest themselves in memory more effortlessly.

If learning is responsible for the lower share of *comp* users in the auditory group in studies 1 and 3, this difference is expected to disappear with the adaption of the learning phase introduced above.

4.7.1 Method

Design and measures. Study 4 was identical to study 1 regarding all variables and design.

Participants. 107 subjects (*85* women, *1* not specified, $M_{age} = 19.6$ years) recruited via ORSEE (Greiner, 2004) from the University of Erfurt's subject pool participated. Participation was credited as course fulfillment or rewarded with 3 Euro for successful completion of the study.

Procedure. The data were assessed at the Hermann-Ebbinghaus laboratories of the University of Erfurt during November 2015. The procedure was identical to the procedure stated for study 1 (see 4.4.1). Differences arose regarding the learning phase. Participants in the auditory and pictorial-auditory group were asked to wear headphones. After reading the instructions, the learning phase was started. On the introductory screen additional instructions and the four cue dimensions along with the two possible values[12] were named. Then a practice trial started. As described in 4.3, participants were now given the name of a cue dimension in the center of the screen, followed by ten customer preferences, which were varied randomly in order. A customer preference consisted of one of the two cue values of the respective cue dimension. The number of repetitions per value corresponded to the cue validity. For the cue dimension bathroom equipment with a validity of 0.8 for instance, the cue value bathtub was presented in 8 and the cue value shower in 2 trials.

In the pictorial condition, each customer preference was given subsequently as an image in the center of the screen with the corresponding name denoted below. In the textual condition only the respective name was displayed and accompanied by the corresponding sound in the auditory condition. In the pictorial-auditory condition, cue values were presented

[12] On this introductory slide no information regarding the evaluation or validity of cue values was given.

with image, sound and text. After each preference sequence, participants chose the value they had seen more frequently. Then the sequence was shown again and participants subsequently guessed in what percentage of trials this value predominated. This procedure was repeated four times per cue dimension.

On a final screen, the number of correct guesses regarding percentage was displayed in a table. The number of correct responses was controlled by the experimenter instantly and not recorded or saved into a data file. Only when at least 70 percent of the answers had been correct, a participant was allowed to continue to the next phase.

The decision phase was again analogous to study 1 (see 4.4.1), with options in the decision phase including four cues per option.

The retrieval phase was implemented in SoSci Survey (2014). This time participants' own preference was not assessed as it turned out to not influence *comp* application in the preceding studies. As participants did not learn cues in all display formats, as before, the retrieval phase was kept general and did not include images or sounds, only textual descriptions and names of the cues. They saw the name of each cue dimension on a page and choose which of the two cue values was preferred by most customers, followed by indicating the share of customers showing this preference. Then they were asked about their age and gender. After completion, participants returned to the experimenter, were rewarded, thanked and dismissed.

4.7.2 Results

Preliminary analyses. All participants made at least 75 percent correct guesses in the learning phase. Seven datasets were removed as the wrong keyboard buttons were used during the decision phase. Another eight participants were excluded from the analyses due to a larger error rate than 30 percent in the retrieval phase. A sample of *92* subjects (*72* women, *1* not specified, $M_{age} = 19.2$ years) remained.

Main analyses. The highest fraction of participants (*48.9* percent) could not be classified, followed by a similar share classified as *comp* users (*45.7* percent). On the descriptive level, the pictorial group stands out with a share of *91.3* percent *comp* users. In the other groups unclassifieds form the largest groups with a share as high as *90.5* percent in the auditory group. Distributions are depicted in Table 10 and Figure 10.

Table 10: Study 4 - Distribution of strategy users in the four experimental groups

Strategy	compensatory	non-compensatory	unclassified	Total
pictorial	21 (91.3)	1 (4.3)	1 (4.3)	23 (100.0)
auditory	1 (4.8)	1 (4.8)	19 (90.5)	21 (100.0)
pictorial-auditory	10 (43.5)	1 (4.3)	12 (52.2)	23 (100.0)
textual	10 (40.0)	2 (8.0)	13 (52.0)	25 (100.0)
Total	42 (45.7)	5 (5.4)	45 (48.9)	92 (100.0)

Note. Numbers depict absolute number of classified participants, percentage of strategy users per experimental condition in parentheses.

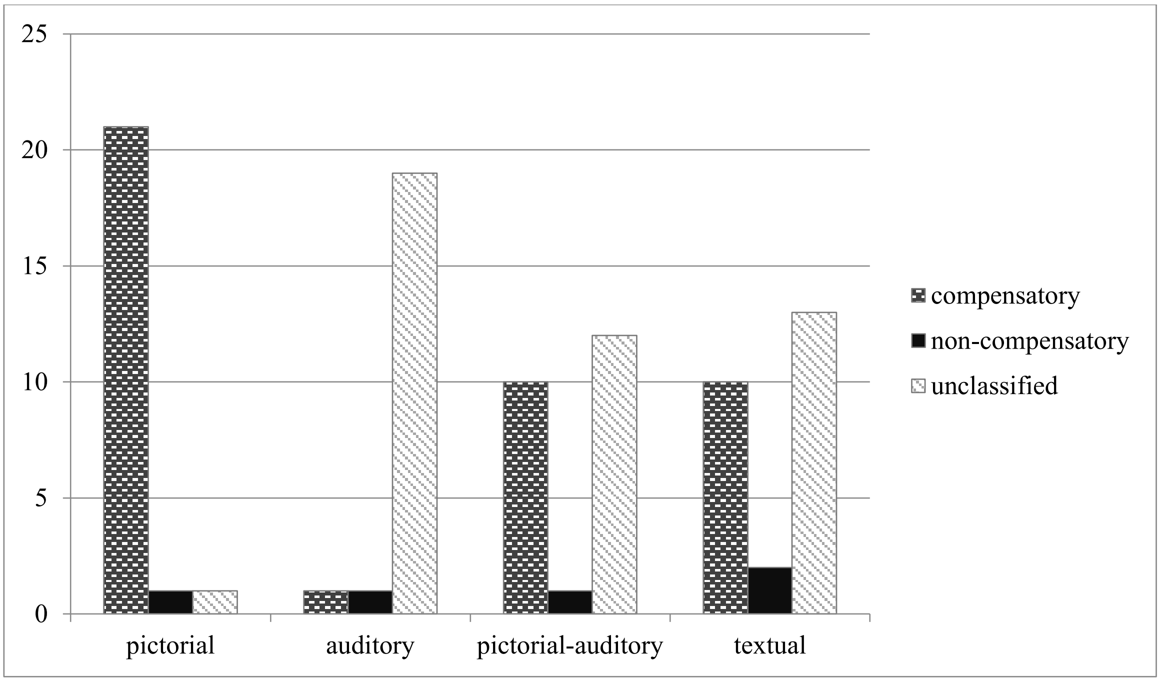

Figure 10: Study 4 - Number of classified participants for the 3 strategies in the four experimental groups

The difference between these groups is significant ($p < .001$, Fisher's Exact Test, $V_{Cramer} = .44$).

4.7.3 Discussion

In study 4 it was assessed whether learning by frequency sampling assimilated the distribution of strategy users in the auditory group to all other groups. It was expected that this type of learning enabled all groups to make their decisions comparably, due to its naturalistic character.

The results are somewhat surprising, as the share of *comp* users increased markedly for the pictorial group from study 1 (*63.6* percent) to study 4 (*91.3* percent), but decreased for the auditory group (from *14.3* percent to *4.8* percent). Small improvements also appeared for the pictorial-auditory and textual groups, which still inherit an even larger number of unclassifiable individuals. Apparently, the auditory group – expected to assimilate to the other groups – was the only one that did not benefit from the adapted learning paradigm.

From a learning perspective and the connectionist approach, incoming information in line with existing knowledge structures should consolidate connections in the network. Sampling in particular is thought of as *"linear summation"* and *"evidence-accumulation"* (Newell & Bröder, 2008, p. 199). Shah and Oppenheimer (2009, p. 235) particularly point out that *"cue values can be more accessible during cue production if they stem from natural assessments [...]"*. This notion is supported by studies showing that base rates are captured more accurately by a sampling approach than verbal descriptions (Gigerenzer, Hell & Blank, 1988).

In the multimodal approach presented in this fourth study, however, sampling does not improve the use of statistical information in all formats. It is assumed that sampling enables a better representation of validities and cue values in memory for any format. This improved representation should favor the use of a compensatory strategy. In fact, this finding only turns out to be true only for a pictorial presentation mode and marginally for textual and pictorial-auditory display. The use of *comp* even seems to decrease when the decision-relevant information has been acquired by sampling.

The distribution of strategy users remains mainly consistent with study 1. This difference of sampling versus self-directed learning is tested empirically in the overall analyses (see 4.10). From the descriptive statistics alone it can already be concluded that the expected assimilation of the four experimental groups upon frequency sampling is not present.

Neither, sequentiality (see Study 2, section 4.5) nor issues with the learning procedure are found to explain the notable differences in strategy use, particularly between the pictorial and auditory group. Decreasing the amount of information relevant to the decision does, however, lead to an assimilation (see Study 3, section 4.6). The latter finding is to some degree trivial, as less information needs less cognitive resources and is likely to result in more consistent cue patterns. Glöckner and Betsch (2012), however, demonstrate in their research article *“Decisions beyond boundaries: When more information is processed faster than less”* that fast comprehensive decision making can also result from cue patterns that may be more extensive, yet high in consistency. Based on this idea the cue patterns used in studies 1 to 4 of this dissertation were adapted to enhance compensatory strategy use by increased consistency.

By generating new cue patterns, a methodological weakness of the first four studies could also be diminished. Out of the four presented cue patterns, only one pattern (25 percent of trials) differentiated between *comp* and *non-comp*. Classifying participants according to these two strategies could be improved by providing a larger number of differentiating cue patterns.

The consideration of structural properties of a decision to explain the auditory group’s large share of unclassified participants and small share of classified *comp* users alone does not suffice to explain group differences. If cue patterns alone were responsible for the distribution of strategy users in the auditory group, then all groups should exhibit this distribution.

Group differences need to be explained differently. One possible explanation lies in the amount of information perceived and encoded by an individual. This amount may differ in-between different types of display. When using encoding as potential explanation, the focus shifts away from information integration – the cognitive process following encoding. In the pictorial condition it is illustrated that most participants are able to make compensatory decisions and integrate eight cues. There is no reason to question the auditory group’s ability to integrate all cue information – if it is readily available during the decision due to being encoded in advance. With this in mind, it was additionally examined within studies 5 and 6 whether the four display groups were able to encode and correctly report all cues of an option.

4.8 Study 5: Display-format-induced differences in decision strategy use – Replication and cue pattern modification

The objective of study 5 was to validate the results of the studies 1 and 4 by replication with varied cue patterns. Cue patterns were adapted and newly developed to suffice two aims:

- Increasing consistency
- Better distinction of *comp* and *non-comp*

The consistency, sometimes called coherence, in cue patterns is specified here as the relative distance of two options' utilities, with a higher consistency indicating a greater distance and thus stronger evidence in favor of the option with the higher utility. Basically this notion relates to how much more preferable an option is among others and the resulting ease by which the best option – according to rational choice – can be identified.

For the old and new cue patterns, which are depicted in Table 4 and Table 5, this distance was calculated by calculating each option's utility and determining the distance between utilities. This distance was considered the consistency of this particular cue pattern. Consistency was also assessed in total for the patterns used within the first four studies and the newly adjusted pattern. The exact values and calculations are reported in Attachment C: Calculation of consistency within the cue pattern.

The new cue patterns show a higher consistency. In sum, the adapted cue pattern inherit a consistency of 92, compared to 58[13] in the earlier cue patterns. According to hypothesis 6, a higher consistency in cue patterns allows to identify the better option (the rational solution) more easily and should lead to a higher share of *comp* users.

The second aim was to provide cue patterns that allow for a more straightforward classification of the two strategies *comp* and *non-comp*. In the first version of cue patterns (see Table 4), only one out of four cue patterns differentiated between the strategies, which corresponds to 25 percent of trials. The newly adapted cue patterns (see Table 5) inherited two differentiating patterns, which were presented in 75 percent of trials. Thus the new series of cue patterns enabled an improved classification of *comp* and *non-comp*. From this improvement a higher share of classifiable strategy users is expected, enabling to reconsider the research hypotheses 1 to 4 (see 3).

As noted in the above section (see 4.7.3), in study 5 the issue of encoding was addressed in addition. It was particularly assessed how much of the available cues of an option could be reported correctly immediately after exposure.

4.8.1 Method

Design and measures. The design of study 5 was kept identical to study 1 with regards to variables and design, as it was intended to replicate this introductory study. Additionally, for six options it was measured how much of the given information had been encoded, by assessing the absolute number and percentage of correctly reported cues per option.

[13] These numbers are somewhat arbitrary as they do not have a particular unit. Thus they can only be interpreted with regards to their odds and do not provide much information when considered in isolation.

Participants. In total *100* subjects (*76* women, *2* not specified, $M_{age} = 20.0$ years) recruited via ORSEE (Greiner, 2004) from the University of Erfurt's subject pool participated in the study. Participation was credited as course fulfillment or granted with 4 Euro for successful completion of the study.

Procedure. The data collection took place at the Hermann-Ebbinghaus laboratories of the University of Erfurt in May of 2016. After entering the lab, participants were welcomed and asked to sign a consent form. Then they were randomly assigned to one of the four experimental conditions, guided to a cabin including a PC workplace and informed to read the instructions laying on the desk. Then they could start the learning phase self-directly at the PC. The learning phase introduced in study 4 (see 4.7.1) and described in section 4.3 was shown in the respective display format. After finishing the learning phase, the experimenter checked whether at least 70 percent of the learning trials had been answered correctly. This information was not saved. Participants not meeting this criterion were dismissed from the study. If the learning phase had been completed successfully, the first of two phases of the encoding test was started, implemented in OpenSesame (Mathôt et al., 2012) and presented in the display format according to experimental condition. Participants were informed that they were going to see and/or hear a series of vacation trips, constructed of the learned attributes, as they would appear later within the decisions. Initially a practice trial was given. A fixation dot was presented in the center of the screen for 1000ms, followed by a single option with four cues for 2000ms. Then a screen appeared asking them to write down all attributes they could remember on a sheet of paper. This was repeated for three measured trials. Then the decision phase was introduced and progressed as in the previous studies (see 4.3) with the newly implemented cue patterns. After the decision phase had been completed, the second phase of the encoding test started and again three different vacation trips (single options) were presented sequentially and participants were asked to write down all attributes they remembered.

