Information Search and Organization in Multi-Attribute Decisions

Results on Strategy-Incompatibility and Processing Costs

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Abstract

A lot of research on multi-attribute decisions (i.e., choice of the best available option based on information provided by cues) has been devoted to investigate the influence of the way information is presented, and it was concluded that decision makers reduce costs (e.g., effort and time) by adapting information search to the way information is organized. However, two aspects had largely been neglected in this research: (1) Are costs for strategies deviating from the one supported by the information presentation a necessity for effects on decision behavior—or could also purely perceptual presentation manipulations affect decision behavior by providing “visual guidance” for information search? (2) What can be learned about the decision process if the well-structured, often artificial information presentation formats typically used in multi-attribute decisions are abandoned and information organization is left to participants?

Within the scope of this dissertation, the first question was approached with manipulations drawing on Gestalt principles to induce the impression of groups of information. That is, the information was presented in a matrix, and either the rows (representing one information-providing cue each) or the columns (representing one choice option each) were highlighted. Acquiring information column-wise when rows were highlighted or vice-versa was as easy as acquiring the information along the highlighted dimension because the grouping was merely perceptual. No effects on decision behavior emerged with these perceptual manipulations. This result contrasts with previous findings from experiments using much stronger information presentation manipulations (e.g., separate sheets of paper or separate booklets to isolate groups of information). Differential processing costs for the application of different strategies due to the way information is organized are therefore a necessity for information presentation effects to occur; perceptual grouping is not sufficient. Adaptive cost–benefit considerations are thus an adequate explanation for information presentation effects.

The second question was approached with the introduction of a new task format and a corresponding index to assess and quantify subjective information organization. The basic idea was that participants would use subjective information organization to establish a coherent task representation and that subjective information organization would therefore mirror the decision process. In a validation experiment, the task proved sensitive to different decision strategies, and in a simulation study, the index was shown to fulfill basic statistical requirements. In investigations on the importance of a strategy-compatible information organization (i.e., the organization mirrors the strategy's process), only users of compensatory decision strategies, but not participants using the more frugal non-compensatory Take-the-Best heuristic, organized information in a strategy-compatible manner. Thus subjective information organization did not generally mirror the decision process to support a coherent task representation.

Further investigations showed that the type of display used for the subjective information organization task only increased processing costs for the most information-intensive, strictly compensatory strategies when the organization was strategy-incompatible rather than -compatible. That is, strategies that are considered more cumbersome per se (i.e., more effortful to apply) are more easily affected by a strategy-incompatible information organization. Concerning strategy selection, there was no evidence for an adaptive reduction of the use of strictly compensatory strategies when information was organized in a strategy-incompatible manner. However, whether people really are insensitive to subtle processing costs is subject to future research.

Manuscripts

Manuscript 1

Ettlin, F., & Bröder, A. (2015). Perceptual grouping does not affect multi-attribute decision making if no processing costs are involved. *Acta Psychologica, 157*, 30–43. doi: 10.1016/j.actpsy.2015.02.002

Manuscript 2

Ettlin, F., Bröder, A., & Henninger, M. (2015). A new task format for investigating information search and organization in multiattribute decisions. *Behavior Research Methods, 47*, 506–518. doi: 10.3758/s13428-014-0482-y

Manuscript 3

Ettlin, F., & Bröder, A. (2015). *Strategy-compatible information organization is not generally preferred in multi-attribute decisions.* Manuscript submitted for publication

Manuscript 4

Ettlin, F., & Bröder, A. (2015). *Strategy-incompatible information displays incur only subtle processing costs in multi-attribute decisions: Evidence from eye tracking data.* Manuscript submitted for publication

Introduction and Background

To be in possession of relevant information when taking decisions is a necessity, however, it is not sufficient. Information also needs to be processable (Russo, Krieser, & Miyashita, 1975). That is, information needs to be easy to use and comprehensible (Bettman, Payne, & Staelin, 1986). The advent of the information era made the first point, availability, mostly a banality. The second point, processability, became of paramount importance, however. Bringing order to the flood of information is one aspect of making it processable. A vivid example of that issue is the tremendous amount of files on one's computer; already one's own accumulation of files is so overwhelming that it is hard to keep track of. Luckily, our computers have fancy programs like Finder to help us retrieving the required files. With such programs, files can be sorted according to specific criteria, for instance, alphabetically, by date of the last change, or by type of file. That is, the sorting can be adjusted to the search strategy we consider most suitable to quickly find a specific file. Other information is more difficult to rearrange, however. In a supermarket, the consumer only sees the information about the different breakfast cereals bundled for each product. Each breakfast cereal package is brimming with information, but the consumer in the store does usually not get different lists for the various different attributes described on these packages (e.g., calories, sugar, fat etc.) with the corresponding information for each product. The information is organized according to products, not according to the products' attributes.—In short, availability of (abundant) information foregrounds the importance of the way information is organized, and the final example highlights its potential significance in information-based decision making. Information presentation has indeed received a lot of attention in research on information-based decisions, and it has repeatedly been shown that this factor affects decision behavior (e.g., Bettman & Kakkar, 1977; Bettman & Zins, 1979; Jarvenpaa, 1989; Russo, 1977; Schkade & Kleinmuntz, 1994).

In this dissertation based on two published articles and two submitted manuscripts[1], I present new findings on the effect of information presentation on decision behavior in information-based decisions, specifically, in multi-attribute decisions in which the quality of the choice options can be inferred from cues that provide information about these options. The focus is on processing costs induced by the way information is organized and their relevance for effects on decision behavior. In the experiments presented in the four manuscripts, information organization was either manipulated (manipulations of information presentation) or participants organized the information themselves (subjective information organization). In the first manuscript, we investigated the effect of information presentation manipulations that induced no differential processing costs for different decision strategies (i.e., that neither hindered nor facilitated any specific strategy's application), and we thereby identified a boundary condition of information presentation effects on multi-attribute decision making. In the second manuscript, we introduced a new task format with an associated measure to assess and quantify subjective information organization. The aim was to provide a standardized method and objective measure for subjective information organization in order to learn more about the decision process by considering organization behavior as a process variable. We used this newly developed task format in the experiments presented in the third manuscript to investigate the importance of information organization for building a coherent task representation under conditions that foster or hinder a convenient application of the best performing decision strategy. The surprising results we observed in these experiments led us to investigate processing costs due to an unbeneficial information organization with the display of the new task format. The investigations and the corresponding results are presented in the fourth manuscript, and they showed that certain decision strategies are more susceptible than others to costs caused due to the way information is organized.

[1] For the sake of consistency, I will henceforth refer to all articles and manuscripts as *manuscripts*.

But before presenting the four manuscripts, I will provide the theoretical background of the herein presented research projects by starting with briefly outlining different decision making frameworks; especially the herein adopted multiple-strategy framework. I will then continue with the strategy selection problem that emerges with the adoption of a multiple-strategy view: I will present different approaches to strategy selection as well as empirical findings on factors influencing strategy selection with the main focus on the factor information presentation. In this context, I will outline research gaps leading to two research questions. To tackle these questions, I will then summarize the four manuscripts, and will conclude with discussing the findings and providing a brief outlook.

Multi-Attribute Decisions and the Multiple-Strategy View

In our experiments, we used multi-attribute decision tasks to investigate information presentation effects and subjective information organization. Multi-attribute decisions are tasks in which a number of cues describe different options, and the goal is to identify the best option. For instance, the options might be two tennis players, and the decision could be to infer who of them is going to win the next encounter. The cues would then be the players' characteristics and further information, like the strength of their service, which has predictive validity for that inference. Thus the decision maker relies on available information concerning the options in order to take a decision when the actual values of the options are not (yet) available. There are different conceptions of how a decision maker might use information in multi-attribute decisions, however.

One single strategy or multiple strategies?

For a rough categorization, the different conceptions can be assigned to one of two clusters of frameworks, to those assuming a single-strategy view or to those assuming a multiple-strategy view. A single-strategy view is assumed in the evidence accumulation model by Lee and Cummins (2004); a sequential sampling model for multi-attribute decision tasks. Such models assume sequential sampling of information to accrue evidence for the choice options until an evidence threshold is met or until all information is acquired; then the option favored by the evidence is chosen (Lee & Cummins, 2004; Newell & Lee, 2011; Söllner, Bröder, Glöckner, & Betsch, 2014). A further model applicable to multi-attribute tasks which assumes a single decision mechanism is from the family of connectionist networks, the parallel constraint satisfaction network model (PCS) by Glöckner and Betsch (2008). This model assumes that decision tasks can be represented in a network structure and that automatic information integration (i.e., an automatic consistency maximizing process) leads to a decision. In contrast, multiple-strategy views assume that decision makers are equipped with a repertoire of *different* decision mechanisms. The fast and frugal heuristics framework by Gigerenzer and colleagues (Gigerenzer, Todd, & the ABC Research Group, 1999) and the adaptive decision maker framework by Payne and colleagues (Payne, Bettman, & Johnson, 1993) represent two multiple-strategy views for multi-attribute decisions. These frameworks assume that the decision maker selects a decision mechanism, that is, a decision strategy, which is adaptive with respect to the task and the situation.