In study 5 the retrieval phase was implemented in paper-pencil format. On a sheet of paper, participants were given the four travel dimensions and asked which of the two cue values per option had been preferred by most customers and to choose the corresponding percentage.

After completing all three stages, participants returned to the experimenter, were debriefed and thanked, and received a certificate for partial course credit or 4 Euro, respectively.

4.8.2 Results

Preliminary analyses. All participants made at least 75 percent correct guesses in the learning phase. Two datasets were removed as participants had used the wrong keyboard buttons during the decision phase. Ten participants were excluded from the analyses due to a larger error rate than 30 percent in the retrieval phase. The remaining sample consisted of *88* subjects (*67* women, *1* not specified, $M_{age} = 19.6$ years) valid samples.

Main analyses. The distribution of strategy users in the four experimental groups exhibits a predominant use of *comp* in all groups. In total *73.9* percent of participants were identified as *comp* users with the highest share in the pictorial group (*81.8* percent) and the lowest in the auditory group (*57.1* percent).

Table 11: Study 5 - Distribution of strategy users in the four experimental groups

Strategy	compensatory	non-compensatory	unclassified	Total
pictorial	18 (81.8)	0 (0.0)	4 (18.2)	22 (100.0)
auditory	12 (57.1)	3 (14.3)	6 (28.6)	21 (100.0)
pictorial-auditory	16 (80.0)	0 (0.0)	4 (20.0)	20 (100.0)
textual	19 (76.0)	2 (8.0)	4 (16.0)	25 (100.0)
Total	65 (73.9)	5 (5.7)	18 (20.5)	88 (100.0)

Note. Numbers depict absolute number of classified participants, percentage of strategy users per experimental condition in parentheses.

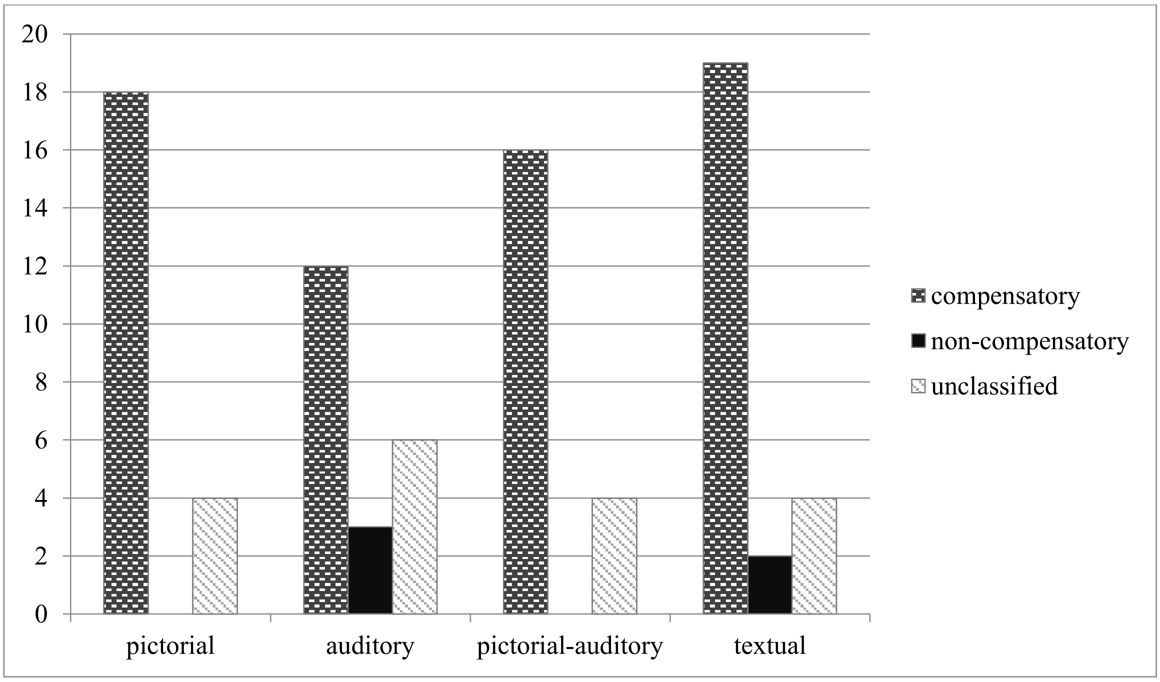

Figure 11: Study 5 - Number of classified participants for the 3 strategies in the four experimental groups

The remaining difference between the groups is not significant ($p = .34$, Fisher's Exact Test, $V_{Cramer} = .21$). The auditory group differs marginally with regards to strategy distribution ($p = .05$, Fisher's Exact Test, $V_{Cramer} = .21$).

In study 5, the expected higher share of *comp* users in the textual group compared to the auditory group was present on the descriptive level (*76.0* versus *57.1* percent), but the difference was not statistically significant ($\chi^2(1) = 1.85, p = .17$).

Additional analyses. Within study 5 it was checked whether the amount of cues encoded within an option were different between the four experimental conditions, which turned out to be true. The mean percentages of correctly identified cues of the three trials prior to and after the decision and in total are given in Table 12. In Figure 12, the absolute number of correctly reported cues in the four experimental conditions is depicted, split into the number of cues reported pre- and post-decisional.

Table 12: Mean percentage of correctly encoded cues in encoding test in study 5

Correctly remembered cues	Pre-decisional	Post-decisional	Total
pictorial	88.7 (11.2)	97.0 (6.0)	92.8 (7.3)
auditory	76.6 (23.3)	75.5 (19.7)	76.0 (20.8)
pictorial-auditory	95.9 (6.9)	96.0 (6.3)	95.8 (6.0)
textual	94.7 (10.7)	96.4 (10.5)	95.5 (10.3)
Average	89.1 (16.0)	91.5 (14.8)	90.2 (14.7)

Note. Numbers represent the mean percentage of correctly identified cues before and after the decision phase and in total. Standard deviation is given in parentheses.

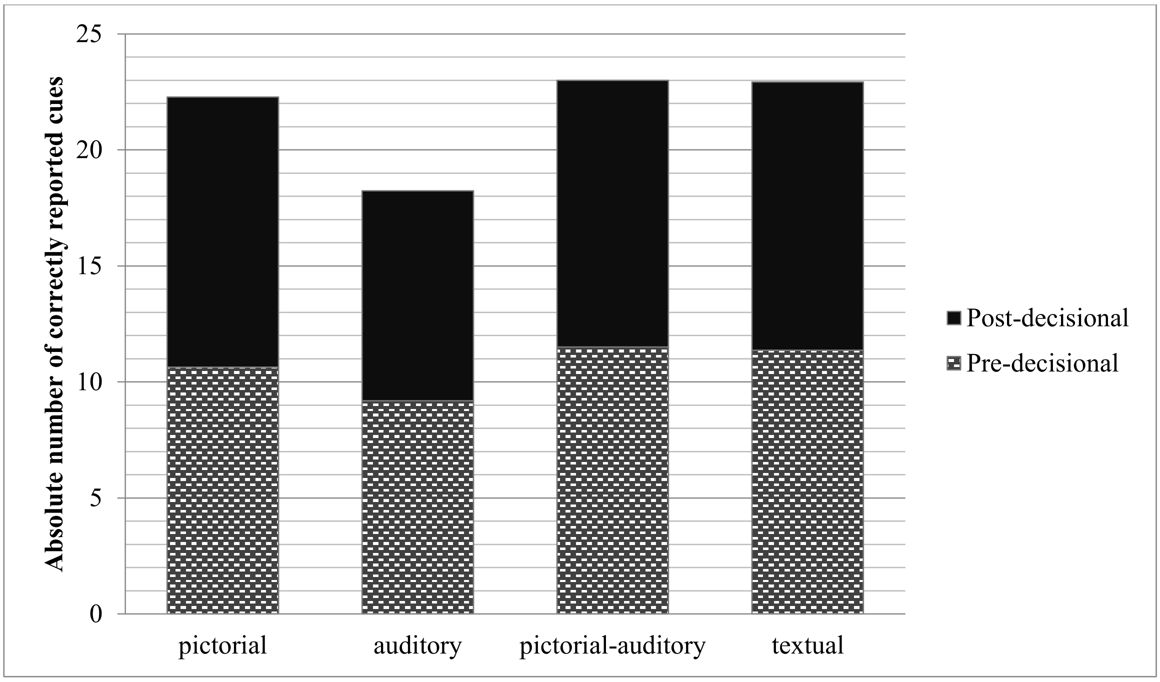

Figure 12: Number of correctly reported cues in the encoding phase of study 5

Note. The total number of presented cues was 12 before and 12 after the decision phase, resulting in a maximum of 24 cues that could be reported correctly in total.

Participants in all groups performed well and were able to correctly report *90.2* percent of the presented cues correctly. This proportion was substantially lower for the auditory group, who correctly reported only *76.0* percent. This difference is significant ($t(22.0)=-4.03, p <.01$).

The number of correctly reported cues was also significantly higher after the decision phase than prior to the decision ($t(87)=-2.39, p < .05$). This effect manifested itself in the descriptive statistics only slightly though (*89.1* percent prior and *91.5* percent after).

It was also found that the number of correctly encoded cues showed a medium correlation to the use of *comp* ($r = .30, p < .01$) and even correlated highly with *comp* use in the auditory group ($r = 0.48, p < .05$). How many cues had been encoded and reported correctly was apparently linked to the use of all cues in the decision in a compensatory manner.

4.8.3 Discussion

With the adapted cue pattern proving a higher consistency and a better classifiabilty of *comp* and *non-comp,* the share of not classifiable participants decreased substantially from *54.7* percent in study 1 and *48.9* percent in study 4 to *20.5* percent in this fifth study. As the decisions were identical in their appearance and only the underlying structure changed, this finding is likely due to the new cue patterns. These can be considered an improvement of the experimental method, as they allow to distinguish between *comp* and *non-comp* more clearly. Yet the results are likely to stem also from the increased consistency. In how far the improved classifiability and higher consistency contribute individually to the results cannot be disentangled here though. In so far hypothesis 6, predicting an increase in *comp* users upon higher consistency in cue patterns, can only partially be validated. The statistical test of the different types of cue patterns is reported in the overall analyses (see 4.10).

The evidence completely supports hypothesis 1, as a predominant *comp* use is found in all groups. Yet the more strict hypotheses 2 and 3, predicting exclusive *comp* use in the pictorial and pictorial auditory conditions, are not confirmed. According to the fourth hypothesis, textual display should be associated with a higher *comp* use than auditory display. This difference was only found on the descriptive level and not statistically significant. As the auditory group had the lowest share of *comp* users in all studies so far, it is evident though that these differences are robust and not coincidental.

In the theoretical introduction of this dissertation (see 2.2) a clear point was made that decision making is based upon effortless automatic processes and only supported by effortful conscious thinking if a consistent mental representation cannot be formed easily. The ease by which such a mental representation can be formed was improved within this fifth study and participants do rely on the extensive compensatory strategy more often. Hereby it can be concluded that it was easier for participants to identify the best option according to all cue values. When pursuing this idea according to the *PCS* perspective (Glöckner & Betsch, 2008a) and unified models of decision making (e.g. Lee and Cummins, 2004), this can be considered indicative of participants partially relying on automatic processes. Effortful controlled processes – which can only capture part of the available information – did probably play a smaller role in study 5 than in the first studies, because of the increased consistency.

In the fifth study, a crucial source of the intergroup differences, which are stable over all studies, was identified: Differences in encoding. These are found to be linked to the use of *comp.* All groups performed very well and were able to correctly report most of the cues of an option presented immediately before. However, the auditory group performed significantly worse, being able to report *76.0* percent of cues compared to *94.7* percent on average in the other groups. This is still an impressive number, but is also likely to explain this group's smaller share of *comp* users. The reason for the lower percentage of encoded cues in the auditory condition is an issue to discussion (see 5.2). It may result from both properties of the given auditory cues and properties of hearing itself.

Interestingly the pictorial-auditory group did perform extremely well and did not show any shortcomings in encoding the vast majority of cues. As they had to encode 50 percent less auditory cues, the amount of auditory information that can be encoded within a short time frame seems to play an important role. In study 3 (see 4.6) it has already been demonstrated that the auditory group assimilated towards the other groups when the number of cues per option was decreased from four to three.

In the sixth study, reported below (see 4.9), the three-cue-per-option version of the study was replicated with both the adapted cue pattern introduced in study 5 (see 4.1.2 and 4.8.1) and the modified learning phase introduced in study 4 (see 4.7.1).

The aim was to validate the results of the preceding studies and to examine the applicability of the three-cue version of the adapted cue pattern from study 5.

4.9 Study 6: Display-format-induced differences in strategy use in decisions with reduced complexity – Replication and cue pattern modification

In the fifth study of this dissertation (see 4.8), different features of the paradigm introduced initially (see 4.3) were re-combined to validate the hypotheses formulated initially, cross-validate results (see 3) and to replicate the preceding studies. This goal was extended in the sixth study for the three-cue version of the study.

According to hypothesis 5, reducing less decision-relevant information should result in a larger number of *comp* users. This hypothesis was supported by the data from study 3 (see 4.6) and shall be validated with this sixth study. In this study, again, the least valid cue was removed from the cue patterns. The resulting patterns allow for a better differentiation between *comp* and *non-comp* as 75 percent of decision trials allow to discriminate the strategies, as opposed to 25 percent in study 3. Removing the least valid cue does not change the consistency within the new cue pattern (see Attachment C: Calculation of consistency within the cue pattern); it remains at 92. For the cue patterns used within the first four studies, however, removing the least valid cue leads to an increase in consistency from 58 to 100. Thus the results from study 3 which were explained by the decrease in decision-relevant information, according to hypothesis 5, may alternatively stem from increased consistency and not be explained by the amount of information at all. Within this sixth study this can be ruled out, because the consistency in the three-cue version is identical to the consistency in the four-cue version for the adapted cue patterns.

In addition it can be assessed more safely how large the impact of the improved classifiability due to adapted cue pattern is. In study 5 is was not possible to disentangle the impact of classifiability and consistency on strategy use. In study 6 the consistency is lower than in study 3 (92 versus 100, respectively), but the classifiability has increased from 25 to 75 percent. If the share of *comp* users is larger in study 6 than in study 3, then this difference should result from classifiability and not consistency, as the consistency is not higher.

4.9.1 Method

Design and measures. Study 6 was a reproduction of study 5 with a lowered number of cues. Design and variables were – as in study 5 – identical to study 1.

Again it was measured additionally how much of the cues of six given options was encoded – both the absolute number and the relative percentage.

Participants. 93 subjects (*77* women, M_{age} = *22.6* years) from the University of Erfurt's subject pool recruited via ORSEE (Greiner, 2004) participated in the study. Participants received either a certificate for course fulfillment or 4 Euro for taking part in the study.

Procedure. Study 6 was conducted subsequently to study 5 at the Hermann-Ebbinghaus laboratories of the University of Erfurt in May 2016. It was structurally identical to study 5. As the least valid cue dimension (type of hotel) was dismissed, it did not appear in any part of the study. Thus all phases were slightly shorter and less extensive.

4.9.2 Results

Preliminary analyses. One dataset was removed as the wrong keyboard buttons were used during the decision phase. Eleven participants were excluded from the analyses due to a larger error rate than 30 percent in the retrieval phase. The remaining sample consisted of *81* subjects (*68* women, $M_{age} = 22.3$ years).

Main analyses. In the distribution of strategy users a drop to *6.2* percent non-classifiable participants was observed. *7.4* percent were identified as users of *non-comp*, whereas *86.4* percent were classified as *comp* users. The groups are highly assimilated and show only slight differences on the descriptive level. The auditory group has a visibly smaller share of *comp* users (*75.0* percent).

Table 13: Study 6 - Distribution of strategy users in the four experimental groups

Strategy	compensatory	non-compensatory	unclassified	Total
pictorial	18 (90.0)	2 (10.0)	0 (0.0)	20 (100.0)
auditory	15 (75.0)	3 (15.0)	2 (10.0)	20 (100.0)
pictorial-auditory	18 (85.7)	1 (4.8)	2 (9.5)	21 (100.0)
textual	19 (95.0)	0 (0.0)	1 (5.0)	20 (100.0)
Total	70 (86.4)	6 (7.4)	5 (6.2)	81 (100.0)

Note. Numbers depict absolute number of classified participants, percentage of strategy users per experimental condition in parentheses.

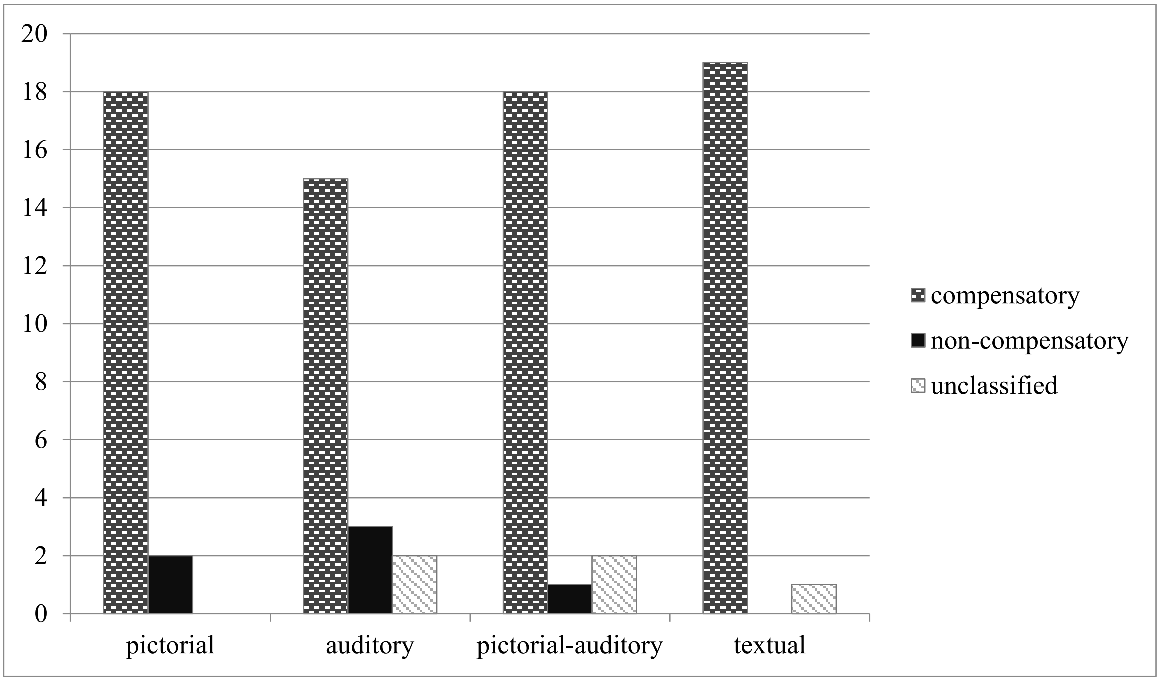

Figure 13: Study 6 - Number of classified participants for the 3 strategies in the four experimental groups

Neither is the difference between the experimental groups statistically significant ($p = .41$, Fisher's Exact Test, $V_{Cramer} = .19$), nor does the auditory group differ significantly from the other groups ($p = .12$, Fisher's Exact Test, $V_{Cramer} = .20$).

As in the previous studies *comp* was not exclusive in either the pictorial or the pictorial-auditory group. Also the difference in *comp* use between the textual and auditory group was not of statistical significance ($\chi^2(1) = 3.14, p = .08$).

Additional analyses. In study 6 the performance in reporting the cues presented during the encoding test was extremely good. Compared to study 5 the maximum of cues that were to be retrieved dropped from 24 to 18, as the six presented options now only consisted of three cues each.

In total *96.2* percent of cue values were reported correctly. Percentages of correctly reported cues are denoted in Table 14 and the absolute numbers are depicted graphically in Figure 15.

Table 14: Mean percentage of correctly encoded cues in encoding test in study 6

Correctly remembered cues	Pre-decisional	Post-decisional	Total
pictorial	98.4 (4.0)	98.9 (4.9)	98.6 (3.1)
auditory	85.7 (15.6)	89.5 (18.2)	87.5 (14.4)
pictorial-auditory	98.4 (5.3)	99.0 (3.3)	98.7 (3.9)
textual	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)
Average	95.7 (10.0)	96.9 (10.3)	96.2 (9.0)

Note. Numbers represent the mean percentage of correctly identified cues before and after the decision phase and in total. Standard deviation is given in parentheses.

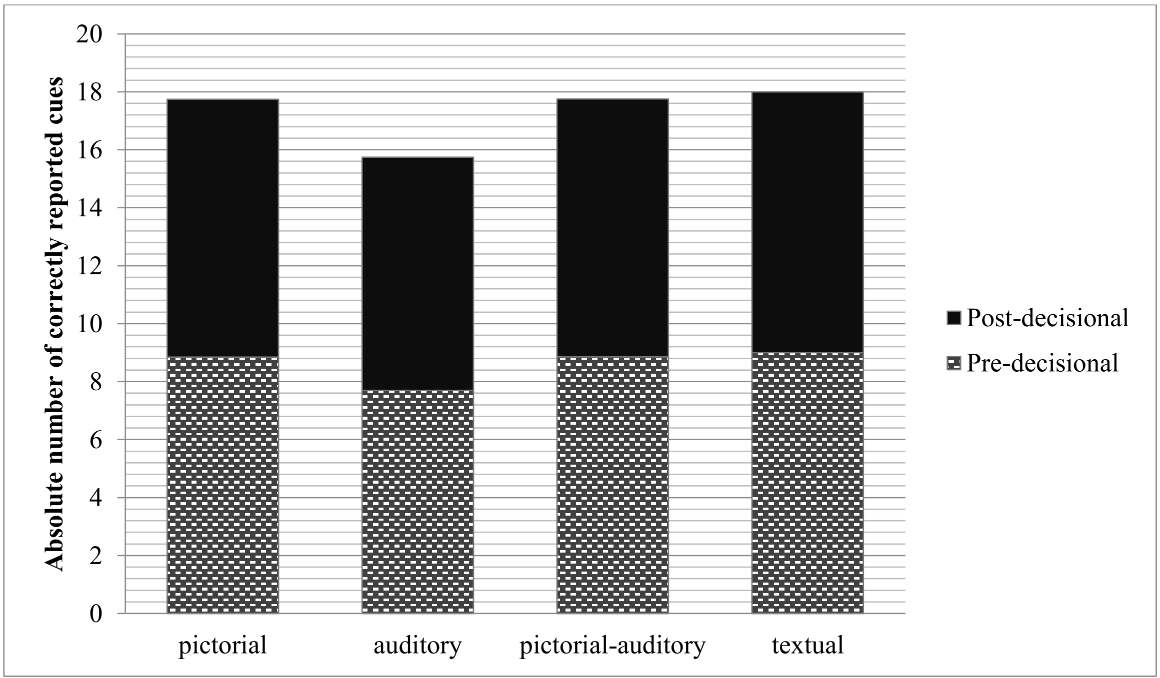

Figure 14: Number of correctly reported cues in the encoding phase of study 6

Note. The total number of presented cues was 9 before and 9 after the decision phase, resulting in a maximum of 18 cues that could be reported correctly in total.

Again the auditory group performed significantly worse ($t(19.51) = -3.57, p < .01$). The number of correct reports before and after the decision phase did not differ ($t(80) = -1.14, p = .26$). The use of *comp* is found to correlate with the number of cues that have been reported correctly ($r = .30, p < .01$).

4.9.3 Discussion

With this sixth study the results of the previous studies could be validated and different influencing factors could be disentangled on the descriptive level.

The influence of the increased classifiability can now be estimated more accurately. In study 6, *6.2* percent of participants could not be classified, as opposed to *12.2* percent in study 3. So the increase of classifiability induced by the new cue patterns from 25 to 75 percent decreased the share of non-classifiable participants by 50 percent. Thus the increased classifiability likely accounts for the larger share of classified users and particularly the larger share of classified *comp* users, which rose from *75.6* percent in study 3 to *86.4* percent in study 6.

It could additionally be demonstrated on the descriptive level that dropping the number of relevant cues by 25 percent increased the share of *comp* users from *73.9* percent in study 5 to *86.4* percent in study 6 – despite the unchanged consistency. This finding corresponds to hypothesis 5 and demonstrates that the rise in *comp* use in study 3 compared to study 1 is not explained by increasing consistency alone. Providing more consistent cue patterns is, however, likely to partially account for the increase in *comp* use from study 1 to study 3. Here the observed rise was from *34.9* to *75.6* percent – a difference of *40.7* percent. The increase from study 5 to study 6, where consistency remained identical, was only *12.5* percent. At least the descriptive data is in favor of hypothesis 6, predicting a higher *comp* use for more consistent cue patterns.

In study 6 participants did extremely well in the encoding test in the three-cue-per-option version, with almost perfect report of all cues in the pictorial and auditory-pictorial conditions. In the textual group de facto all participants were able to report all cues correctly. This group had the advantage that the target format was identical to the perceived format: They saw the cue names on the screen and were to write these down, while the other groups saw sound and/or images and had to transfer them into written words. However, this task was again more difficult for participants in the auditory group, who, again, performed significantly worse. This finding confirms results from study 5 and compensatory strategy use seems highly connected to the number of encoded information, which is also implied by the notable correlation between these two.

In the next section overall analyses of the studies 1, 3, 4, 5, and 6[14] are reported. Aggregating the data provides two major advantages: Due to the enhanced sample size the statistical power increases and provides more tenable conclusions, especially regarding the hypotheses of this dissertation. It is also possible to statistically examine effects of influencing factors that were varied between the studies and could only be discussed on the descriptive level so far.

[14] Study 2 was not subject to analysis, as it did not include a comparison of the four display modalities pictorial, auditory, auditory-visual and textual.

4.10 Overall analyses

For the overall analyses the data from studies 1, 3, 4, 5 and 6 were aggregated into one data file. This allowed to retest hypotheses over all participants. The advantage of an increased sample size is a rise in statistical power, associated with a larger probability of detecting effects that are actually present in the population. In addition this procedure allows for interstudy comparisons, which could only be reported on the descriptive level in the studies presented above. Concretely the overall analyses were carried out on two levels:

(1) Theoretical level

Retest hypotheses with increased statistical power.

(2) Methodological level

Analyze the groups with regards to differences in

a. Cue learning versus cue sampling

b. Classifiability

4.10.1 Sample and distribution

The aggregated sample consisted of *437* subjects (*360* women, *4* not specified, M_{age} = *21.1* years), collected in the first, third, fourth, fifth and sixth studies reported in this dissertation. The aggregated distribution of strategy users is illustrated in Table 14 and Figure 15. In addition the mean errors ε for the application of the two strategies *comp* and *non-comp* are provided in Attachment D: Erroneous strategy application within the studies

Table 15: Distribution of strategy users in the four experimental groups aggregated for studies 1, 3, 4, 5, 6

Strategy	compensatory	non-compensatory	unclassified	Total
pictorial	90 (81.8)	7 (6.4)	13 (11.8)	110 (100.0)
auditory	43 (41.0)	13 (12.4)	49 (44.6)	105 (100.0)
pictorial-auditory	69 (63.9)	8 (7.4)	31 (28.7)	108 (100.0)
textual	73 (64.0)	8 (7.0)	33 (29.0)	114 (100.0)
Total	275 (62.9)	36 (8.2)	126 (28.8)	437 (100.0)

Note. Numbers depict absolute number of classified participants, percentage of strategy users per experimental condition in parentheses.