The research presented in our manuscripts is mainly about how people search for information (i.e., on the sequence of information acquisition) and how they organize it. In the typical research paradigms for multi-attribute decisions, the latter aspect is generally a given factor rather than an investigated process. But the former aspect, information search, has received quite a bit of attention in theory and empirical research. According to multiple-strategy views, not only the way information is utilized differs between different decision strategies, but also the way information is searched for is assumed to differ (Gigerenzer et al., 1999; Payne et al., 1993), and therefore information acquisition has received a lot of attention in research conducted in multiple-strategy frameworks (e.g., Bettman & Kakkar, 1977; Bröder & Schiffer, 2003a, 2006; Creyer, Bettman, & Payne, 1990; Lohse & Johnson, 1996; Mata, Schooler, & Rieskamp, 2007; Payne, 1976; Payne, Bettman, & Johnson, 1988;

Renkewitz & Jahn, 2010; Russo & Dosher, 1983; for a recent overview of methods for tracing information acquisition, see Schulte-Mecklenbeck, Kühberger, & Ranyard, 2011). The single-strategy model PCS, however, does not formally model the process of information search. Information search is assumed to be based on deliberate strategies. These deliberate strategies support the automatic processing that finally determines the decision after reaching the desired level of consistency; but the formal details on information search were not elaborated. In short, PCS specifies a (general-purpose) mechanism for information *integration*, but information *search* is rather vaguely specified and is not considered a necessity in many "mundane situations" (Glöckner & Betsch, 2008, 2010; Marewski, 2010). Also the evidence accumulation model for multi-attribute decisions suggested by Lee and Cummins (2004) does not so much focus on the sequence of information search but rather on when search is terminated. Even though, in the model by Lee and Cummins, the way information is acquired is clearly specified (i.e., one cue after the next is considered for each option), this type of evidence accumulation model cannot accommodate search patterns deviating from the specified one (Newell & Lee, 2011). As mentioned above, in our research, we mainly focused on how information is acquired and we then extended the assumptions about information search to derive predictions for subjective information organization. Thus, since information search has received most attention in the multiple-strategy frameworks, the multiple-strategy view provides an appropriate setting for our research.

Multiple-strategy frameworks: Inferences versus preferences

The two above-mentioned multiple-strategy frameworks for multi-attribute decisions grew from two different domains. While the adaptive decision maker framework focuses on preferences, like the choice of an apartment, a car, or breakfast cereals, the fast and frugal heuristics framework focuses on inferences, like investment decisions, predicting the winner of a tennis match, or diagnosing a disorder.[2] A main difference is the availability of objective performance criteria for the latter kind of decision but not for the former one. For instance, shares have an objective value, one of the opponents will triumph, and a diagnosis can be right or wrong. But when it comes to apartments, cars, breakfast cereals, and the like, I may prefer one specific option to all others, but someone else may prefer a different option. There is no objective criterion, and therefore strategy performance has to be evaluated against some baseline (e.g., against a maximization strategy, that is, the type of strategy which is typically considered the gold standard, and/or against random choice [see e.g., Payne et al., 1988]; see also Gigerenzer & Todd, 1999, on performance criteria for inference strategies). The basic structure of the tasks in (multi-attribute) preferences and inferences are essentially identical, though. But since the experiments included in this dissertation all deal with inference tasks, I will mainly focus on the corresponding framework, namely the fast and frugal heuristics framework.

Multiple-strategy frameworks: The fast and frugal heuristics framework

The fast and frugal heuristics framework builds on Herbert A. Simon's idea of bounded rationality: "…a great deal can be learned about rational decision making by taking into account, at the outset, the limitations upon the capacities and complexity of the organism, and by taking account of the fact that the environments to which it must adapt possess properties that permit further simplication [*sic*] of its choice mechanisms" (Simon, 1956, p. 129; see also Gigerenzer & Selten, 2001). Fast and frugal heuristics are decision strategies that allow inferences "using realistic amounts of time, information, and computational resources" (Gigerenzer & Todd, 1999, p. 24). Accordingly, in my dissertation, I will refer to

[2] For inference tasks, multiple cues provide information about the choice options. But preferences are often investigated using different brands or consumer goods as choice options, and information about these brands' and goods' *attributes* is provided; thus the expression *multi-attribute decisions*.

these decision strategies as descriptive models for the actual behavior of decision makers in our experiments.

In the fast and frugal heuristics framework, providing descriptive models is not the only goal, however. There is also a normative goal: investigating the ecological rationality of heuristics. That is, the goal is to identify environments in which specific heuristics perform well (Gigerenzer, Hertwig, & Pachur, 2011; Todd, Gigerenzer, & the ABC Research Group, 2012). When the heuristics are applied in an ecologically rational manner, they may be at least as good as more complex decision rules while being more frugal and less time consuming, in short, less resource-intensive (Czerlinski, Gigerenzer, & Goldstein, 1999). Finally, there is one more goal, this one is concerned with engineering, thus with designing environments and heuristics to improve decision making (Gigerenzer et al., 2011).

For one thing, this dissertation touches upon the third goal: The focus is on design aspects, specifically on information presentation and subjective information organization, and on whether and when these aspects may foster or hinder decision making. For another thing, the first of the three goals described in the fast and frugal heuristics framework is of relevance in this dissertation because, as mentioned above, I will refer to the strategies in the adaptive toolbox to describe actual behavior. Yet when the goal is to describe decision behavior, a challenge arises for all multiple-strategy approaches: How do decision makers select among the strategies in their repertoire?

Strategy Selection

Different approaches to strategy selection emerged and they generally did so in the environs of a specific framework. However, the approaches are not inextricably linked to the respective frameworks. Both afore-mentioned multiple-strategy frameworks assume adaptive strategy selection (Gigerenzer et al., 1999; Payne et al., 1993). That is, people are assumed to select among the strategies at their disposal in an adaptive manner depending on the decision situation.

In the fast and frugal heuristics framework, the adaptive toolbox is used as a metaphor to describe “the collection of heuristics and building blocks an individual or a species has at its disposal for constructing heuristics, together with the core mental capacities that building blocks exploit” (Gigerenzer & Gaissmaier, 2011, p. 456; see also Gigerenzer & Todd, 1999). But back in 1999, Gigerenzer and Todd remained relatively vague about the actual mechanisms of adaptive strategy selection. They stated: “The domain-specific bins in the adaptive toolbox could often hold only a single appropriate tool. In cases where there *is* more than one applicable heuristic, the knowledge that the decision maker has can be used to select the heuristic” (p. 32). They referred to knowledge, for instance, about cues and the cues’ potential to make good inferences, as a requirement to be able to apply certain heuristics in the first place.

Later on, the idea that knowledge may manage strategy selection was developed further by Marewski and Schooler (2011). In their ecological approach to strategy selection, the authors proposed “cognitive niches” for strategies. The niche of a strategy describes the situations in which that strategy is applicable. For instance, if no information about choice options is known, the information-based decision strategies discussed in this dissertation are not applicable and the decision maker would have to switch to strategies that are, for instance, recognition-based (i.e., choice of a recognized rather than an unrecognized option; Goldstein & Gigerenzer, 2002). These niches allow the identification of an applicable strategy without feedback or learning and limit the need to select among competing strategies to situations with overlaps of different strategies’ niches. Thus the basic idea is that the interplay between strategies, cognitive capacities, and the environment defines the situations in which a given strategy can be applied. It is a complement to rather than a substitute for other approaches.

How strategies are selected in case of overlapping niches is far from being resolved. But different mechanisms for and factors influencing strategy selection have been discussed and investigated: When diverse strategies are applicable, strategy selection may depend on cost–benefit mechanisms or learning; that is, mechanisms that consider accuracy, effort, and time because, within overlapping niches, there are areas in which a strategy is more accurate and/or less effortful than another applicable strategy. In the following, I will briefly describe two different kinds of mechanisms for strategy selection in overlapping niches as well as individual factors influencing strategy selection.

Strategy selection based on reinforcement learning

One such mechanism that could potentially sort out strategy selection in case of overlapping niches is the strategy selection learning model by Rieskamp and Otto (2006). Contrary to the selection based on cognitive niches, the approach by Rieskamp and Otto is a learning approach and therefore requires feedback. The authors assume that there is an initial preference for a strategy and they also assume that this strategy is not always selected but only with a certain probability. These initial probabilities for selecting strategies are adapted when people get feedback on their decisions. That is, it is expected that people are most likely to select a strategy they expect to perform well, and the adaption of the selection probabilities results from reinforcement learning depending on the strategies' experienced performance.

Rieskamp and Otto (2006) thus provided a computational approach to strategy selection when multiple strategies could be applied. However, the approach has certain limitations. For instance, it comes with the problem of an exploding number of parameters when more strategies are added to the repertoire (see Marewski & Schooler, 2011; Rieskamp & Otto [2006] dealt with that problem by grouping the individual strategies to model the selection of strategy groups). In addition, it was only vaguely discussed where initial preferences for strategies come from (but see the General Discussion and Outlook section in this dissertation), and only monetary reinforcements for strategy selection learning were incorporated (Rieskamp & Otto, 2006).

Strategy selection based on cost–benefit tradeoffs

A different approach to the selection of strategies in overlapping niches, which is popular in the framework of the adaptive decision maker by Payne and colleagues (1993; Johnson & Payne, 1985), assumes a cost–benefit tradeoff. That is, more complex strategies requiring more effort (e.g., because more monetary or temporal resources are required) are adopted if a higher benefit is expected (e.g., in terms of money earned with a decision; see also Beach & Mitchell, 1978; Christensen-Szalanski, 1978; Payne, 1982).[3] The cost–benefit approach was criticized, however, because the computations for identifying the strategy that maximizes the expected net gain (from expected benefit and expected cost) would lead to infinite regress (the *recursive homunculi problem*; see e.g., Gigerenzer & Todd, 1999; Rieskamp & Otto, 2006).

Factors influencing strategy selection

A further approach to the strategy selection problem is to focus on specific factors influencing strategy selection without specifying an exact mechanism for strategy selection, and that endeavor proved to be quite fruitful (for an overview, see Pachur & Bröder, 2013). Among the identified factors are, for instance, monetary costs of cue information (e.g., Bröder, 2000a, 2003), information redundancy (e.g., Dieckmann & Rieskamp, 2007), time pressure (e.g., Payne et al., 1988; Rieskamp & Hoffrage, 2008; but see Bröder, 2000a), whether information is provided or needs to be retrieved from memory (Bröder & Schiffer, 2003b), salience (MacGregor & Slovic, 1986; Platzer & Bröder, 2012), occupation with a

[3] In contrast to the normative goal of the fast and frugal heuristics framework, which is concerned with the ecological rationality of heuristics (Todd et al., 2012), the cost–benefit approach to strategy selection generally assumes that more complex strategies yield a higher probability of being correct (see Christensen-Szalanski, 1978).

secondary task (Bröder & Schiffer, 2003a), intelligence (Bröder, 2003), age (Mata et al., 2007), and expertise (e.g., Garcia-Retamero & Dhami, 2009; Pachur & Marinello, 2013). Personality traits that explain individual differences in strategy preferences could not be identified, however (see Bröder, 2012). In this dissertation, I will focus on one particular factor that was shown to influence the use of decision strategies: the way information is presented; specifically, how the information is grouped or organized (Bettman & Kakkar, 1977; Bettman & Zins, 1979; Jarvenpaa, 1989; Russo, 1977; Schkade & Kleinmuntz, 1994; for summaries, see Payne, 1982; Payne et al., 1993).