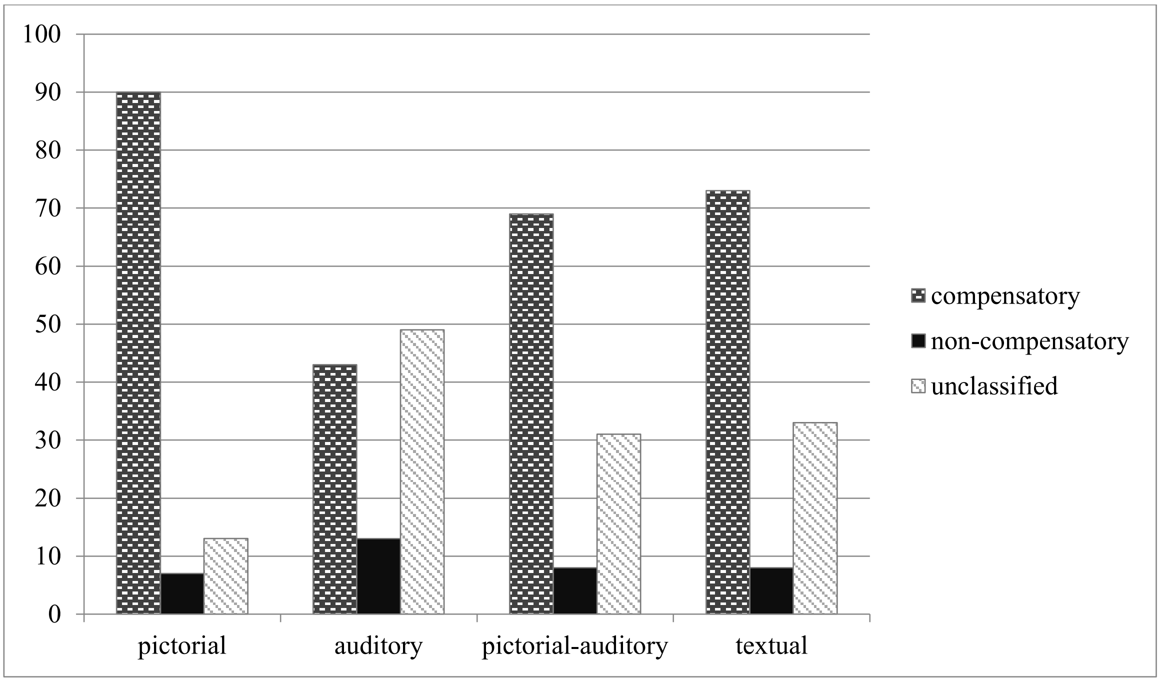

Figure 15: Number of classified participants for the 3 strategies in the four experimental groups aggregated for studies 1, 3, 4, 5, 6

The groups differ significantly regarding this distribution ($\chi^2(6) = 39.9, p < .001$, $V_{Cramer} = .21$).

4.10.2 Theoretical level

The first hypothesis of a predominant *comp* use regardless of display modality is supported by the total percentage of *comp* users over all groups (*62.9* percent). It is, however, partially limited, as the auditory group shows a higher share of not classified participants (*44.6* percent) than *comp* users (*41.0* percent).

The extension of hypothesis 1 – *non-comp* use is not expected under any condition – does not hold. A percentage of 8.2 percent of all subjects was found to use this strategy.

The second and third hypothesis predicted, that *comp* would be the only strategy applied when decisions were presented pictorially or pictorially-auditory. The strict version of this hypothesis is not confirmed, as not all subjects in these experimental conditions were found to use *comp*. *Comp* is, however, predominantly found in these groups with a share of 81.8 percent in the pictorial and *63.9* percent in the pictorial-auditory group.

The fourth hypothesis contrasted the auditory and the textual group. In particular it was expected that the textual group would exhibit a larger share of *comp* users than the auditory group, which is covered by the data. In the auditory group *41.0* percent *comp* users could be classified, as opposed to *64.0* percent in the textual group. This difference is significant ($\chi^2(1) = 11.69, p < .01$) and completely in favor of hypothesis 4.

In the fifth hypothesis a higher share of *comp* users was predicted for a decreased number of cues. To examine this prediction, the share of *comp* users for studies 1, 4, and 5 were contrasted with studies 3 and 6. The latter presented participants with 3 cues per option, while all of the former included 4 cues per option.

Figure 16 impressively demonstrates the rise in *comp* use from *51.5* percent in the 4-cue versions to *80.7* percent in the 3-cue versions. This difference is statistically significant ($\chi^2(1) = 38.04, p < .001$) and provides strong support for this hypothesis.

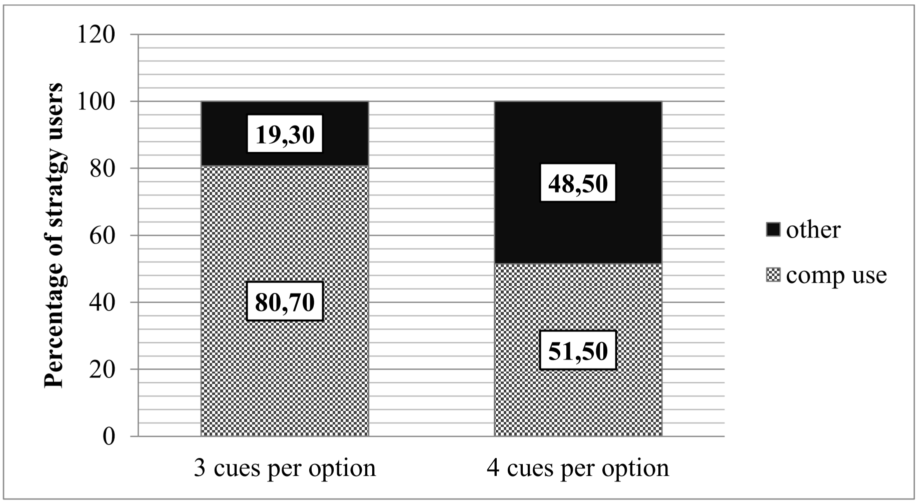

Figure 16: Percentage of *comp* users in the 3-cue and 4-cue study versions

Finally with hypothesis 6 the expectation was formulated that a rise in consistency would increase *comp* use. For each dataset the consistency in the cue patterns underlying the decision was assigned and the correlation of *comp* use and consistency was assessed. As calculated in Attachment C: Calculation of consistency within the cue pattern, the cue patterns used within the studies 1 and 4 had a consistency of 58, the consistency for patterns of study 3 was 100, and 92 in studies 5 and 6.

With increasing consistency a higher share of *comp* use was observed ($r = .38, p <.001$).

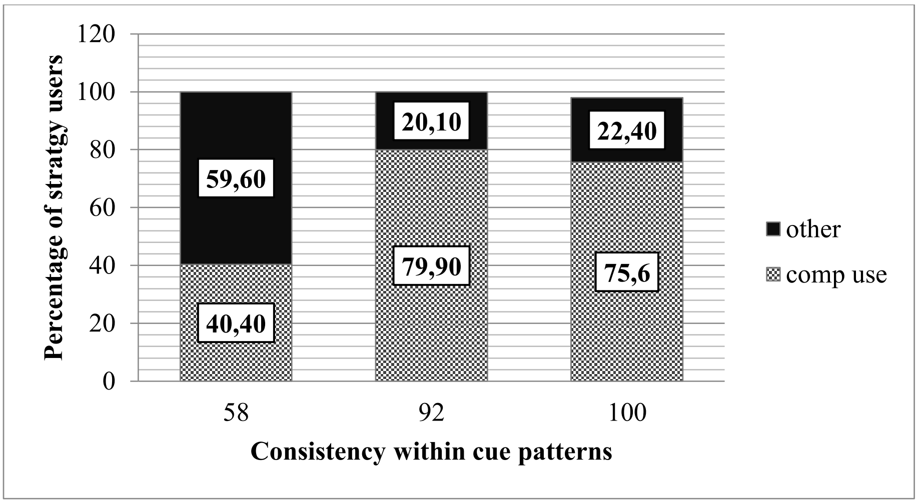

Figure 17: Percentage of *comp* users in relation to the consistency of cue patterns

It is apparent in Figure 17 that with an increasing consistency the share of *comp* users increases. This increase does not appear to be linear here, as *comp* use is slightly less in the group with the highest consistency of 100 compared to the group with a consistency of 92. It should be noted, though, that only cue patterns in study 3 had a consistency of 100 and studies 5 and 6 had a consistency of 92. As these studies differ substantially on several matters, including learning procedure and classifiability by cue patterns, the above finding should be interpreted carefully.

At this point multivariate analyses would be appropriate, but are not applicable to the categorical data presented here. At the same time this dissertation can only provide hints to the large set of influences of the strategy use exhibited under different display modalities and is by no means intended to be exhaustive.

Yet this overall analysis allows to draw a clearer picture of the tested hypotheses, which were partially constrained and partially supported. Aggregating the data from all studies – excluding study 2 – additionally provides the opportunity to make interstudy comparisons concerning methodological adaption. These are reported in the next section (see 4.10.3).

4.10.3 Methodological level

In the studies reported above, two major adaptions in the experimental method were made. These included a change in the learning procedure and a change in cue patterns, increasing the classifiability of *comp* and *non-comp*.

The learning procedure was initially based on the self-paced acquisition of explicitly displayed cue values and validities. In the fourth study a sampling based learning approach was introduced, which was kept for the subsequent studies 5 and 6. The effect of the learning procedure is difficult to assess as studies 5 and 6 additionally differ to the preceding studies with regards to classifiability, and the influence of learning alone cannot be estimated safely. Thus only studies 1 and 4 were compared regarding strategy use. Both were identical in their structure and only differed with regards to the learning phase. However, no difference in strategy use between these studies – and thus between the two learning procedures – can be observed ($\chi^2(2) = 2.99, p = .23$).

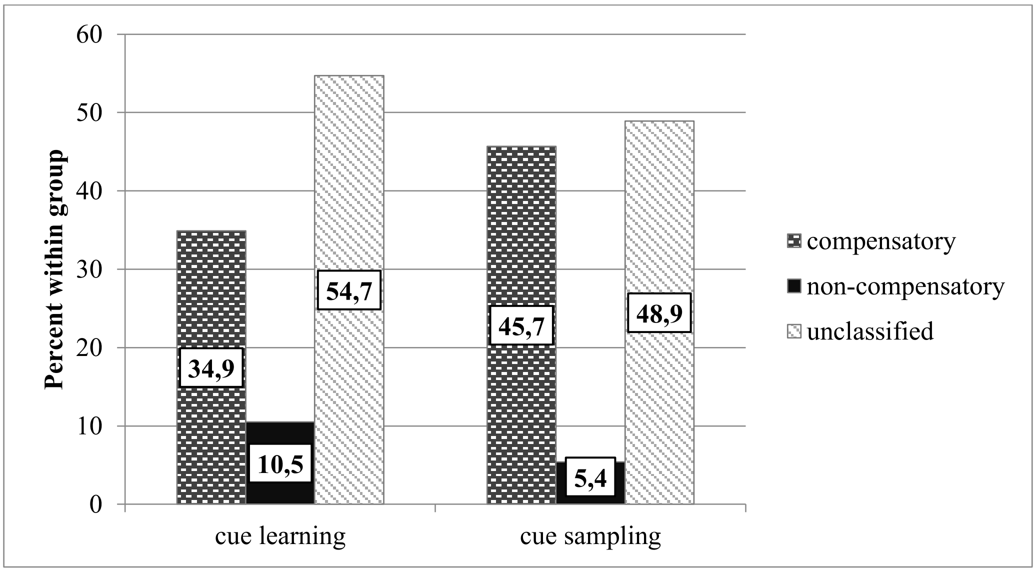

Figure 18: Percentage of strategy users in study 1 (cue learning) versus study 4 (cue sampling)

A second methodological adaption was the change in cue patterns for studies 5 and 6, which increased classifiability between *comp* and *non-comp* from 25 to 75 percent. To test whether this change in classifiability actually led to a change in the share of classified participants, strategy use was compared between studies 1, 3, and 4 versus studies 5 and 6[15].

The share of classified and unclassified users for the studies with low classifiability (studies 1, 3 and 4) are contrasted to the share in the studies with high classifiability (studies 5 and 6) in Figure 19.

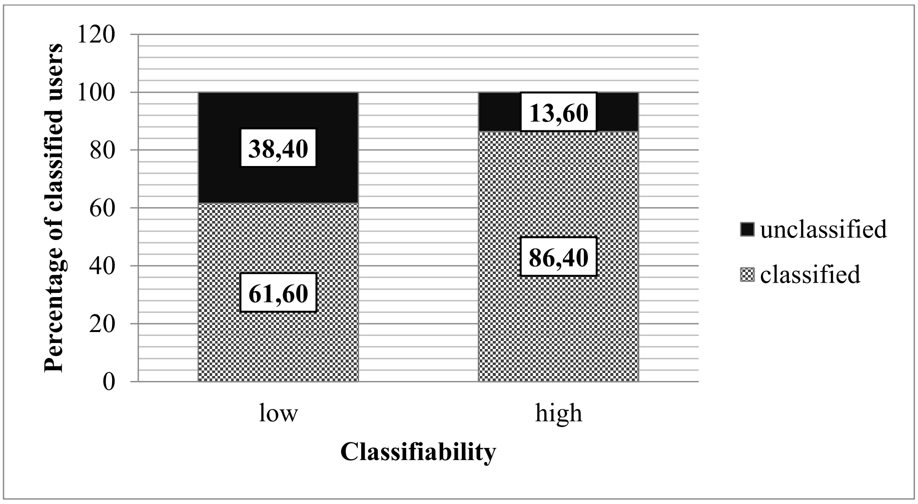

Figure 19: Percentage of classified users when classifiability was low versus high

On the descriptive level the difference is apparent. The general classifiability has increased from *61.6* to *86.4* percent, a difference that is statistically significant ($\chi^2(1) = 31.12$, $p < .001$). In line with the increased classifiability the percentage of classified *comp* users has increased from *52.2* to *79.9* percent ($\chi^2(1) = 33.95$, $p < .001$).

[15] Studies 1 and 3 are in addition different to studies 5 and 6 regarding the learning procedure, which may also account for differences. A difference between the two learning approaches was, however, not found, as reported above, and is therefore unlikely to interfere with the examination of classifiability.

With these analyses it can be demonstrated that the identified proportion of strategy users is somewhat sensitive to the structure of the decision, but not to the learning phase. Contrary to the expectations formulated above (see 4.7), cue sampling did not provide a better learning base than merely presenting cue values and validities. Presenting decisions according to highly strategy-differentiating cue patterns, however, significantly impacts the number of classified participants. As the number of participants that could not be classified within the first four studies was relatively high, the adapted cue patterns from studies 5 and 6 provide a more appropriate basis for assessing strategy use.

5 Discussion

5.1 Summary

Within this dissertation the objective was pursued, to identify differences in decision making within six studies, when decision-relevant information was presented as texts, images, sounds or a mixture of the latter. Decision making was examined in terms of strategy use. An outcome-based measure (Bröder & Schiffer, 2003a) helped to identify whether all available information was used in a compensatory manner (*comp*), whether only the most important information was utilized non-compensatorily (*non-comp*) or whether decision making did not follow this systematics (unclassified). From a theoretical perspective the application of *comp* was to be expected predominantly. It was argued that most decision making is based upon effortless automatic processes and only supported by capacity-limited controlled processes under some circumstances. Automatic processes allow to consider a multitude of information in a compensatory manner with ease (Glöckner & Betsch, 2003b; Lee & Cummins, 2004). *Comp* use was found as the predominant decision strategy, with differences between the four experimental groups. It always dominated in the pictorial display mode and stayed unaffected when pictorial cues were presented in a sequence as opposed to a simultaneous display. At the same time, presenting decision-relevant cues auditorily as sounds led to a lower number of *comp* users. Often the decision strategy in that group could not be identified. The pictorial-auditory and textual groups always stayed in-between the two extreme groups pictorial and auditory.

However, external factors largely influenced how strategy use was distributed between and within groups. Simplifying decisions by lowering the number of relevant cues and structuring decisions more consistently in favor of a dominant option enhanced compensatory strategy use. Yet the auditory group always exhibited a visibly smaller share of *comp* users.

This result is most likely explained by the finding that this group was found to encode and report significantly less cues per option.

Table 16: Overview over the studies 1 to 6

Study	N	Objectives	Central findings
1	86	Examining the use of a compensatory versus non-compensatory decision strategy in binary decisions based upon pictorial, auditory, pictorial-auditory and textual display	Compensatory strategy use is predominant when decisions are presented pictorially; participants in all other groups remained largely unclassified
2	56	Comparison of decision strategy use in pictorial decisions where the single cues of an option are displayed sequentially or simultaneously	No differences between a simultaneous and sequential pictorial cue display; compensatory strategy use is predominant in both groups
3	90	Reproduction of study 1 with decreased number of cues of 75 percent	Compensatory strategy use is predominant in all groups, but significantly smaller in auditory group
4	92	Reproduction of study 1 with an altered learning phase; learning was changed from self-directed learning of cue values and validities to cue sampling	The altered learning phase does not change the distribution of strategy users within and between groups
5	88	Reproduction of study 1 with adapted cue pattern that enhanced classifiability of the strategies and consistency; Additionally it was assessed how many cues of a single option were reported correctly	Compensatory strategy use is predominant in all groups, but significantly smaller in auditory group
6	81	Reproduction of study 5 with decreased number of cues of 75 percent	Compensatory strategy use is predominant in all groups; group differences are not significant
∑	493		

The non-compensatory strategy use, which was also addressed in the six studies of this dissertation, was found in very few cases. For the scenario presented herein it does not seem to play a major role – a finding that is in line with the theoretical reasoning presented in the introduction.

The objectives and central findings of each of the six studies are illustrated in Table 16.

With the six studies presented in this dissertation it could be demonstrated that decision makers are highly efficient in using the information provided in a compensatory manner. While the pictorial presentation of decision-relevant information favors the use of *comp*, an auditory display is found to hinder it.

The experimental paradigm introduced to derive these conclusions is novel and was constructed elaborately for the studies. It stands out particularly with its learning phase prior to the decision phase for several reasons. With the learning phase cue values and validities could be induced and were available from memory during the decision phase. Decisions were presented in the four different formats pictorial, auditory, pictorial-auditory and textual, but structured according to cue patterns. Cue patterns inherit information about cue values and validities which is normally expressed in a symbolic or textual format. It cannot readily be transferred to a pictorial or auditory format. Therefore an approach was chosen where this information was learned before decisions were made and retrieved from memory during the decision.

With this approach limitations of earlier studies (Bröder & Schiffer, 2003b; Jahn et al., 2007) can be overcome. In these studies complete options were learned in a pictorial or textual format and validities were disclosed immediately before a decision was made. It can be argued that this approach is somewhat artificial, as information is normally stored in memory together with evaluation criteria. Humans are able to match incoming information, e.g. particular options, to these categories (Newell & Bröder, 2008). In the studies of this dissertation the latter notion was implemented by letting participants learn the relevant cue dimensions, their weight and the cue values along with their evaluation. Weight and evaluations of cues were not chosen arbitrarily, but pretested to be in line with the preferences exhibited by the majority of people.

The learning phase was altered over the course of the studies from a self-directed learning to a sampling approach. In fact, both forms of learning were suited equally well to allow participants to form memory representations of the presented cue dimensions. Another methodological adaption was the alteration of cue patterns, to allow for a better differentiation and classification of the compensatory and non-compensatory strategy. This turned out to increase the general number of classified users – mostly in favor of a *comp* classification. By gradually improving the experimental methodology over the course of the studies, factors influencing the strategy use within and between the groups could be identified. At the same time central findings were replicated and conclusions can be drawn straightforwardly.

5.2 General Discussion

The studies reported and summarized above enable to draw conclusions regarding the addressed research hypotheses (see 3). The dominance of the compensatory strategy is repeatedly shown. Hypothesis 1b made the strong claim that non-compensatory strategy use would not be observed. *Non-comp* was hardly present yet not absent, which contradicts the strict version of this hypothesis. The same is true for hypotheses 2 and 3. The expected exclusive *comp* use in the pictorial and pictorial-auditory group was empirically impaired by *non-comp* users and unclassified participants. A weaker version of the hypothesis could, however, be confirmed as the majority of participants in these groups were identified as *comp* users. The reported data were supportive of hypothesis 4, a larger share of *comp* users was observed in the textual group, as compared to the auditory group. Hypotheses 5 and 6 are also supported by the data, both lowering the number of decision-relevant cues and increasing the consistency within cue patterns increased *comp* use. A seventh hypothesis was derived from the results of study 1. It was expected that a holistic display of cues would enhance *comp* use compared to a sequential display mode. This hypothesis, which was tested by comparing groups deciding upon images displayed sequentially or simultaneously, does not hold. The groups did not differ.

The main question left after six studies is why the auditory group persistently inherits a smaller share of *comp* users. From the theoretical derivation of the hypotheses (see 3) it makes sense that this group is inferior. There were arguments to conclude an exclusive *comp* use in the pictorial group and the pictorial-auditory group. The argumentation also led to the expectation that the textual group would show a larger number of *comp* users than the auditory group. Thus the auditory group having the smallest *comp* share is not surprising. It was demonstrated in the studies that this group encoded and reported the fewest cues from an option presented separately.

It is subject to discussion if the lower reproducibility is a result of the materials used in these studies or an actual disadvantage of the auditory modality. Working memory could be discussed as a potential source for the differences, but is unlikely to account for them. Two different working memory components – the *visual-spatial sketchpad* and the *phonological loop* (Baddely, 1992) – are proposed for visual and auditory input. Textual information, however, is coded phonologically as well. This group had an outstanding performance with regards to reproducibility. As both textual and auditory display are coded phonologically, they should profit from the same capacities and show a similar reproduction rate. As this is not the case, it is not expected that differences in visual and auditory working memory explain the findings[16].

The lower reproduction rate in the auditory group is likely to result from a higher difficulty in encoding. This implies that participants may have been able to reproduce all cues of an option, but only if they had encoded these. This explanation also makes sense when focusing on the auditory-visual group: This group only needed to encode half as many auditory cues and performed as well as the pictorial and textual group – despite the simultaneous encoding and report of visual stimuli. It can be concluded cautiously that the reproducibility for auditory cues drops somewhere between two and three cues and is hardly affected by pictorial cues presented at the same time.

Differences may also stem from the materials themselves. The pictorial and textual representation formats were probably more familiar to participants in this specific setting. The auditory display format is somewhat artificial in comparison. Using sounds in the way presented in this dissertation is a rather atypical scenario for routinized decision makers. How familiar a decision scenario is, does in fact largely impact how "fluently" information is processed, as noted by Shah and Oppenheimer (2009, p.233):

[16] The Cowan model of working memory introduced earlier (see 2.1) does not postulate different systems for visual and auditory memory at all. Rather it proposes modality specific memory representations that can be currently activated and accessed by executive control. Therefore the different stores for vision and audition proposed by Baddeley may not be adequate to describe the processing of these different types of information in general.

> *"However, decision environments can still make some cues more fluent, or easier to process, than others. Fluency often increases when information is presented in familiar ways. That is, cues can be processed less effortfully to the extent that they have been seen before or are similar to cues encountered previously."*

In conclusion, visual information – pictorial information in particular – may provide a more familiar basis for making decisions and enable comprehensive and effortless decision making. While the "difficulties" of the auditory group are a subject to discussion, the consistently high number of compensatory strategy users in the pictorial group was less surprising and in line with the hypotheses introduced earlier.

Next to the consideration of encoding and fluency, two related but different approaches may also serve as explanation for the "superiority" of images. Bröder and Schiffer (2003b) assumed that the internal representation format of images allows for simultaneous feature matching mechanisms, operating in an automatic and parallel fashion. Therefore more information can be processed at a time than in sequential processing styles. This idea may be accurate when images are presented holistically as integrated images or retrieved from memory simultaneously. In this dissertation it is also demonstrated that a sequential image presentation (thus retrieval) of options' cues leads to the same distribution of strategy users. The "superiority" of images apparently also persists outside of an internal or external holistic representation. It is possible that images are constructed or integrated into one holistic representation even when retrieved sequentially. Alternatively a more general mechanism may make it easier to encode, store (*picture superiority*, see Paivio et al., 1968) and possibly process pictorial information. Such a mechanism might in turn build the basis for an increased fluency.

Dijksterhuis and Nordgren (2006) state:

> *"The entire human system combined, [...] can process about 11,200,000 bits per second. The visual system alone processes about 10 million bits per second."*

If this is true, it would provide further evidence for the assumption that visual processing is more powerful than audition.

While the two extreme groups with pictorial and auditory display have very robust distributions over all studies, it is difficult to draw a clear picture for the textual and pictorial-auditory group. The latter profits from two different channels of perception, which enable to encode more input at the same time. From the encoding test in studies 5 and 6 it can be told that participants of this group were able to report almost all presented cues correctly. The same goes for the textual group. In the first and fourth study, both groups had a far smaller share of *comp* users than the pictorial group. This difference vanished when the number of cues was lowered and the cue patterns were adapted.

Above, the assumption was formulated that the reproducibility for auditory cues decreased at two to three cues. This conclusion was drawn from data where one option had to be reported. In the decisions given within the decision phases of the six studies of this dissertation, however, two options were presented before a choice was required. The number of cues that had to be encoded, remembered and integrated into the decision was twice as much. The pictorial-auditory group was presented with a total four auditory cues in the 4-cue-per-option scenarios and on average three auditory cues in the 3-cue-per-option version. The share of *comp* users in the pictorial-auditory group was smallest in studies 1 and 4 – both studies incorporating 4 auditory cues per decision and providing low consistency and classifiability within the cue patterns. This result is well explained by the idea that encoding and reproducibility of auditory cues drops at three cues. *Comp* use for the pictorial-auditory group was highest in the studies where the total number of auditory cues per decision ranged from two to four, studies 3 and 6.

The textual group always showed a similar distribution of strategy users as the pictorial-auditory group. These two display modes are very different in nature, but have a common feature: Both possess elements of visual perception and auditory encoding. Text is perceived by the eye and coded phonologically. As perception itself is not auditory, it is not affected in reproducibility. The textual group showed the best performance in reporting all cues of separately displayed options. Still this group showed a lower percentage of *comp* users in studies 1 and 4. One explanation for the high fraction of *comp* users in the pictorial group is the possibility to integrate single images into a holistic percept, a consistent mental representation. If images particularly favor this process, then it will likely be restrained in textual display. In that case textual display may allow for encoding and reporting all cues with a high accuracy, but make it more difficult to integrate all available information into a consistent mental representation – in decisions, for instance.

An idea which has been discussed repeatedly throughout this dissertation is the role of automatic and controlled processes in decision making. Examining these processes was no central aim. Yet they served to derive research hypotheses and are able to partially account for the findings. In particular it is demonstrated that *comp* is more frequent, the easier a consistent mental representation can be formed – for instance by lowering the number of cues of increasing consistency. This finding is in line with models of decision making that presume that decisions are made automatically and are only supported by controlled construction processes when a consistent mental representation cannot be built easily (Glöckner & Betsch, 2008b; Horstmann et al., 2009; Lee & Cummins, 2004).

Bröder and Schiffer (2003b, p. 287) describe compensatory decision making as "*[...] some kind of default option [...]*". They particularly point out that high information costs trigger the use of non-compensatory strategies. This idea is supported by studies from Bröder (2000a), who finds an increased use of the non-compensatory *TTB* heuristic when monetary cost for information retrieval is high. Information search in memory is also considered a potential cost (Gigerenzer & Goldstein, 1996; Gigerenzer & Todd, 1999). The latter idea is not completely in line with approaches to memory and cost from cognitive psychology. Researchers widely agree that declarative knowledge is effortful to collect and retrieve, while procedural knowledge operates automatically without effort (for an overview, see Brocas & Carrillo, 2016).

In the studies presented in this dissertation, cue values and validities had to be retrieved from memory, which did not seem to trigger non-compensatory strategy use at all. In the scenario presented here it was particularly difficult to apply such a heuristic. The two options of a decision were never present at the same time, which made a cue-wise comparison tricky. Decisions were also never displayed in a way that allowed to identify the most valid cue from the given cues. Cues were not displayed according to validity and validity was not presented within decisions. Thus validities were only memory-based. As it is assumed that validities are intuitively used as weights within memory, this weighting should need little effort. Thus there is no argument for not weighting and integrating all cues. In fact applying a non-compensatory strategy would require executive control, as participants would have to actively search for the most valid cue during option display.

Apparently the environment presented within the studies of this dissertation did not promote non-compensatory strategy use. Participants always tended to use compensatory strategies. Thus there is support for the idea of automaticity playing a major role in decision making, supported by controlled and effortful processes when triggered by environmental factors.