Information Presentation

The strategies discussed in the fast and frugal heuristics framework are based on stepwise processes (Gigerenzer & Todd, 1999) and depending on whether the information presentation matches the process of a given strategy or not, it is either compatible or incompatible with the strategy, respectively. The above-referenced research on information presentation effects generally showed that decision makers tend to select a strategy with a process that matches the information presentation.

The strategies

These strategies are defined by a combination of building blocks. Such building blocks might be a search rule, a stopping rule, and a decision rule to determine the sequence of information search, the amount of information searched, and how to use the acquired information, respectively (Todd & Gigerenzer, 2007). Furthermore, the strategies are either compensatory or non-compensatory. That is, they either integrate information and make tradeoffs (compensatory strategies) or they do not compensate more valid information with a combination of less valid information (non-compensatory strategies; e.g., Gigerenzer et al., 1999; Payne et al., 1993; see also Svenson, 1979, for a more fine-grained categorization of strategies). The prototypical non-compensatory strategy for multi-attribute inferences, the

Take-the-Best heuristic (TTB) consists of the three above-mentioned building blocks (Gigerenzer & Goldstein, 1996; cf. Fishburn, 1974, on lexicographic orders). The search rule prescribes that information from the most valid[4] cue is acquired first. If only one of the options has a positive value on that first cue, information search is stopped and the option with the positive cue information is chosen; otherwise, information search is continued with the second most valid cue (i.e., cue-wise search along the validity hierarchy until a discriminating cue is found).[5]

Compensatory strategies are typically captured with the Weighted Additive Rule (WADD [6]; e.g., Payne et al., 1988; also referred to as Weighted Linear Model [e.g., Gigerenzer & Goldstein, 1996] or Franklin's Rule [e.g., Bröder & Schiffer, 2006]) and the Equal Weight Rule (EQW, e.g., Payne et al., 1988; also referred to as Dawes's Rule [e.g., Bröder & Schiffer, 2006] according to Dawes, 1979). These strategies choose the option with the highest sum (decision rule) which is computed by summing the cue-information for each

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[4] Validity according to Gigerenzer and Goldstein (1996) means the number of correct inferences drawn with a given cue relative to the total number of inferences that can be drawn with that cue (i.e., the number of times the given cue is able to discriminate between the options). See, for instance, Lee and Cummins (2004) for a Bayesian approach to cue validities as an alternative to Gigerenzer and Goldstein's frequentist approach. With the Bayesian approach, a cue that makes 90 decisions and gets all 90 decisions correct gets a higher validity than a cue that can decide between the options only once and gets that one inference correct. On the frequentist validity measure, both cues have a validity of 1 (100%). For cues that discriminate very often between the options, the two validity measures converge.

[5] Gigerenzer and Goldstein (1996) defined TTB for a two options-scenario. In all experiments presented in this dissertation, we used tasks with four options. We defined TTB such that information for all four options is acquired on the first cue, and if more than one option has a positive value on that cue, the search is continued on the second cue, but only for those options which had a positive value on the first cue.

[6] Even though WADD has been used as a gold standard in previous research (e.g., Payne et al., 1988), it is not the "optimal" strategy. Multiple regression is commonly considered the optimal strategy because it also considers interdependencies between cues (cf. Gigerenzer & Goldstein, 2011).

option either by weighting all information equally (EQW) or by weighting the information by a measure of the respective cue's validity (WADD). These strategies do not abort information search before all available information is acquired (no stopping rule; however, "intelligent" versions of those strategies, which rely on less information, have been discussed by Bröder & Gaissmaier, 2007, and Rieskamp & Dieckmann, 2012). In addition, it is typically assumed that information search is option-wise (corresponding to the way information is integrated; e.g., Payne et al., 1988; Riedl, Brandstätter, & Roithmayr, 2008; but see Bröder, 2000b, for a critique).

Open Questions

Depending on whether a strategy proceeds cue- or option-wise, the corresponding way of grouping information represents a strategy-compatible information presentation. Effects of the way information is presented on decision behavior have been taken for granted for quite some time (Payne et al., 1993). However, boundary conditions of such effects remain to be investigated. Furthermore, instead of accepting information presentation as a given factor, which is typically done in research on multi-attribute decisions (but see, Coupey, 1994), subjective information organization could be treated as a dependent variable to learn more about decision processes. These gaps lead to the two research questions my dissertation is based on:

Do purely perceptual manipulations of information presentation affect decision behavior?

Kleinmuntz and Schkade (1993) argued that the way information is presented influences "decision processes by facilitating some decision strategies while hindering others" and that "a decision maker balances the desire to maximize accuracy against the desire to minimize effort" (p. 221). Thus the authors suggested cost–benefit tradeoffs as a motor for information presentation effects. The above-cited research on effects of information presentation mostly relied on strong manipulations inducing rather high processing costs for decision strategies deviating from the one suggested by the manipulation (e.g., Bettman & Kakkar, 1977, grouped information in different booklets). More recent results, however, led to the assumption that also perceptual factors might guide strategy selection (Brandstätter & Gussmack, 2013; Bröder, Glöckner, Betsch, Link, & Ettlin, 2013; Pachur, Hertwig, Gigerenzer, & Brandstätter, 2013). But none of these studies had directly compared different information displays with purely perceptual manipulations. Thus, to test whether information presentation effects on decision behavior also emerge in the absence of differential processing costs for different strategies, we grouped information in a purely perceptual manner and compared different ways of grouping it (Manuscript 1).

When decision makers compose their own information presentation: What can we learn about decision processes from subjective information organization as a process tracing tool?

Subjective information organization had largely been neglected as a means to learn more about the decision process in multi-attribute decisions (but see Coupey, 1994; Coupey & DeMoranville, 1996). We argued that a likely cause for this gap was the lack of a standardized, easy to use measure and we introduced and validated a new task format for automatically assessing and quantifying subjective information organization (Manuscript 2). Next, we used the newly developed task format to investigate the role of information organization in situations that differed in how favorable they were toward the application of the best performing strategy (Manuscript 3). The unexpected results from these investigations led us to conduct experiments that brought us back to the concept of processing costs: We investigated whether certain strategies are more susceptible to experience higher processing costs due to a strategy-incompatible information presentation than other strategies (Manuscript 4).

Summaries of Manuscripts

In the following, I will tackle the two above-stated questions by summarizing the four manuscripts that this dissertation is based on. I will mainly focus on issues related to the two research questions; further information and details can be found in the original manuscripts included toward the end of this dissertation. Furthermore, I will only briefly discuss each manuscript after the respective summary, and a more extensive General Discussion and Conclusion will follow as subsequent chapters. First of all, however, I will start with a brief description of the process tracing methods we repeatedly used in our experiments to investigate information search and organization.

Process Tracing

The above research questions that this dissertation is based on are mainly concerned with aspects of the decision *process*. To assess aspects of the decision process (i.e., direction of information search as well as further measures like time spent on acquired information etc.; see Schulte-Mecklenbeck et al., 2011), various different process tracing techniques were developed. The general idea of process tracing methods is to "offer a window onto the cognitive processes that result in a preference or an inference" (Schulte-Mecklenbeck, Sohn, de Bellis, Martin, & Hertwig, 2013, p. 243; see also Schulte-Mecklenbeck et al., 2011).

For the experiments in this dissertation, we used three different process tracing methods. One of them was the Mouselab technique (Johnson, Payne, Schkade, & Bettman, 1989; Willemsen & Johnson, 2011). With the computerized Mouselab technique, information is hidden in the cells of a cues by options-matrix, and participants need to click on the cells (or boxes) to reveal the information they need in order to take a decision; thereby the information search process is registered. This technique requires two assumptions concerning the relation of information search and cognition: "The first, *occurrence,* noncontroversially states that if information is used by a decision maker, it must have been seen by opening a box. The second, *adjacency,* assumes that information acquisition is temporally proximate to information use" (Willemsen & Johnson, 2011, p. 24).

As a further process tracing technique, we used eye tracking, that is, gaze data recordings, to assess the information search process. Also with eye tracking, there are assumptions; most importantly, it is assumed that attention is in line with foveal gaze direction: "In general, attention is used to focus our mental capacities on selections of the sensory input so that the mind can successfully process the stimulus of interest" (Duchowski, 2007, p. 4).

Finally, we also used a new task format, the *search and organization task* (SOT). The SOT is based on the Mouselab paradigm and extends it by allowing the assessment of subjective information organization. I will explain the SOT in some detail in the summary of Manuscript 2, in which we introduced this new task format.

Information Presentation in Multi-Attribute Decisions: Do Purely Perceptual Manipulations of Information Presentation Affect Decision Behavior?

Manuscript 1

Ettlin, F., & Bröder, A. (2015). Perceptual grouping does not affect multi-attribute decision making if no processing costs are involved. *Acta Psychologica, 157*, 30–43. doi: 10.1016/j.actpsy.2015.02.002

The goal of the four experiments presented in Manuscript 1 was to investigate whether purely perceptual manipulations of information presentation influence decision behavior in multi-attribute decisions. The idea to investigate information presentation effects (display effects in Payne et al.'s, 1993, terminology) was not a new one. On the contrary, it had long been accepted that the way information is presented in multi-attribute decisions may influence the way information is acquired (e.g., Bettman & Kakkar, 1977; Jarvenpaa, 1989; Schkade & Kleinmuntz, 1994; for a summary, see Payne et al., 1993). Furthermore, when the way information is provided is not compatible with an instructed strategy's process, the decision times increase and confidence may decrease (Bettman & Zins, 1979). But decision makers may also turn to the application of a search rule that is congruent with the information presentation (but deviates from the instructed strategy) and may then still apply the decision rule of the instructed strategy (Jarvenpaa, 1989). Finally, there is also evidence for the impact of information presentation on choices (i.e., on the outcome rather than the process level; Russo, 1977; but see Bettman & Zins, 1979, and Schkade & Kleinmuntz, 1994). Overall, the evidence in favor of information presentation effects is rather overwhelming.

Information presentation effects occur when a given way of presenting information is more convenient for the application of a certain strategy but makes the application of other strategies more cumbersome; that is, when information presentation induces differential processing costs. But in spite of the persistent interest in information presentation effects, the question whether differential processing costs are a necessity for such effects on decision behavior remained uninvestigated. The above-cited research relied on rather strong information presentation manipulations resulting in high processing costs for deviating strategies (e.g., the information was grouped in different booklets; Bettman & Kakkar, 1977). Cost–benefit tradeoffs were occasionally used to explain the effects (e.g., Bettman & Kakkar, 1977; Jarvenpaa, 1989), but it was unclear, whether also manipulations that did not induce differential processing costs would affect the decision behavior. That is, a purely perceptual manipulation that induces the visual impression of groups but that does not physically separate the information (or just insignificantly so) had not been investigated. It was therefore unclear whether people responded to the groups and interpreted them as meaningful with respect to the selection of a decision strategy (or at least to the selection of a search rule) or whether they merely responded to the processing costs that would have resulted in case of the application of a strategy with a process that deviated from the one suggested by the way the information was grouped.

To tackle this research question, we investigated purely perceptual effects of information presentation by applying color and spatial manipulations based on Gestalt principles in three Mouselab experiments and an eye tracking experiment with an open information matrix. Specifically, we used color to highlight either the rows (containing the cues) or the columns (containing the options) of the matrix used to present the decision task (Experiments 1 and 2 [both with Mouselab technique] and 4 [eye tracking technique]). In one of the experiments (Experiment 3 [Mouselab technique]), we slightly reduced the distance between either the information cells in the rows or those in the columns in order to induce the perception of rows and columns, respectively, within the matrix. We then investigated the direction of information search (cue- vs. option-wise) and classified strategies based on participants' choices[7]. The result was unambiguous: None of the perceptual manipulations influenced the decision process or the decision outcome; neither with closed information matrices (Mouselab) nor with open information presentation (eye tracking).

The major difference of our experiments in comparison to previous research showing information presentation effects was the lack of differential processing costs due to the information presentation manipulation. Therefore, we concluded that differential processing costs for different strategies are necessary for information presentation effects on decision

[7] In this dissertation, I will generally use expressions like "TTB users" or "participants classified as users of strategy x" when I refer to different groups of participants that we classified as users of a particular strategy. This wrongly suggests a clear allocation of participants to strategies without uncertainty. What the outcome-based strategy classification we applied (method by Bröder & Schiffer, 2003a) actually does, however, is to compare the vector of choices made by a participant to the different choice vectors representing the strategies under investigation. The strategy for which a participant's choice vector is most likely is thereby identified and the participant is classified as user of that strategy.

behavior. Purely perceptual manipulations of information presentation do not influence the decision behavior in multi-attribute decisions.

In short, people only follow processes suggested by information presentation manipulations if processing costs would otherwise make information acquisition more cumbersome. This is in line with a cost–benefit account of strategy selection. If the way information is presented facilitates a certain search rule, participants tend to rely on that rule (e.g., Bettman & Kakkar, 1977; Jarvenpaa, 1989) and thereby save costs (e.g., time and cognitive effort). If the way information is presented does not affect the costs of relying on one search process versus another, the information presentation does not enter the cost–benefit tradeoff. Not even the first few decision trials were affected by our perceptual manipulations. Participants did thus not even interpret the perceptual grouping as a hint when confronted with a new task and in complete oblivion of the best performing strategy.[8] Thus our experiments revealed a boundary condition of information presentation effects—but one that is fully compatible with adaptive cost reduction in strategy selection (e.g., Payne et al., 1993).

In the above-cited research on information presentation effects in multi-attribute decision tasks, information was presented in a pre-arranged way. That is, information was presented either in a well-structured matrix or grouped according to cues or options, and with information presentation manipulations favoring certain search processes and hindering others, decision behavior was shown to be affected. But the question how people would organize information themselves was disregarded (but see Coupey, 1994; Coupey & DeMoranville, 1996). We approached this question in the second and third manuscript.

[8] In order not to clearly favor a particular strategy, we used payoff structures that led to good outcomes for all strategies of interest.

When Decision Makers Compose Their Own Information Presentation: What Can We Learn About Decision Processes From Subjective Information Organization as a Process Tracing Tool?

Manuscript 2

Ettlin, F., Bröder, A., & Henninger, M. (2015). A new task format for investigating information search and organization in multiattribute decisions. *Behavior Research Methods, 47*, 506–518. doi: 10.3758/s13428-014-0482-y

In everyday decision situations, we might have to gather information from different places and organize it ourselves in a meaningful manner in order to be able to take a decision. But there is barely any research on subjective information organization (but see Coupey, 1994; Coupey & DeMoranville, 1996), and we argued that the lack of a standardized method for an easy assessment and evaluation of information organization was a likely cause of this negligence. In line with Kirsh (1995) who argued that organization may simplify one's representation of a task (see also, Cafferty, DeNisi, & Williams, 1986, on information organization and memory), we deemed information organization a potentially useful variable to reveal valuable insights into information usage in multi-attribute decisions.

We could identify only one previous approach that treated spatial information organization as a process variable in a similar way to how we conceived of it. This approach by Coupey (1994; Coupey & DeMoranville, 1996) allows for the analysis of information restructuring (incl. rearrangements) and is based on participants' notes. Coders are necessary to identify different kinds of restructuring in those notes and to classify them accordingly. Hence the method is cumbersome and rather subjective.

With the new task format we introduced in Manuscript 2, we provided an easy to use standardized method for assessing information organization and with it an index that can be computed immediately during the experiment and that expresses subjective information organization numerically. The new task format is computer-based and includes most of the process tracing possibilities provided by the Mouselab technique (Willemsen & Johnson, 2011) with the assessment of subjective information organization as a new, additional feature. Figure 1 shows a screenshot of this new method, the search and organization task (SOT).

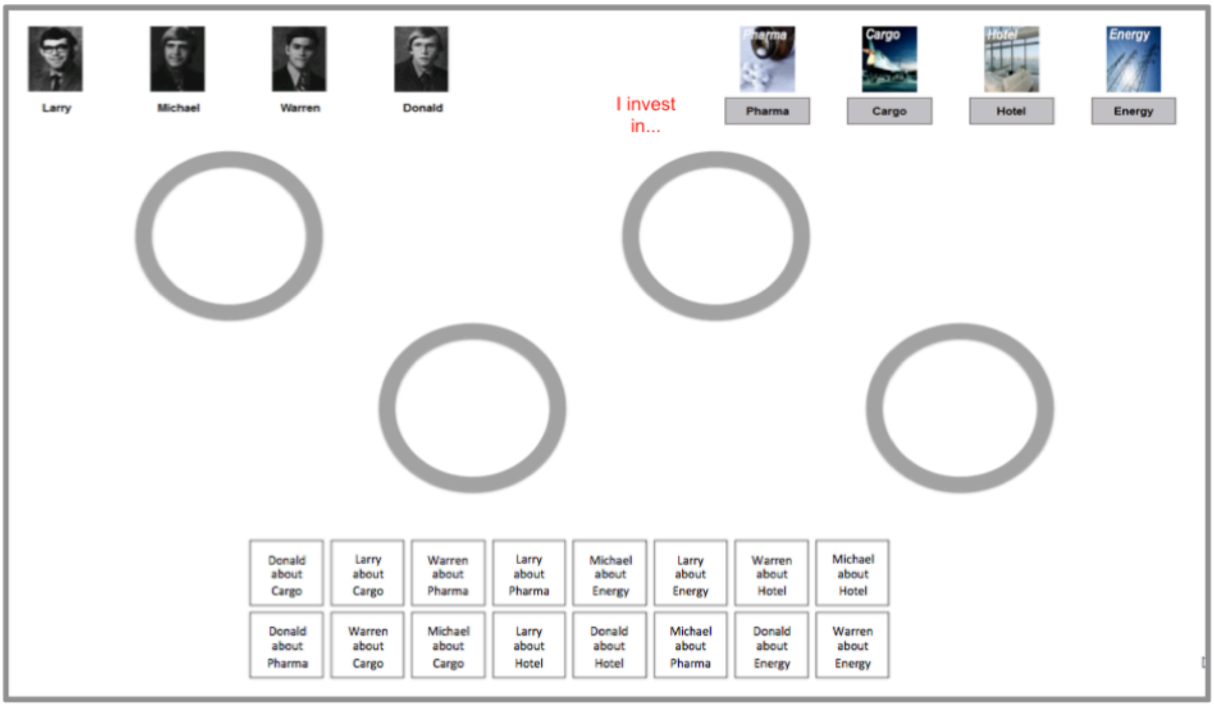

Figure 1. Screenshot of the search and organization task (SOT; figure taken from Manuscript 2): Experts (cues; upper left corner) provide information about investment alternatives (options; upper right corner). Further details are described in the text.

In the example presented in Figure 1, the 16 labels of the available information (4 cues * 4 options) are presented in the lower half of the screen, in random order. The cues are in the upper left corner and the options in the upper right corner. The basic functioning of the task is as follows: Participants acquire as many pieces of information as they need to make a decision by clicking on one of the 16 labels and then into one of the four circles. This places the chosen piece of information in the respective circle and reveals the value of the information. A maximum of four pieces of information fits within each circle, and when the participant ends a trial by clicking on one of the options to indicate her decision, the organization index (OI) is computed from the organization of information in the circles.