Another subject for discussion is how cues from different modalities are integrated jointly to build a consistent mental representation and arrive at a decision. The formation of such representations on a neural basis is a matter of the so-called *binding problem* (Holocombe, 2009; Treisman, 1996). The binding of multiple sources of input to one consistent mental representation was particularly interesting to observe in the pictorial-auditory group. These had an enormous advantage, as they profited from two different perceptual channels and possibly two different working memory systems (Baddeley & Hitch, 1974), thus possessing an increased short-term memory span (Frick, 1984). This group should have been able to integrate and process the most information with ease (Ernst & Bülthoff, 2004). As this was not the case in all studies, it can be concluded that the resources necessary to integrate all decision-relevant information were not lacking on the level of perception or memory, but with regards to the central executive (Bonnel & Hafter, 1998). The central executive can only attend to a limited number of stimuli at a time (Cowan, 1995; Gallun, Mason, & Kidd, 2007). This notion supports the idea that controlled processes did support automatic processes in the reported studies, which also explains why *comp* use was not always predominant.

By conducting and analyzing six studies, the findings presented within this dissertation can be considered very robust and reliable. Changes in the experimental methodology were carried out to increase validity and generalizability. Still only a limited range of multimodal decision making can be captured by the paradigm presented here. In the next section potential limitations of the studies are highlighted and discussed.

5.3 Limitations

The studies reported in this dissertation were designed and constructed carefully to provide a high validity and reliability. Still some properties of the experimental procedure need to be addressed critically.

The outcome-based strategy classification method from Bröder and Schiffer (2003a) forms a solid basis to assess strategy use in decisions. Yet it does come up with some shortcomings that have been discussed by other researchers earlier. Moshagen and Hilbig (2011) criticize this method with regards to neglecting global model fit and treating error as random, thus leaving systematic error unconsidered. It is also pointed out that selecting particular strategies to classify is somewhat random and may not include the strategy that was actually used. In addition, the outcome-based strategy classification method is unable to detect changes in strategy use during the experiment, as classification is conducted over all trials. The outcome-based method is very sensitive to the concrete ideas and implementations of the researcher. This problem becomes evident in the reported studies of this dissertation. The number of classified users, *comp* users in particular, rose significantly when cue pattern were adapted to be more discriminative – despite everything else being identical. This finding is important and highlights the limitations of the outcome-based strategy classification method. Yet the intergroup differences found in the six studies are robust and unlikely to result from the limitations of this classification method.

The implementation of the outcome-based strategy classification method in this dissertation was chosen to be very general. No distinction was made between an *Equal Weight* and *Weighted Additive* strategy. Here the focus was put on the amount of information to be considered in general, so compensatory strategies were not differentiated according to the use of validities. Validity, however, provides important additional information in decision making and it cannot be inferred from *comp* use alone, whether validity was considered or not. From the tests after learning and within the retrieval phase of the studies, it can be concluded safely that validities were learned and remembered correctly. No answer can be given regarding the integration within decisions. If validity information was ignored, then this would also explain the relatively small numbers of *non-comp* users. Jahn et al. (2007) found participants to neglect validities in image-based decisions to which they attribute their low share of *TTB* users upon pictorial display. At the same time implementing validities in auditory or pictorial decisions is rather difficult, as they are expressed in a numerical format. An attempt to induce validities by sampling in study 4 was not superior to the mere numerical display. Yet it provides an alternative way of inducing validity. This approach could be picked up in future studies.

A more global problem of the studies in this dissertation is the external validity. The experimental procedure is artificial and restricted to some degree. An advantage of experimental studies is the ability to keep external factors constant and only vary those variables that are of interest. In how far the differences between the display modes are applicable to other scenarios and real-life situations is a matter to discuss. The auditory stimuli used in the six studies were very unfamiliar, compared to the images and texts. In the above section (see 5.2) the issue of fluency was introduced. The visual cues are likely to be processed more fluently due to a larger familiarity with this type of decision. Sounds are an important feature of human environments, but may be more relevant in perceptual decision making. In the field of probabilistic and preferential decisions, auditory decisions have not been considered before at all. The literature reviewed regarding vision and audition in the theoretical introduction (see 2) mainly originates from cognitive and perceptual psychology and neuroscience. In the majority of cases, visual and auditory integration are examined by very abstracted paradigms. Here dots, flashes or simplified geometric shapes are presented on a screen. Sounds are artificial noises, clicks or beeps. These studies are important to examine very general mechanisms, like an isolated inspection of working memory capacity. It is, however, difficult to translate them to complex probabilistic inference decisions one-to-one.

Despite exhibiting unarguable limitations, the studies of this dissertation provide fruitful insights into multimodal decision making in a novel paradigm. They build a solid basis for further investigation and open up a wide variety of paths to pursue. Some possible directions for future research are introduced in the next and final section of this dissertation.

5.4 Directions for future research

A current topic in research on judgment and decision making is the unification of models presuming multiple strategy use (e.g. *The Adaptive Toolbox,* Gigerenzer & Selten, 2001) and models proposing a single mechanism (e.g. the *PCS model*, Glöckner & Betsch, 2008b). This dissertation is theoretically embedded into such unified models (e.g. Lee & Cummins, 2004; Söllner & Bröder, 2016). Unified models are based on the assumption that compensatory decision making is the default (Bröder & Schiffer, 2003b) and the application of strategies takes place adaptively to the environment (Kämmer et al., 2013; Söllner & Bröder, 2016). Lee and Cummins (2004) emphasize the role of information availability. It is much easier to consider all information when it is given compared to information that has to be searched for actively. The latter is found to promote the use of simplifying decision strategies. Within the studies reported here, information was always given. An information search paradigm could provide fruitful insights to multimodal decision making. In this dissertation it was shown that an auditory display allows for a compensatory strategy use under specific conditions. It would be particularly interesting to see whether auditory information can be used in a heuristic way at all. In addition, inter- and intragroup differences between the four types of displays could be assessed within this modified environment more thoroughly.

Next to the four types of displays examined in this dissertation, the investigation of other modalities will give further insights to multimodal decision making. Particularly promising is the case of spoken language. It is perceived auditorily, like sounds, and coded as speech, like text. Examining spoken language in a study like those presented here would help to explain differences in auditory and textual display.

It is also imaginable and possible to vary the stimulus materials within each modality. Variations in the sound and image presentation may provide a structure and environment that promotes or favors a certain information integration. One could think of an environment where auditory cues are presented validity-wise for both options, like displaying the most valid cue for option 1 and for option 2, then presenting the second most valid cue, and so on. This procedure might trigger *TTB* use. It is also analogous to a cue-wise search of information, instead of an option-wise search. Lee and Cummins (2004) describe such search behavior as well-suited to describe information search in human decision making.

One of the limitations within this dissertation was the insufficient consideration of cue validities within decisions. The role of validity should be emphasized more strongly to draw a clearer line between *WADD* and *EQW* and potentially explain the absence of non-compensatory decision making.

Another shortcoming – particularly of lab experiments – is the limited external validity and generalizability. The differences in information use in decisions with varied display modes have an important impact in real-life decisions and how decisions can be structured to induce a particular decision behavior. Therefore the evidence presented here needs a lot more confirmation from studies inside and outside the lab. Decisions, like those presented in the studies, are embedded into a larger context in real-life, which is well expressed by Seger and Peterson (2013, p. 17):

> *"However, in the real world perceptual categories are embedded in complex conceptual knowledge representations (Rehder and Kim, 2006; Lambon Ralph et al., 2010) that combine information across modalities and functions, and in humans interface with language and lexical representations (Rogers and McClelland, 2011, Strnad et al., 2011)."*

This notion should be translated to the experimental investigation of multimodal decision making.

As a final remark it has to be pointed out that vision and audition are different in nature. The same presuppositions are not necessarily applicable to both, especially when it comes to the problem of self-directed versus predetermined perception. Vision and audition serve different purposes and have specific advantages and disadvantages. Their comparability may not be infinite. With this dissertation a first approach was started to examine differences and commonalities of information use in decisions presented pictorially, auditory, pictorially-auditory and textual. A safe conclusion is that it is easiest to use all decision-relevant information in a pictorial display mode and most difficult upon auditory display. It was also demonstrated that changes in the structure and environment of these decisions improve the ability to consider all relevant information.

These findings are thus crucial when it comes to the format decision-relevant information is presented in. The recommendations that can be given include to aid decisions by providing image-based representations of important features. The number of information should be kept as small as possible, especially when deciding upon heard input. Whenever possible, decisions can be aided by structuring them consistently. A way to do so, is to withhold information that is conflicting, but of low importance.

The presented findings are particularly interesting for all instances that provide decision-relevant information. It is highly relevant in health communication and could also be transferred to other areas like consumer decision making – for instance when it comes to advertising vacation trips.

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Attachments

Attachment A: Instructions and material

Attachment A-1: Pretest instructions and material

Wie wichtig sind Ihnen folgende Dinge, wenn Sie eine Urlaubsreise buchen?
Bitte klicken Sie auf der Linie immer jeweils auf die Stelle, die am ehesten der von Ihnen vergeben Wertung entspricht.

	gar nicht wichtig	sehr wichtig
Nähe zur Natur		
Badausstattung		
Personendichte (z.B. wenige Menschen oder viel Getümmel)		
Spezielle Ausrichtung des Hotels (z.B. Businesshotel, Wellnesshotel)		
Transportmittel (z.B. Auto, Flugzeug, Zug)		

Welche dieser jeweils beiden Optionen würden Sie bei der Buchung einer Urlaubsreise präferieren?
Bitte schieben Sie den Schieberegler immer an die Stelle, die am besten Ihre persönliche Präferenz widerspiegelt.

Ausstattung mit Badewanne

Ausstattung mit Dusche

Verkehrsnahe Lage

Naturnahe Lage

Anreise mit dem Flugzeug

Anreise mit dem Bus

Attachment A-2: Instructions and stimulus materials for studies 1-6

Liebe Versuchsteilnehmerin, Lieber Versuchsteilnehmer,

vielen Dank für Ihre Bereitschaft an dieser Studie teilzunehmen. Die Studie führe ich im Rahmen meiner Promotion am Lehrstuhl für Sozial-, Organisations- und Wirtschaftspsychologie unter der Betreuung von Prof. Dr. Tilmann Betsch durch. Für Ihre Teilnahme erhalten Sie ein kleines Dankeschön und bei Bedarf eine dreiviertel Versuchspersonenstunde.

In der Studie wird Ihr Ziel darin bestehen, Entscheidungen mittels zuvor gelernter Inhalte zu treffen. Als Einkäufer einer Reisefirma wird es Ihre Aufgabe sein, neue Pauschalreisen für Ihre Firma auszuwählen. Jede Pauschalreise unterscheidet sich auf mehreren Dimensionen. Um im Sinne Ihrer Firma schnell und effizient Entscheidungen zu treffen, müssen Sie diese Dimensionen gut kennen. Daher erhalten Sie zu Beginn die Möglichkeit, die Dimensionen in Ruhe kennenzulernen und sich damit vertraut zu machen.
Die Studie wird sich dabei in die folgenden drei Teile gliedern:

1. Lernphase
In der Lernphase werden Ihnen die Reisedimensionen, deren Wichtigkeit und Ausprägungen (Attribute) vorgestellt. Das Ziel besteht darin, diese so gut einzuprägen, dass Sie die in dieser Phase gestellten Fragen korrekt beantworten können.

2. Entscheidungsphase
Hier müssen Sie schnell entscheiden, welche von zwei Reisen die bessere ist, um für Ihre Firma die bestmögliche Alternative auszuwählen.

3. Prüfphase
In der Prüfphase werden noch einmal die Reisedimensionen und Ihre Ausprägungen aus der Lernphase wiederholt.

Sollten Sie Fragen haben oder Unklarheiten bestehen, wenden Sie sich bitte an die Versuchsleitung.
Andernfalls beginnen Sie bitte mit der Bearbeitung am PC.
(Bitte setzen Sie die Kopfhörer, die sich neben dem PC befinden auf.)

Vielen Dank.

Learning phase in studies 1-3: Exemplary slides

Herzlich willkommen zum ersten Experimentteil!

Im Experiment wird es darum gehen, dass Sie als Einkäufer einer Reisefirma entscheiden müssen, welche von zwei Reisen Sie jeweils einkaufen. Dazu stehen Ihnen Marktforschungsdaten von Urlaubern zur Verfügung.

Es gibt vier verschiedene Dimensionen, auf denen Reisen bewertet wurden: Badausstattung, Art des Hotels, Transportmittel und Lage. Auf jeder Dimension gibt es zwei Ausprägungen: Eine, welche von Urlaubern stark präferiert wird und eine die eher abgelehnt wird. Zudem besitzt jede Dimension eine andere Wertigkeit. Auf der nächsten Seite wird Ihnen ein Beispiel angezeigt, anhand dessen Sie einen Eindruck davon gewinnen können, wie solche Dimensionen aussehen und auf was Sie als Einkäufer achten müssen.

In diesem ersten Teil besteht das Ziel darin, diese Dimensionen und deren Ausprägungen auswendig zu lernen, denn in der anschließenden Entscheidungsphase ist es wichtig, dass Sie die Dimensionen gut kennen, um schnell Entscheidungen treffen zu können. Sie werden in dieser ersten Phase genügend Zeit haben, alles zu lernen und Ihr Wissen zu überprüfen.

Eine Besonderheit besteht darin, dass die Ausprägungen der Dimensionen in Worten, als Bilder und als Töne gegeben sein werden. Daher sollten Sie sich immer ebenso gut an die Namen, die Bilder, als auch an die entsprechenden Töne erinnern, da Sie in der später folgenden Entscheidungsphase nicht alle Informationen zur Verfügung haben werden.

Mit der LEERZEICHEN-Taste geht's weiter.

1

2

Nun folgt die Abfrage der eben gelernten Dimensionen und Ausprägungen.
Ihnen wird zunächst immer ein Bild und der jeweils zugehörige Ton angezeigt. Danach müssen Sie angeben, ob diese Ausprägung abgelehnt oder präferiert wurde, welche Wichtigkeit sie besaß und welches andere Bild zur entsprechenden Dimension gehört.

Mit der LEERZEICHEN-Taste geht's weiter.

3

Lage: Straße

4

Wie bewerten Urlauber diese Hoteleigenschaft?

5

Richtig!

Mit der LEERZEICHEN-Taste geht's weiter.