This index assesses whether more information from the same cue or about the same option is grouped in the individual circles. Negative numbers indicate cue-wise grouping of information while positive numbers indicate option-wise grouping, and the index ranges from –1 to +1 like Payne’s (1976) search index (SI). The SI was developed for Mouselab studies but it can also be assessed with the SOT. It is a relative measure of option- and cue-wise transitions in information search, and a negative index indicates cue-wise search while a positive index indicates option-wise search (for a critique of the SI, see Bettman & Jacoby, 1976; Böckenholt & Hynan, 1994; Shi, Wedel, & Pieters, 2013; but see the reply by Payne & Bettman, 1994, and the section on the simulation study in Manuscript 2).

To investigate statistical properties of the OI and to compare the index to the SI, we conducted a simulation study. We randomly sampled information in a 4 cues * 4 options scenario and then randomly placed each bit of information into one of 16 slots representing the circles of the SOT (four slots per circle * four circles): For random search and organization the expected mean SI and OI, respectively, were both zero (i.e., neutral with respect to cue- and option-wise search/organization). In addition, the distributions of the SI and OI were both symmetrical and very similar, and the two indices were a priori independent. The latter result ensures that empirically observed correlations are not methodological artifacts. Thus we showed that basic requirements for the OI are fulfilled.

Next, we conducted a validation experiment. We instructed one group of participants to use the compensatory EQW strategy and a second group to use the non-compensatory TTB heuristic. The main results were, first, participants searched more option-wise in the EQW

Condition and more cue-wise in the TTB Condition—like we had expected based on the respective strategy models, and because for TTB the search rule was actually instructed. Second, participants organized information more option-wise in the EQW Condition and more cue-wise in the TTB Condition. This again conformed to what we had expected: Participants organized information in a strategy-compatible manner. However, we observed a more clear-cut result in the EQW Condition than in the TTB Condition with respect to the preference for a strategy-compatible information organization. Therefore, we concluded that information organization might be of more importance for compensatory strategies, which are more cumbersome to apply per se (Christensen-Szalanski, 1978; Gigerenzer et al., 1999; Payne et al., 1993). Nevertheless, the observed patterns reflected the compensatory and non-compensatory strategies' processes. We thus concluded that the SOT, with the OI to quantify subjective information organization, may serve as a valuable process tracing tool to approach empirical questions about the decision process and the role of information organization in multi-attribute decisions.

However, the standardization introduced with the SOT's template and the OI came with the drawback of restrictions. For instance, the number of circles has to correspond to the number of cues and the number of options, which hence have to be identical. Without this symmetry, the number of circles provided on the screen would introduce bias. In addition, we provided the circles as a template for information organization rather than leaving organization completely up to participants. This restriction was necessary because the computation of the OI requires defined groups. I will return to this issue in the General Discussion.

Manuscript 3

Ettlin, F., & Bröder, A. (2015). *Strategy-compatible information organization is not generally preferred in multi-attribute decisions.* Manuscript submitted for publication

In the third manuscript, we applied the newly developed task to investigate the importance of information organization when strategies were not instructed but learned from outcome feedback. Because of the findings in the validation experiment (Manuscript 2), we speculated that information organization might be of higher relevance to users of compensatory strategies for building a coherent task representation than to users of more frugal strategies like TTB. Therefore, in the two experiments included in the third manuscript, we manipulated situational aspects with the goal to vary the importance of a strategy-compatible information organization, and we expected that, in situations that hinder convenient strategy application, a strategy-compatible organization would be strongly favored by all types of strategies.

In the first experiment, we applied two different payoff environments to reinforce the use of either WADD or TTB. Additionally, we manipulated the sequence in which information could be acquired such that it was either compatible or incompatible with the best performing strategy, and we also included the typical unrestricted search situation. We expected that the unbeneficial restriction would increase the preference for a strategy-compatible organization of information because the latter could then serve the construction of a coherent task representation against the obstructive manipulation of the information acquisition sequence by spatially grouping information that needs to be compared (TTB) or integrated (WADD).

Surprisingly, the acquisition restrictions did not encourage the hypothesized information organization behavior. On the contrary, information organization depended on acquisition sequence, and there was barely any influence of the decision strategy (i.e., classification based on participants' choices) on organization. The compensatory decision makers organized information only slightly more option-wise than the TTB users.[9] But in fact, there was a general preference for an option-wise information organization.

These results were surprising: Even when information acquisition was unbeneficial, TTB users did not rely on a strategy-compatible information organization to support a coherent task representation. We therefore conducted a further experiment in which we adapted the task as to maximally increase the importance of information organization. We separated information acquisition and organization from the decision phase to prevent the information from being available in working memory when participants made the decision. That is, they searched and organized information without deciding and, after a whole block of trials, they saw several of their own organizations again and only then they had to make a decision by relying on the information on the screen. In order to further increase the importance of preparing a meaningful organization, the maximum available time for each decision was 5 s and monetary compensation was fully performance contingent. We again used two payoff environments, one favoring TTB and the other one WADD. Information acquisition was either unrestricted or restricted to be incompatible with the best performing strategy (both factors between-subjects).—Despite all adaptations, the results of the previous experiment were replicated: Organization depended on search and differed only slightly between the compensatory strategies and TTB, and there was a general preference for organizing information in an option-wise manner.

These results deviated from our expectation that information organization would

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[9] The only subgroup of participants showing a clearly negative median OI (indicating cue-wise grouping) was the group of TTB users in the non-compensatory payoff environment who were forced to acquire the information in a cue-wise manner. But the 95% confidence interval comprised a large part of the total range of the OI (see Fig. 2, Manuscript 3). A comparison between conditions (irrespective of strategy classification) yielded positive median OIs for all six conditions.

mirror the strategies' processes. But whether the decision process and the choice level match as typically assumed in the strategy models is an empirical question (cf. Bröder, 2000b). Our findings are not the first ones to show discrepancies between the process and the outcome level (Jarvenpaa, 1989; Schulte-Mecklenbeck & Kühberger, 2014; Senter & Wedell, 1999) and thus a rather flexible linkage between the two.

Nevertheless, for compensatory strategies, subjective information organization was strategy-compatible and the idea that it supports a coherent task representation remained a plausible explanation. For TTB users however, the generally preferred option-wise organization deviates from the strategy's cue-wise procedure and must therefore have a different explanation. We speculated that TTB users use information organization to double-check their decision before indicating their choice; that is, they organize the information such that the units of choice (i.e., the options) are grouped together and that they can see them holistically even if they do not use a strategy that integrates information in an option-wise manner. This is in accordance with findings that information acquisition gets more option-wise in the final stage of the decision process (Russo & Leclerc, 1994; van Raaij, 1977). In fact, Russo and Leclerc (1994) referred to this final stage as the *verification stage*.

Despite the TTB users' incompatible organization behavior, the application of TTB was not hindered; not even when the acquisition restriction was unbeneficial as well. But in order to be in line with the adaptive decision maker considering processing costs in strategy selection (cf. Manuscript 1), it remained to be shown that TTB users were not only unaffected on the outcome level but that this was also true on the process level. That is, it remained to be shown that, with the current display, a strategy-incompatible information organization did not increase processing costs for TTB users. Only for users of compensatory strategies, there may be higher processing costs with a strategy-incompatible organization than with a compatible one. Hence the final manuscript focuses on the question whether strategies that are more cumbersome per se are more easily affected by higher processing costs due to a strategy-incompatible information presentation than more frugal, less cumbersome strategies.

Investigating Processing Costs: Are Different Strategies Differentially Susceptible to Processing Costs due to a Strategy-Incompatible Information Presentation?

Manuscript 4

Ettlin, F., & Bröder, A. (2015). *Strategy-incompatible information displays incur only subtle processing costs in multi-attribute decisions: Evidence from eye tracking data.* Manuscript submitted for publication

Processing costs induced by the way information is presented can be understood as a continuum (see Manuscript 1). At the minimum end, there are purely perceptual manipulations that do not induce differential processing costs for different strategies. Towards the maximum end, there are high costs like the extra time and motor activity required for a deviating strategy when information is grouped in different booklets (see Bettman & Kakkar, 1977). With respect to this continuum, the circle display used in the SOT supposedly lies somewhere in the intermediate range: It clearly separates different groups of information but does so by still providing all information on a single screen. With that display, we only observed strategy-compatible information organization for compensatory strategies that are assumed to be more cumbersome than non-compensatory strategies (cf. Christensen-Szalanski, 1978). With the type of display we used, a strategy-incompatible organization might thus have been strong enough to increase the processing costs for compensatory strategies, but not for the frugal non-compensatory TTB heuristic.

In two eye-tracking experiments, we pre-arranged all information in the circles of the SOT, either grouped according to cues or according to options (see Fig. 2). In the first experiment, we used a statistical payoff environment that was equally favorable toward TTB and WADD, and we analyzed gaze- and time-based measures. Since the number of people who used the non-compensatory TTB heuristic was extremely low, we omitted them from the analyses and focused on the compensatory strategies (cf. Gigerenzer & Todd, 1999: situations with openly displayed information are not expected to foster the use of TTB). By comparing the strategy-incompatible, Cue-wise Condition to the strategy-compatible, Option-wise Condition, we could only detect increased processing costs for a strictly compensatory version of WADD that integrates all available information. That is, with the classification procedure, the type of items, and the number of cues we used, three different versions of WADD differing in their compensatory nature could be distinguished; the more compensatory the nature to the WADD, the more information it tends to require.[10] In the current experiment, all three versions of WADD performed equally well. We generally treated these versions as one group of WADD users, but since we were surprised to observe barely any differences between the conditions with cue- and option-wise grouping, we conducted more detailed analyses that indeed revealed different effects on the different versions of WADD: Participants who used a strictly compensatory version of WADD (incl. EQW) looked back to previously inspected information more often, they fixated the information more and longer, and they took longer to decide. Participants using only partially compensatory versions of WADD only showed an increase in the number of times they looked back to previously inspected information; no further investigated variable was affected.

[10] In short, less compensatory versions of WADD need less information because it is not always necessary to acquire all information to determine that the current option cannot beat a previously inspected one. This understanding of WADD deviates from the original version of WADD which is assumed to acquire all available information (see section “The strategies” in the Introduction).

Figure 2. Adapted version of the SOT for eye tracking experiments with a cue-wise organization of information (upper panel) and an option-wise organization (lower panel; figure taken from Manuscript 4).

In the second experiment, we used a statistical payoff environment that favored a strictly compensatory WADD strategy in order to promote the use of the affected strategy. We observed a larger share of strictly compensatory strategies, and the results were replicated. In short, with our manipulation, which clearly separated groups of information but still presented them on one single screen, only participants using a very information-intensive, strictly compensatory strategy experienced higher processing costs when the information was grouped in a strategy-incompatible, cue-wise manner. These processing costs were subtle, however. They emerged as somewhat elongated decision times and more effortful gaze patterns.

In order to demonstrate that the organization behavior of TTB users observed in the experiments presented in Manuscript 3 was not maladaptive, we showed that they did not commit more errors when applying their strategy with a strategy-incompatible information organization (Manuscript 3). In the current experiments, due to a lack of data, we could not analyze potential processing costs for the application of TTB. But a strategy-incompatible organization did not affect partially compensatory strategies rendering an impact on the more frugal TTB unlikely. Subjective organization behavior (Manuscript 3) was therefore in line with the idea of the adaptive decision maker (e.g., Payne et al., 1993).

However, concerning strategy selection (i.e., concerning choices), adaptivity is questionable. In the second experiment (Manuscript 4), the number of participants using a strictly compensatory strategy was equally high in the strategy-incompatible, Cue-wise Condition as in the Option-wise Condition. Yet this could be explained by an adaptive cost–benefit tradeoff that may have led some participants to accept an increase in effort in exchange for a higher benefit.[11] But in the first experiment (Manuscript 4), all strategies

[11] This did not hold for EQW users. In the second experiment, EQW was separable from a strictly compensatory WADD strategy and performed worse than the latter. However, there were only four participants relying on EQW and we did therefore not analyze them separately.

performed equally well, thus this tradeoff did not apply, and nevertheless, strictly compensatory strategies were applied equally often with both kinds of organizations. This leaves serious doubt to people's awareness of subtle processing costs (cf. Schkade & Kleinmuntz, 1994, who observed that the objectively measured and the subjectively estimated effort were not fully in accordance). But the number of participants who presumably used a strictly compensatory strategy in Experiment 1 was rather low (n = 14), and inferring maladaptivity would therefore be premature.

General Discussion and Outlook

In a nutshell, we provided evidence for the key role of processing costs in information presentation effects on decision behavior and, inspired by surprising results from investigations of subjective information organization, we investigated different strategies' susceptibility to processing costs due to a strategy-incompatible information organization. Our research on information presentation effects (Manuscript 1) relied on perceptual grouping of information (i.e., no differential processing costs for different strategies). Previous research generally relied on rather strong information presentation manipulations inducing higher processing costs for strategies deviating from the process suggested by the information presentation. The latter type of manipulation affected decision behavior (e.g., Bettman & Kakkar, 1977; Bettman & Zins, 1979; Jarvenpaa, 1989). Our Gestalt-based perceptual grouping manipulations did not. Thus, if the way information is presented does not favor a certain kind of processing, that is, cue- or option-wise search for information, by inducing higher processing costs for deviating proceedings, there is no effect on decision behavior.

In subjective information organization, we did not start with the idea of investigating processing costs. Rather, the goal was to introduce subjective information organization as a process tracing measure for multi-attribute decisions. We therefore developed a new task format, the search and organization task SOT, and an index to quantify subjective information organization analogously to how it is typically done for information search. However, we were surprised to discover a general preference for an option-wise information organization. The compensatory WADD and EQW strategies and the non-compensatory TTB heuristic differ in that the former are of option-wise nature while the latter is of cue-wise nature, and the corresponding difference in information acquisition patterns is typically observed. But in subjective information organization, rather than relying on a strategy-compatible grouping of information, people generally organized information in an option-wise manner—except in the validation experiment but there might have been demand effects due to the instruction of decision strategies.

This led to the hypothesis that compensatory strategies suffer more easily from higher processing costs due to a strategy-incompatible information organization than the more frugal TTB heuristic. In a next step, we therefore used an adapted version of the SOT to investigate information presentation rather than subjective information organization and we observed higher processing costs with a strategy-incompatible compared to a strategy-compatible organization of information only for strictly compensatory, very information-intensive strategies. With these strategies, participants had indeed organized information in a strategy-compatible, option-wise manner in our previous experiments.

However, participants had *generally* grouped information in an option-wise manner, irrespective of their strategy. We hypothesized that this grouping was preferred also by users of the cue-wise proceeding TTB heuristic because it presents the units of choice (i.e., the options) holistically, and therefore allows for verification before the actual decision is indicated. This explanation for the preference for an option-wise organization may also apply to strictly compensatory strategies, though. It is therefore unclear whether the preference for an option-wise information organization with strictly compensatory strategies really emerged due to the sensitivity to subtle processing costs like more cumbersome gaze patterns and longer decision times. When considering the strategies participants used with the two different organizations in the experiments in the fourth manuscript, the frequency distribution did *not* support an adaptive cost–benefit tradeoff in strategy selection; the strictly compensatory strategies occurred equally often with a strategy-compatible and -incompatible information organization. However, statistical power was too low to conclude maladaptive behavior. Option-wise information organization with strictly compensatory strategies might thus have been preferred either for reasons of saving processing costs or for similar reasons that applied to other strategies; reasons which we did not further investigate and are thus subject to future research. Nevertheless, we showed that information-intensiveness makes a difference for the strategies' susceptibility to increased processing costs due to a strategy-incompatible information organization. Our way of grouping information was too weak to affect less information-intensive strategies; only the most information-intensive strategies for that task became more effortful to apply due to a strategy-incompatible versus a strategy-compatible information organization.

Moreover, from the investigation of subjective information organization, we learned that information search and information organization are of different importance for the different classes of strategies. In Manuscripts 2 and 3, we observed that the value for the search index SI was more extreme[12] for those classified as users of the non-compensatory TTB heuristic while the value for the organization index OI was more extreme[13] for those classified as WADD or EQW users. This result is very much in line with the strategy models: TTB has a clearly defined, step-wise search procedure (and decisions are made by simple comparisons), and WADD and EQW lack a clear definition of how information is acquired but they comprise a clearly defined and rather elaborate integration rule. The application of the latter may therefore profit more from a strategy-compatible information organization.

In the remainder of this General Discussion, I will focus on the role of processing costs in strategy selection and will then discuss possible limitations of the research presented in this dissertation. Finally, I will end with a brief Conclusion.

Processing Costs and Strategy Selection

Our investigations contributed to a better understanding of information presentation effects on decision behavior by identifying a boundary condition: the necessity of differential

[12] That is, it showed a higher deviation from zero. An SI of zero indicates neither cue- nor option-wise search.

[13] That is, it showed a higher deviation from zero. An OI of zero indicates neither cue- nor option-wise organization.

processing costs for different strategies induced by the information presentation. This is in line with approaches focusing on adaptive cost–benefit tradeoffs (Beach & Mitchell, 1978; Christensen-Szalanski, 1978; Johnson & Payne, 1985; see also Payne et al., 1993). Decision behavior is adapted to the way information is presented to evade high processing costs.

But also Rieskamp and Otto's (2006) strategy selection learning model (SSL) can explain adaptive strategy selection learning when information costs exist (see their Experiment 3). However, Rieskamp and Otto, for reasons of simplicity, only considered monetary reinforcements in the SSL model; other kinds of costs, like cognitive effort due to strategy application, that could affect initial strategy preferences and that could also be included in reinforcements were not considered and would have to be addressed in the future. In short, SSL is not blind to effort considerations. However, the role of effort is more explicitly discussed and investigated in cost–benefit approaches and we therefore contemplated our results from that point of view.

As mentioned in the introduction, the idea of cost–benefit tradeoffs was criticized in the fast and frugal heuristics framework (Gigerenzer & Todd, 1999; Rieskamp & Otto, 2006). But by assuming that the consideration of effort (e.g., due to the combination of a specific strategy and the way information is presented) feeds into the contemplations leading to the selection of a suitable strategy without assuming that the cost–benefit tradeoff is maximized, the demonic assumptions criticized by Gigerenzer and Todd (1999) can be lessened. Marewski and Schooler (2011) described that many recent approaches focusing on accuracy, effort, time, and cognitive capacity do so without assuming a "metastrategy" (e.g., Bröder, 2003; Bröder & Schiffer, 2006; Newell & Shanks, 2003; see also the section "Factors influencing strategy selection" in the introductory section of this dissertation). In other words, the focus is on investigating different *factors* influencing strategy selection. This focus, however, makes the approach more vague because the *mechanisms* for strategy selection remain obscure (for more details on this issue, see Marewski & Schooler, 2011).

Thus there is currently no quantitative model to *describe how* people trade off costs and benefits when selecting a strategy. But there is evidence that they contemplate costs and benefits at least in a rough manner. Rieskamp (2008) stated that cost–benefit tradeoffs could influence initial strategy preferences, and Bröder and Schiffer's (2006; reanalyzed by Rieskamp, 2008) data provided supportive evidence. Considering the initial preference for TTB in the non-compensatory environment in that data, Rieskamp stated that

> This is surprising considering that in similar studies an initial preference for WADD has often been observed. One explanation might be the high search costs. [...] This procedure might have made it more salient that a strategy that requires a lot of information cannot perform well, leading to an initial preference for TTB. (p. 268)

This explanation for the initial preference for TTB suggests at least an approximate form of a cost–benefit tradeoff. Also Bröder and Schiffer (see also Bröder, 2005) themselves had concluded that people seem to begin with a more conscious reflection of the strategies' adaptivity in a new task. But afterwards they switched to a routinized application of those strategies and further adaptations may then have occurred through slower learning processes (cf. Rieskamp & Otto's, 2006, SSL model).