6

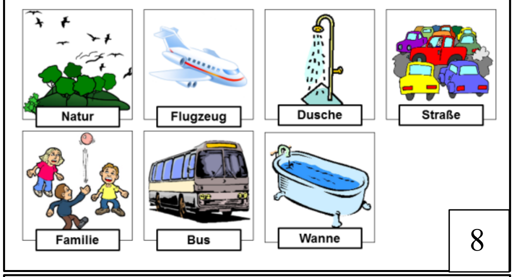
Leider falsch.

Bitte versuchen Sie es erneut.

Nochmal versuchen

7

Die dargestellte Eigenschaft gehört in dieselbe Kategorie wie:



8

Richtig!

Mit der LEERZEICHEN-Taste geht's weiter.

9

Der Sound gehört zum Bild:

(Durch Anklicken des Lautsprechersymbols kann der Sound erneut wiedergegeben werden.)

10

Richtig!

Mit der LEERZEICHEN-Taste geht's weiter.

11

Der Gedächtnisteil ist nun abgeschlossen.

Bitte wenden Sie sich an die Versuchsleitung.

12

Learning phase in studies 4-6: Exemplary slides and seqeunce

Herzlich willkommen zum ersten Teil der Studie!

Herzlich willkommen zum ersten Teil der Studie!

In dieser Studie wird es darum gehen, dass Sie als Einkäufer einer Reisefirma wiederholt entscheiden müssen, welche von 2 Reisen Sie einkaufen. Dazu stehen Ihnen Marktforschungsdaten von Urlaubern zur Verfügung.

Reisen unterscheiden sich immer hinsichtlich:

Art des Hotels:	Familienhotel oder Wellnesshotel
Transportmittel:	Bus oder Flugzeug
Lage:	Natur oder Straße
Badausstattung:	Wanne oder Dusche

Sie werden für jede dieser Dimensionen nacheinander die Präferenzen von 10 Urlaubern sehen.
Nachfolgend erhalten Sie eine Beispielabfolge, in der Ihnen für 10 Urlauber angezeigt wird, ob diese viele oder wenige andere Gäste bevorzugen.
(Dieses Beispiel dient nur zur Illustration und wird Ihnen in der eigentlichen Studie nicht weiter begegnen.)

Mit der LEERZEICHEN-Taste geht's weiter.

[Exemplary sequence is given on the next page]

Ergebnis: 11 Antworten waren Korrekt.

Runde 1	
Transport	korrekt
Lage	falsch
Hotelart	falsch
Badausstattung	korrekt

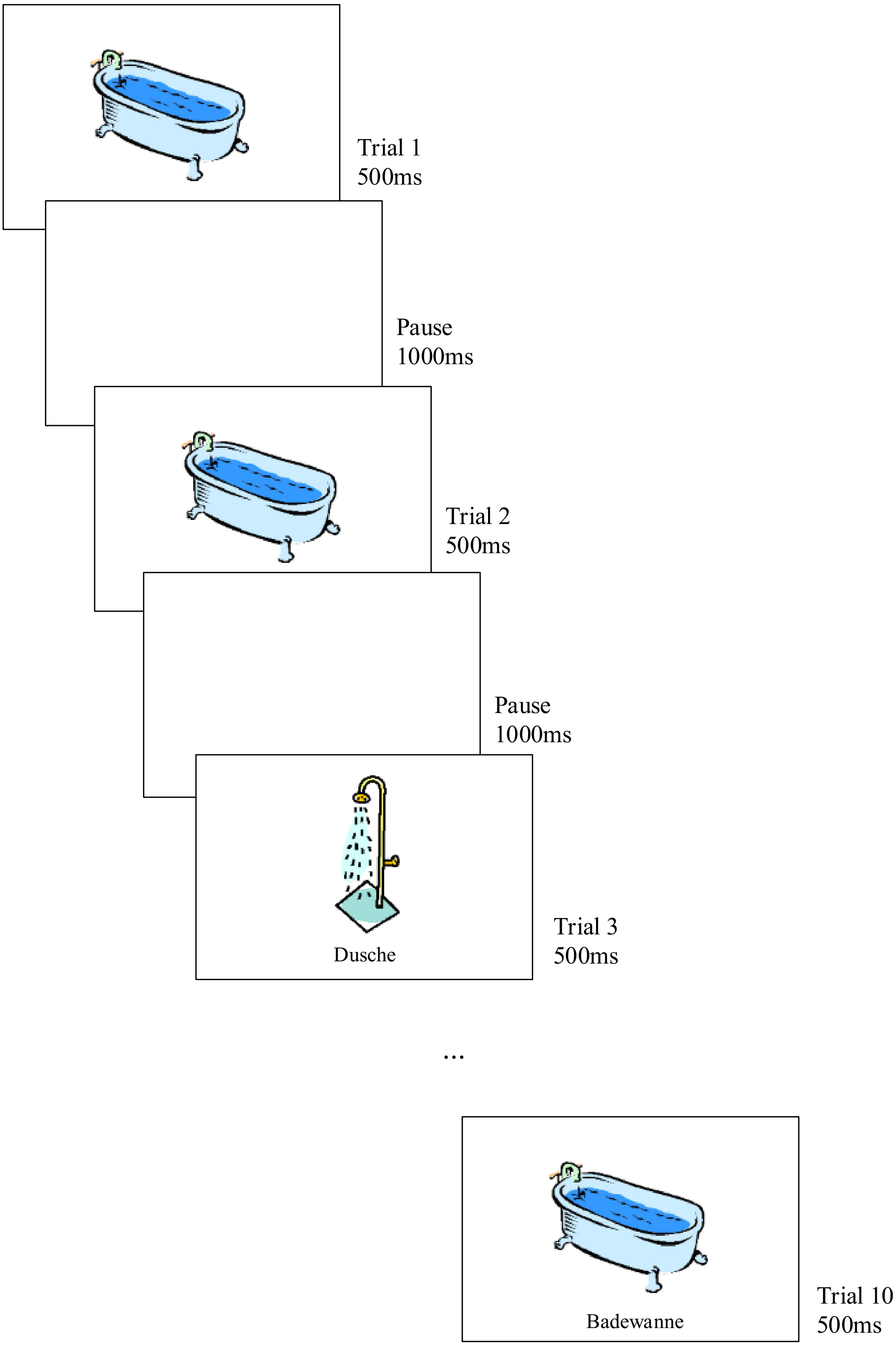
Runde 2	
Transport	korrekt
Lage	falsch
Hotelart	falsch
Badausstattung	korrekt

Runde 3	
Transport	korrekt
Lage	korrekt
Hotelart	korrekt
Badausstattung	korrekt

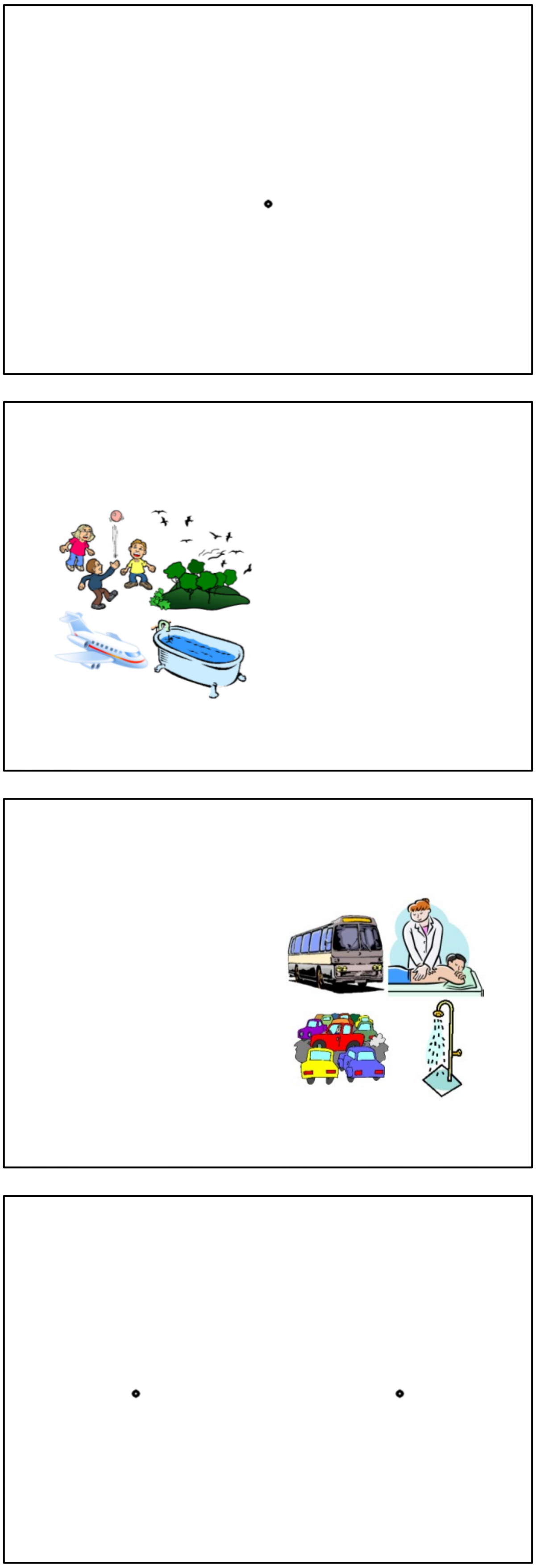
Runde 4	
Transport	korrekt
Lage	falsch
Hotelart	korrekt
Badausstattung	korrekt

Bitte wenden Sie sich an die Versuchsleitung.

Exemplary sequence within learning phase of studies 4-6 (cue sampling)



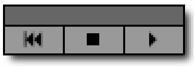
Decision phase: Exemplarly sequence in the pictorial condition



Retrieval phase in studies 1-4

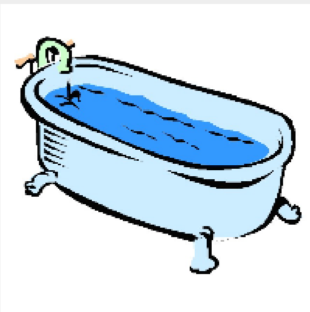
Im letzten Teil der Studie werden Sie erneut gebeten, sich an die gelernten Reiseeigenschaften zu erinnern. Danach folgen noch einige kurze Auskünfte und die Studie ist beendet.

Bitte hören Sie sich den Sound an. Zu welchem der unten dargestellten Bilder gehört dieser Sound?

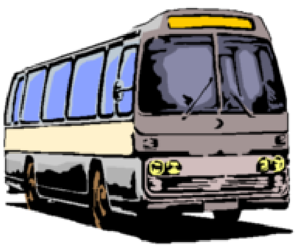


Dusche

Wellness

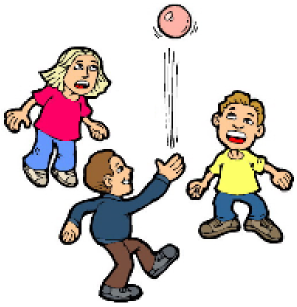


Wanne



Bus


Natur


Familie


Straße


Flugzeug

Abschließend möchte ich Sie bitten, die am Anfang der Studie gelernten Kategorien erneut wiederzugeben. Sie werden oben jeweils den Namen der Kategorie sehen und sollen im Feld danach die gelernte Wichtigkeit in Sternen angeben. Dann wählen Sie jeweils das Bild aus, das der positiven bzw. negativen Ausprägung dieser Kategorie entspricht.

[Name of vacation dimension]

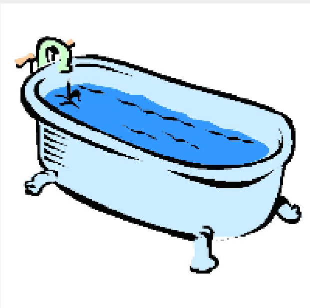
[Bitte auswählen]

[Bitte auswählen]
0.6
0.7
0.8
0.9

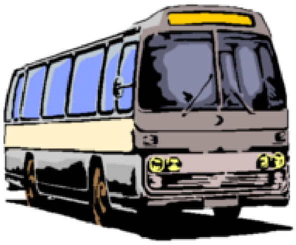
Welches Bild gehört zur positiven Ausprägung dieser Kategorie?

Dusche

Wellness

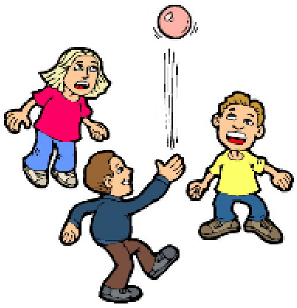


Wanne

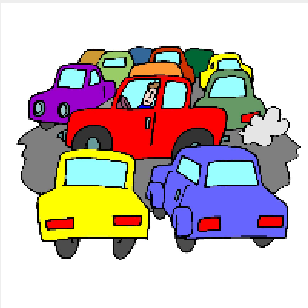


Bus

Natur



Familie



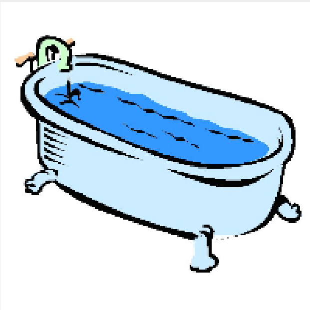
Straße

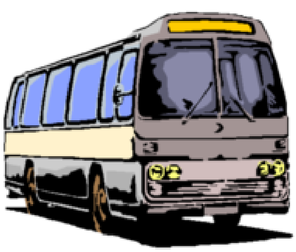
Flugzeug

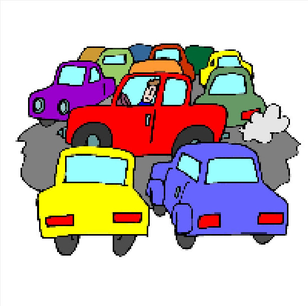
Welches Bild gehört zur negativen Ausprägung dieser Kategorie?


Dusche


Wellness


Wanne

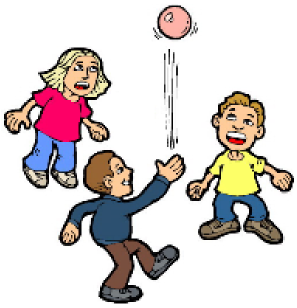

Bus



Straße

Flugzeug

Natur



Familie

Nun möchte ich Sie noch kurz um einige Angaben zu Ihrer Person bitten.

Selbstverständlich sind alle Angaben, die Sie machen vertraulich und werden in anonymisierter Form und nur im Rahmen dieser Studie weiterverarbeitet.