In the data of Newell, Weston, and Shanks (2003; reanalyzed by Rieskamp, 2008), however, there was no initial preference for TTB even though there were relatively high information costs. But even if the participants had concluded—after a tradeoff—that they would fare best by not using too much information, they would not have been able to start with TTB right from the beginning because they were not informed about the cue validity hierarchy. To figure out that hierarchy, it presumably makes more sense to start with looking at a lot of information in order to learn as quickly as possible. In contrast, in Bröder and Schiffer's (2006) experiment discussed above, participants were informed about the cue validity hierarchy right from the beginning (they were not informed about the exact validities as emphasized by Rieskamp [2008], but they *were* informed about the hierarchy [A. Bröder, personal communication, March 17, 2015; see also Bröder, 2003, Experiment 2, from which the experiments in Bröder & Schiffer, 2006, were conceived]). Also the initial preference parameters observed in Rieskamp and Otto's (2006) four experiments are in line with a cost–benefit explanation: In Experiment 2, the typically observed WADD default was extinguished (on the WADD default, see also e.g., Bröder & Schiffer, 2006; Mata et al., 2007), and Rieskamp and Otto argued that the introduction of higher cognitive costs by changing the task such that acquired information did not stay available during a decision trial might have extinguished that default. In addition and in contrast to the other experiments, this experiment included 70 items (approx. 40 min) for participants to learn the cue validities before the actual decision task started. That is, the lower preference for exhaustive strategies might thus also have resulted from exhaustion due to the prior leaning phase. In Experiment 3, the acquired information stayed on the screen until a decision was made, but monetary information costs were introduced, and this also led to a somewhat weaker initial preference for WADD compared to Experiments 1 and 4 which were similar to Experiment 3 but dispensed with monetary cue costs.

To summarize, the strategy selection problem is far from being resolved, and specifically concerning cost–benefit approaches to strategy selection, there is a lack of quantitative models. Nevertheless, there is evidence for factors influencing strategy selection that suggest the consideration of effort and accuracy (see also Chu & Spires, 2003, on decision makers' *perception* of costs and benefits of decision strategies). Among those factors are differential processing costs resulting for the application of certain strategies due to the way information is presented. However, it remains to be investigated whether this only holds for high processing costs or whether people are also sensitive to subtle processing costs like more cumbersome gaze patterns.

Possible Limitations

Comparing different information presentation manipulations

In the first manuscript, we did not directly compare information presentation manipulations with and without processing costs; we only focused on different manipulations without differential processing costs for the strategies. However, various different rather strong manipulations had been investigated before and were shown to affect decision behavior (e.g., Bettman & Kakkar, 1977; Bettman & Zins, 1979; Jarvenpaa, 1989). In addition, the only research showing effects of a purely perceptual manipulation in a multi-attribute task (Bröder et al., 2013) did not manipulate the information presentation but the feedback presentation, and therefore the influence could not have stemmed from a direct guidance of information acquisition by the manipulation. Further hints for perceptual effects (Brandstätter & Gussmack, 2013; Pachur et al., 2013) did not stem from direct manipulations of information presentations but from a comparison of displays across experiments that were not designed to investigate information presentation effects. Thus the overall pattern of results speaks in favor of the processing costs explanation.

Investigating subjective information organization

In our experiments on subjective information organization, we observed that information organization was not random and we therefore concluded that information organization is important for strategy application and may even serve different purposes for different strategies. However, the display we provided as a template for information organization may have yielded demand effects. Even though we provided a template that was not biased in either the direction of cues or options, it may nevertheless have suggested to group information according to either of these criteria. However, in a pilot study (run by M. Oberländer for her Bachelor thesis) in which we did no restrict subjective information organization and in which we assessed information organization with an ordinal distance-based measure, we observed the initially hypothesized difference in organization behavior between participants classified as TTB and WADD/EQW users. But due to the elimination of restraints, further ways of organizing information become possible and need to be considered in analysis (e.g., analyzing the rank order of x- and y-coordinates of the organized information to detect patterns resembling matrix-like arrangements[14]).

Conclusion

In the beginning, I outlined two questions. The first question was whether information presentation *only* affects decision behavior if it induces differential processing costs for different strategies. It showed that differential processing costs are indeed a necessity: With purely perceptual manipulations, no information presentation effects occur in multi-attribute decisions.

The second question asked what we could learn from subjective information organization as a process tracing tool. The main result with respect to this question is a further demonstration of the overestimation of the conjunction between the process level (i.e., information acquisition and organization) and the outcome level (i.e., choice). This was impressively demonstrated by decision makers who applied TTB with a strategy-incompatible acquisition sequence as well as a strategy-incompatible organization of information without any losses in performance. Thus strategy application is much more flexible than suggested by the strategy models. Eventually, it will be crucial to learn more on factors effectuating a decoupling of the decision process and the decision outcome; for instance, because it has repeatedly been suggested to include process data, rather than only choice data, in strategy classification methods (e.g., Glöckner, 2009; Mata et al., 2007; Riedl et al., 2008).

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Statement of Originality

I hereby declare that I am the sole author of this thesis and have made use of no other sources than those cited in this work.

Place, Date	M.Sc. Florence Ettlin
______________________	______________________

Co-Authors' Statement

I hereby confirm that the following articles were primarily conceived and written by M. Sc. Florence Ettlin, School of Social Sciences, University of Mannheim.

Ettlin, F., & Bröder, A. (2015). Perceptual grouping does not affect multi-attribute decision making if no processing costs are involved. *Acta Psychologica, 157*, 30–43. doi: 10.1016/j.actpsy.2015.02.002

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Place, Date

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Appendix: Manuscripts

Manuscript 1

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Perceptual grouping does not affect multi-attribute decision making if no processing costs are involved

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ABSTRACT

Adaptive strategy selection implies that a decision strategy is chosen based on its fit to the task and situation. However, other aspects, such as the way information is presented, can determine information search behavior; especially when the application of certain strategies over others is facilitated. But are such display effects on multi-attribute decisions also at work when the manipulation does not entail differential costs for different decision strategies? Three Mouselab experiments with hidden information and one eye tracking experiment with an open information board revealed that decision behavior is unaffected by purely perceptual manipulations of the display based on Gestalt principles; that is, based on manipulations that induce no noteworthy processing costs for different information search patterns. We discuss our results in the context of previous findings on display effects; specifically, how the combination of these findings and our results reveal the crucial role of differential processing costs for different strategies for the emergence of display effects. This finding describes a boundary condition of the commonly acknowledged influence of information displays and is in line with the ideas of adaptive strategy selection and cost–benefit tradeoffs.

1. Introduction

Perceptual cues are often used to influence behavior. For instance, green lit signs point toward exits and should attract people's attention and in case of emergency evacuations, people are supposed to follow these signs. But aspects of perceptual design can also exert their influence in subtler ways. For instance, roads can be designed to create the illusion of increasing speed. By applying parallel stripes across the tarmac with increasing spatial frequency, the impression of increasing speed is induced, and with a curve ahead, the impulse is to slow down (Thaler & Sunstein, 2009). These behavioral effects notwithstanding, do purely perceptual design aspects of information presentation also influence the selection of decision strategies in information-based decisions?

The influence of information presentation manipulations on the decision process has long been taken for granted (Payne, Bettman, & Johnson, 1993), and was investigated already decades ago (e.g., Bettman & Kakkar, 1977; Bettman & Zins, 1979; Jarvenpaa, 1989; Russo, 1977). Decision makers adapt information processing to the way the information is presented (Bettman & Kakkar, 1977; Jarvenpaa, 1989).

Bettman and Kakkar's (1977) research is representative of the experiments that led to the above conclusion. In their Experiment 1 Bettman and Kakkar presented information on different alternatives of breakfast cereal brands in an alternative-wise (i.e., brand-wise organization), an attribute-wise (i.e., organized according to the different properties of breakfast cereals) and a matrix format. The alternative- and attribute-wise formats were implemented by organizing the information in different booklets; either one booklet per alternative or one booklet per attribute. This manipulation strongly influenced participants' information acquisition strategies. Bettman and Kakkar concluded that "consumers seem to process information in that fashion which is easiest given the display used" (p. 237).

There is plenty of evidence supporting this conclusion (see Section 1.2 below). However, the evidence for display effects on decision processes due to the grouping of information stems from experiments that used rather strong grouping manipulations. They relied on implementations of grouping that go beyond a manipulation of perceptual aspects of the display and which therefore imply high processing costs for strategies deviating from the one suggested by the display format.

Throughout this paper, we will consider the costs induced by different grouping manipulations as different implementations of processing costs. Specifically, we consider processing costs as a continuum. Processing costs like the ones resulting in Bettman and Kakkar's (1977) experiment are toward the high end of the continuum. With such manipulations, each booklet contains several pieces of information, grouped according

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to different dimensions to form the different experimental conditions. Similar manipulations group information on different sheets of paper instead of using different booklets. These manipulations require actual switching between different booklets or sheets of paper (motor activity) and therefore more time to perform these acts for strategies that deviate from the strategy suggested by the display than for the suggested strategy. The resulting costs for deviating strategies are considerable and we will refer to these high level processing costs as opportunity costs. Importantly, depending on the kind of grouping, some decision strategies are easier (e.g., quicker) to apply than others; in other words, the manipulations imply differential processing costs for different strategies. At the other end, at the minimum extreme of the processing cost continuum, there are merely *perceptual* information grouping manipulations. With these manipulations, strategies deviating from the one suggested by the type of grouping are not more costly to apply than the suggested one. As mentioned above, evidence for display effects has hitherto been based on manipulations inducing high processing costs (or opportunity costs) for deviating strategies, and possible effects of minimal cost manipulations like perceptual grouping manipulations are yet to be explored.