Welches Geschlecht haben Sie?

- weiblich
- männlich

Wie alt sind Sie?

Ich bin ____ Jahre

Wenn Sie nach Ihren persönlichen Präferenzen eine Reise aussuchen müssten, welche der nachfolgenden Eigenschaften würden Sie wählen?

Bitte wählen Sie von den Eigenschaften auf der linken und rechten Seite immer jeweils eine pro Zeile aus.

Anreise mit dem Bus	○	○	Anreise mit dem Flugzeug
Familiengerechtes Hotel	○	○	Wellnesshotel
Bad mit Dusche	○	○	Bad mit Badewanne
Lage an einer vielbefahrenen Straße	○	○	Lage in der Natur

Haben Sie weitere Anmerkungen zur Studie?

Im nachstehenden Feld können Sie diese eintragen.

Vielen Dank für Ihre Teilnahme.

Die Studie an der Sie soeben teilgenommen haben, ist mit dem Ziel verbunden Entscheidungen unter multimodalen Bedingungen zu untersuchen. Ich möchte Sie bitten über Ablauf und Inhalte der Studie Stillschweigen zu bewahren.
Interessieren Sie sich für nähere Hintergründe, Ziele und Ergebnisse dieser Studie, können Sie dies der Versuchsleitung mitteilen.

Bitte wenden Sie sich nun an die Versuchsleitung.

Anika Wille, Universität Erfurt, 2014

Retrieval phase in studies 5-6: Questionnaire

Bitte machen Sie zuerst folgende Angaben zu Ihrer Person:

Diese werden vertraulich und in anonymisierter Form nur im Rahmen dieser Studie verarbeitet.

Welches Geschlecht haben Sie?

□ weiblich □ männlich

Wie alt sind Sie?

…………………… Jahre

Sollten Sie Fragen haben oder Unklarheiten bestehen, wenden Sie sich bitte an die Versuchsleitung.

Andernfalls beginnen Sie bitte mit der Bearbeitung am PC.

Bitte setzen Sie nun die Kopfhörer, die sich neben dem PC befinden auf.

Teil 2

Vpn.-Nr.

Bitte schreiben Sie jeweils die drei/vier präsentierten Ausprägungen unter die jeweilige Urlaubsreise:

Probeaufgabe

Urlaubsreise 1

Urlaubsreise 2

Urlaubsreise 3

Urlaubsreise 4

Urlaubsreise 5

Urlaubsreise 6

Teil 3

Vpn.-Nr.

Dieser letzte Teil dient zur Überprüfung der Lerninhalte aus Teil 1.
Bitte bearbeiten Sie die folgenden Aufgaben zügig nacheinander.

Reisedimension: Badausstattung

Welche Badausstattung haben die meisten Urlauber bevorzugt?
(Zutreffendes bitte ankreuzen)

o Wanne o Dusche

Wie viel Prozent der Urlauber hatten diese Präferenz?
o 50% o 60% o 70% o 80% o 90% o 100%

Reisedimension: Transportmittel

Welches Transportmittel haben die meisten Urlauber bevorzugt?
(Zutreffendes bitte ankreuzen)

o Bus o Flugzeug

Wie viel Prozent der Urlauber hatten diese Präferenz?
o 50% o 60% o 70% o 80% o 90% o 100%

Reisedimension: Lage

Welche Lage haben die meisten Urlauber bevorzugt?
(Zutreffendes bitte ankreuzen)

o Straße o Natur

Wie viel Prozent der Urlauber hatten diese Präferenz?
o 50% o 60% o 70% o 80% o 90% o 100%

Attachment B: Detailed analyses and results

Attachment B-1: Pretest results

Preferences within and weights assigned to the tested cue dimensions

	weight mean	SD	mean percentage in favor of a)	SD
Transportation a) Plane b) Car	57.48	23.16	78.60*	20.12
Type of hotel a) Wellness b) Family	46.58	25.23	69.98*	26.71
Location a) Nature b) Street	64.18	22.84	74.16*	26.40
Bathroom equipment a) Bathtub b) Shower	59.23	27.12	74.70*	24.60
Crowdedness a) Low b) High	61.21	23.81	71.89*	25.12

Note. Range of values for weight was between 1 (low) to 100 (high).
** Preference differs significantly between values, p < .001*

Mean percentage of match between given images and sounds within the pretest

	sound									
	crowded: high	crowded: low	plane	bus	bathtub	shower	family hotel	wellness hotel	street	nature
image										
crowded: high	**91.00 (12.38)**	79.29 (25.27)	24.81 (33.17)	13.08 (22.53)	5.97 (12.47)	10.57 (20.01)	43.63 (32.50)	10.35 (21.28)	56.41 (36.45)	6.03 (13.23)
crowded: low	24.21 (25.32)	**33.89 (30.13)**	11.84 (21.18)	7.38 (14.08)	5.62 (12.93)	9.11 (15.80)	25.58 (26.97)	19.19 (25.82)	12.53 (20.81)	19.38 (28.10)
plane	29.21 (26.90)	17.89 (23.70)	**58.62 (36.86)**	14.84 (22.98)	6.46 (13.91)	7.22 (13.60)	20.26 (26.44)	13.38 (24.01)	43.83 (33.10)	7.35 (16.24)
bus	34.53 (28.73)	25.23 (28.73)	59.43 (32.56)	**71.03 (27.66)**	5.27 (13.22)	7.54 (17.74)	23.61 (28.01)	7.84 (16.26)	54.00 (30.21)	7.14 (12.38)
bathtub	6.34 (13.08)	4.77 (14.51)	5.24 (11.33)	4.76 (12.22)	**85.97 (21.81)**	43.19 (29.69)	14.74 (24.14)	40.19 (37.22)	11.39 (21.26)	16.59 (29.75)
shower	9.16 (19.21)	5.91 (16.00)	6.27 (12.66)	6.73 (15.15)	46.03 (32.52)	**88.41 (25.95)**	13.95 (21.20)	18.76 (26.86)	14.30 (24.01)	11.59 (22.36)
family hotel	35.13 (27.53)	25.71 (25.29)	13.65 (20.59)	7.14 (15.00)	7.24 (17.86)	7.81 (13.63)	**83.42 (24.65)**	9.81 (16.19)	28.20 (30.04)	8.49 (15.19)
wellness hotel	4.53 (7.50)	5.63 (14.63)	6.41 (15.86)	4.89 (10.58)	25.16 (29.51)	17.78 (25.78)	10.89 (18.49)	**73.11 (29.62)**	7.07 (16.55)	31.41 (32.86)
street	32.58 (33.26)	18.54 (26.80)	45.89 (34.91)	61.62 (34.32)	5.16 (14.46)	10.51 (21.77)	21.89 (26.78)	5.11 (13.71)	**87.43 (19.51)**	4.84 (12.12)
nature	7.24 (13.23)	5.49 (13.39)	6.54 (15.34)	4.46 (12.93)	19.16 (23.20)	24.32 (31.03)	19.47 (25.27)	40.68 (34.41)	10.93 (21.32)	**96.24 (8.59)**

Note. Range of values for image-sound match was between 1 (low) to 100 (high). Values represent mean values, standard deviations are given in parentheses.

Attachment C: Calculation of consistency within the cue pattern

An option *X*'s utility is calculated as the sum of all cue values *w*, weighted by validity *v*.

$$U_X = \sum_{n=1}^{n} v_n \cdot w_n$$

Consistency is conceptualized as the relative distance of two options' utilities, with a higher consistency indicating a greater distance and thus stronger evidence in favor of the option with the higher utility.

The total consistency of an experiment is derived from each cue pattern's consistency multiplied by the number of repetitions (trials).

Cue patterns and consistencies for Studies 1, 2, and 4

Cue pattern		1		2		3		4	
cue no.	cue validity	A	B	A	B	A	B	A	B
1	0.9	+	-	-	+	-	+	+	-
2	0.8	+	-	+	-	-	+	-	+
3	0.8	+	-	+	-	+	-	+	-
4	0.7	-	+	-	-	+	-	-	+
Calculated utility		1.8	-1.8	0	-1.4	-0.2	0.2	0.2	-0.2
Consistency		**3.6**		**1.4**		**0.4**		**0.4**	
Number of trials		10		10		10		10	
Total consistency		**36**		**14**		**4**		**4**	
								∑ = 58	

Cue patterns and consistencies for Study 5

Cue pattern		1		2		3		4	
cue no.	cue validity	A	B	A	B	A	B	A	B
1	0.9	+	-	-	+	+	-	-	+
2	0.8	+	-	-	+	-	+	+	-
3	0.8	+	-	-	+	-	+	+	-
4	0.7	-	+	-	+	+	+	-	-
Calculated utility		1.8	-1.8	3.2	-3.2	0	1.4	0	-1.4
Consistency		**3.6**		**6.4**		**1.4**		**1.4**	
Number of trials		5		5		15		15	
Total consistency		**18**		**32**		**21**		**21**	
								∑ = 92	

Cue patterns and consistencies for Study 3

Cue pattern		1		2		3		4	
cue no.	cue validity	A	B	A	B	A	B	A	B
1	0.9	+	-	-	+	-	+	+	-
2	0.8	+	-	+	-	-	+	-	+
3	0.8	+	-	+	-	+	-	+	-
Calculated utility		2.5	-2.5	0.7	-0.7	-0.9	0.9	0.9	-0.9
Consistency		**5.0**		**1.4**		**1.8**		**1.8**	
Number of trials		10		10		10		10	
Total consistency		**50**		**14**		**18**		**18**	
								∑ = 100	

Cue patterns and consistencies for Study 6

Cue pattern		1		2		3		4	
cue no.	cue validity	A	B	A	B	A	B	A	B
1	0.9	+	-	-	+	+	-	-	+
2	0.8	+	-	-	+	-	+	+	-
3	0.8	+	-	-	+	-	+	+	-
Calculated utility		2.5	-2.5	-2.5	2.5	-0.7	0.7	0.7	-0.7
Consistency		**5.0**		**5.0**		**1.4**		**1.4**	
Number of trials		5		5		15		15	
Total consistency		**25**		**25**		**21**		**21**	
								∑ = 92	

Attachment D: Erroneous strategy application within the studies

Mean error probabilities ε for strategies *comp* and *non-comp* for studies 1-6

Study	N	Experimental condition	ε_{comp}	$\varepsilon_{non\text{-}comp}$
1	86	pictorial	.25 (.11)	.37 (.14)
		auditory	.43 (.09)	.51 (.16)
		pictorial-auditory	.37 (.17)	.42 (.20)
		textual	.32 (.10)	.38 (.12)
		average	.34 (.14)	.42 (.16)
2	66	pictorial - simultaneous	.24 (.12)	.40 (.13)
		pictorial - sequential	.23 (.12)	.37 (.14)
		average	.23 (.12)	.38 (.14)
3	90	pictorial	.09 (.08)	.24 (.08)
		auditory	.26 (.11)	.35 (.11)
		pictorial-auditory	.11 (.12)	.27 (.07)
		textual	.12 (.11)	.25 (.08)
		average	.15 (.13)	.28 (.10)
4	92	pictorial	.17 (.09)	.37 (.10)
		auditory	.50 (.12)	.63 (.15)
		pictorial-auditory	.33 (.10)	.41 (.09)
		textual	.33 (.10)	.43 (.10)
		average	.33 (.15)	.45 (.15)
5	88	pictorial	.15 (.16)	.63 (.11)
		auditory	.32 (.19)	.53 (.18)
		pictorial-auditory	.20 (.13)	.57 (.11)
		textual	.24 (.18)	.54 (.17)
		average	.23 (.17)	.57 (.15)
6	81	pictorial	.09 (.20)	.68 (.21)
		auditory	.20 (.21)	.57 (.20)
		pictorial-auditory	.15 (.20)	.63 (.15)
		textual	.07 (.11)	.69 (.11)
		average	.13 (.19)	.64 (.17)
Overall (studies 1 and 3-6)	437	pictorial	.15 (.14)	.45 (.21)
		auditory	.34 (.18)	.51 (.18)
		pictorial-auditory	.23 (.18)	.45 (.18)
		textual	.22 (.16)	.46 (.18)
		average	.23 (.18)	.47 (.19)

Note. Values represent the mean error probability for having applied strategy k erroneously. Standard deviations are given in parentheses.

Ehrenwörtliche Erklärung

Ich erkläre hiermit ehrenwörtlich, dass ich die vorliegende Arbeit ohne unzulässige Hilfe Dritter und ohne Benutzung anderer als der angegebenen Hilfsmittel angefertigt habe; die aus fremden Quellen direkt oder indirekt übernommenen Gedanken sind als solche kenntlich gemacht. Bei der Auswahl und Auswertung des Materials sowie bei der Herstellung des Manuskripts habe ich keine Unterstützungsleistung erhalten.

Weitere Personen waren an der geistigen Herstellung der vorliegenden Arbeit nicht beteiligt. Insbesondere habe ich nicht die Hilfe einer Promotionsberaterin bzw. eines Promotionsberaters in Anspruch genommen. Dritte haben von mir weder unmittelbar noch mittelbar geldwerte Leistungen für Arbeiten erhalten, die im Zusammenhang mit dem Inhalt der vorgelegten Dissertation stehen.

Die Arbeit oder Teile davon wurden bisher weder im Inland noch im Ausland in gleicher oder ähnlicher Form einer anderen Prüfungsbehörde als Dissertation vorgelegt. Ferner erkläre ich, dass ich nicht bereits eine gleichartige Doktorprüfung an einer Hochschule endgültig nicht bestanden habe.

Erfurt, 2017

Anika Wille

Lebenslauf

Anika Wille (geb. Grudzielski), *03.08.1989

Schulische und universitäre Ausbildung

11/2013 – 11/2017	Universität Erfurt Promotion am Lehrstuhl für Sozial-, Organisations-, Wirtschaftspsychologie
10/2011 – 10/2013	Universität Erfurt Psychologie, Masterstudiengang
10/2008 – 09/2011	Universität Erfurt Lehr-, Lern-, Trainingspsychologie / Mathematik, Bachelorstudiengang
2000 – 2008	Staatliches Gymnasium Neuhaus am Rennweg

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03/2014 – 03/2015	Intershop Communications AG, Jena Studentische Hilfskraft
11/2011 – 07/2013	Max-Planck-Institut für Ökonomik, Jena Studentische Hilfskraft