In a nutshell, grouping of information influences the decision process, but the boundary conditions for these effects are yet to be explored. That is, how far can these effects be pushed? Our goal in this article is to investigate whether purely perceptual grouping manipulations may also impact the decision process. Specifically, whether grouping of information, which induces no differential processing costs for different strategies, influences the decision process, and therefore, whether there is an influence of grouping of information that cannot be explained by adaptive behavior reducing processing costs.

Next, we will introduce the relevant decision strategies and summarize previous research on the effects of displays on decision strategies in multi-attribute decisions. Thereafter, we will outline our approach to investigating perceptual display effects and the details of our experiments. Our manipulations are based on Gestalt principles; that is, the display is manipulated such that different groupings of the task-relevant information should be perceived. We will present four experiments, including three Mouselab experiments and one eye tracking experiment. All of them show that there is no effect of purely perceptual Gestalt-like display manipulations on decision strategies in multi-attribute decisions. Finally, we will discuss our findings in light of previous research by highlighting the differences to our experiments, which may have caused the display effects in that previous research.

1.1. Decision strategies

In our investigations of perceptual grouping effects, we will focus on multi-attribute or multi-cue[1] decisions, which are characterized by various cues providing information about different choice alternatives (options). A number of different inference strategies are commonly investigated for these decision tasks and they are often divided into the two broad categories *compensatory* and *non-compensatory* strategies. The classes differ in their rules on how cue information is searched for, when information search is stopped and how the information is integrated.

One prototypical non-compensatory inference strategy was introduced by Gigerenzer and Goldstein (1996) as the Take-the-Best heuristic (TTB). With this heuristic, information search is cue-wise and goes through the cues in order of their validity. In a two-options decision, a TTB user would acquire the information from the most valid cue for both available options. If this cue discriminates between the options, the information search is stopped and the option favored by the most valid cue is chosen. Otherwise, information search is continued on the second most valid cue and goes on until a discriminating cue is found. The Equal Weight Rule (EQW; Dawes, 1979), a compensatory strategy, describes a strategy that integrates all cue information for each alternative and the option with the highest sum is chosen. Similarly, the compensatory Weighted Additive Rule (WADD, e.g., Payne, Bettman, & Johnson, 1988) prescribes option-wise integration of information, but with this strategy, each piece of cue information is weighted by its importance (i.e., a measure of the cues' validity) before the sum for each option is computed. These compensatory strategies are usually associated with option-wise search for information (e.g., Payne et al., 1988; but see Bröder, 2000b, for a critical discussion).

Various factors that influence the selection of decision strategies have been identified with research conducted in the fast and frugal heuristics framework (Gigerenzer, Todd, & the ABC Research Group, 1999; see Pachur & Bröder, 2013, for a review of factors influencing strategy use). In that framework, it is assumed that people possess an array of different cognitive strategies from which they can select adaptively depending on the task and situation. There is considerable evidence that strategy selection is indeed influenced by and adapted to the payoff structure (e.g., Bröder, 2003; Bröder & Schiffer, 2006; Rieskamp & Otto, 2006) and further task-relevant factors such as, for instance, time pressure (e.g., Pachur & Hertwig, 2006; Payne et al., 1988; Rieskamp & Hoffrage, 1999; but see Bröder, 2000a). But potential effects of purely perceptual manipulations have not gotten much attention, and to the best of our knowledge, the effect of perceptual grouping of information on strategy selection has so far not been investigated directly.

1.2. Influences of displays on strategy selection

The above-mentioned research by Bettman and Kakkar (1977) is but one example of the influence of the task display on people's decision behavior (e.g., Bettman & Kakkar, 1977; Bettman & Zins, 1979; Jarvenpaa, 1989; Russo, 1977; Schkade & Kleinmuntz, 1994; but see Sundström, 1987). Jarvenpaa (1989) reached a conclusion similar to Bettman and Kakkar's: "The results support the notion that decision processes are strongly contingent upon the graphical presentation format" (p. 298). In her experiment, she provided separate graphs for either alternatives or for attributes (i.e., a separate graph for each alternative with all the attribute information or a separate graph for each attribute containing information on all alternatives) printed on separate sheets of paper (and there was a mixed condition, as well). In addition, she provided participants with strategy instructions. Two of the prescribed strategies in the set required alternative-wise processing and the other two required attribute-wise processing. Combined with the different graphical formats, congruent and incongruent conditions resulted. The results mainly supported the hypotheses stating that the format is responsible for the direction of information acquisition and that congruence influences the evaluation phase. In congruent conditions, participants acquired and evaluated in the direction required in the task and supported by the format. But when there was incongruence between the search behavior implied by the graphical format and the kind of search pattern required to complete the instructed task, people searched in the simplest manner given the format, but they adapted information integration to the task instruction. Bettman and Zins (1979) showed that a mismatch between strategy instruction and display format severely increased decision times.

The above-mentioned effects primarily concern the information search process and Jarvenpaa's (1989) results imply that the search and choice rules do not always correspond. There is further evidence

[1] Note that our experiments investigate (multi-cue) inference tasks; however, multi-attribute preference tasks are similar with the crucial difference that there is no objective external criterion for choice quality. In the following, we will not make a difference between preferences and inferences, though, because we are mainly interested in information search patterns rather than in accuracy. The terminology for preferences usually is *alternatives* and *attributes*; with inferences, the terms *options* and *cues* are usually used.

by Senter and Wedell (1999) to show that information search and the choice rule are not always strongly linked. In their experiments with restricted search conditions, participants did not select their choice rule dependent upon the restriction. But there is evidence for salience effects affecting the choice rule: In memory-based decisions (i.e., the information is not presented during the decision process, but has to be retrieved from memory), strategy selection is affected by the (mis-)match between validity and salience: If highly valid information is salient, people rather use the non-compensatory TTB strategy. If information of low validity is highly salient, people integrate further (more valid but less salient) information in a compensatory strategy (Platzer & Bröder, 2012).

To get a better understanding of display effects, of which we just presented a few selected examples,[2] Kleinmuntz and Schkade (1993) separated component characteristics of displays and Schkade and Kleinmuntz (1994) directly tested these different aspects of displays against each other: The effect of *organization* (e.g., matrix or list, in which information was grouped according to alternatives with a random order for the listed attributes or vice-versa for the attribute-wise lists), *form* (numerical, verbal, or pictorial), and *sequence* (e.g., rows in a matrix were ordered according to the utility of the options vs. random sequence). The main conclusion drawn from the direct comparison between these different aspects was that they influence different stages of the decision process. The authors (Schkade & Kleinmuntz, 1994) explained the effect of these aspects of displays with the concept of cost–benefit tradeoffs (Beach & Mitchell, 1978; Payne et al., 1993). That is, if a task change leads to a change in the costs and benefits of different strategies and "if the change is large enough to alter the balance of costs and benefits, then the decision maker will switch strategies" (Kleinmuntz & Schkade, 1993, p. 223). Our manipulations would fit best into the category *organization*; that is, organization without opportunity costs. So we should keep in mind that organization was shown to mainly influence the information acquisition rather than the evaluation of information.

To summarize, "the fact that information display can affect decision behavior is now clearly established" (Payne et al., 1993, p. 52). But Payne et al. (1993) added that the relative magnitudes of different effects and possible interactions are not known. However, there is another point to make: The boundary conditions are not yet explored. One issue much of the above-described research has in common is the (high) processing costs for strategies deviating from the one suggested by the display. The salience manipulation comes much closer to our idea of purely perceptual manipulations. But effects of purely perceptual grouping of information that do not entail differential processing costs are yet to be investigated.

Nevertheless, there is also evidence suggesting the importance of perceptual aspects in decision making. Bröder, Glöckner, Betsch, Link, and Ettlin (2013) showed that the type of information highlighted in the feedback (options vs. cue information) influenced the decision process. However, in this case, the feedback rather than the task display was perceptually manipulated. In the domain of risky choice, there are findings suggesting that also purely perceptual aspects of the task display may influence the decision process (see Brandstätter & Gussmack, 2013; Pachur, Hertwig, Gigerenzer, & Brandstätter, 2013). Pachur et al. (2013) observed less option-wise search than previous process-tracing studies, and they speculated that this might be due to differences in information presentation. Also Brandstätter and Gussmack (2013) argued that many of these previous studies "merely support the Gestalt law of proximity, according to which people perceive entities that are close to one another as belonging together" (p. 187). However, these hints that there might be an effect of purely perceptual display manipulations do not stem from a single experiment comparing the different displays directly but rather from the comparison across different experiments targeting at other research questions.

In the current experiments, different perceptually manipulated displays in a multi-cue inference task are directly compared. The form of the information itself does not differ between the conditions. Rather, information presentation effects on decision behavior are investigated with purely perceptual manipulations applied to otherwise identical information. Information search behavior that deviates from the suggested search rule and focuses on another aspect instead is therefore not costly. Specifically, we use well-established and strong Gestalt principles to highlight either the cues or the options in order to suggest a cue- and option-wise search rule, respectively. We use Gestalt principles of similarity, common region, and proximity. The principle of similarity states that similar items (e.g., similar in terms of color or shape) are perceived as belonging together. The principle of common region states that objects enclosed by a common region are grouped together. Finally, according to the principle of proximity, more closely spaced items are perceived as a group (for examples of these principles, see Peterson & Kimchi, 2013). By use of these manipulations, we do not change the presentation of the pieces of information themselves. We only change the distances between them or the appearance of the area around them. All pieces of information are shown as verbal information in identical information cells, but either their relation to a certain option or their relation to a certain cue is highlighted.

1.3. Perceptual grouping based on gestalt principles

The choice of Gestalt principles as a basis for the perceptual manipulation of information displays seems a natural consequence given the lasting interest in them in visual perception research in the last century (see Wagemans et al., 2012 and Wagemans et al., 2012). However, for our task, it is relevant that grouping may influence behavior implicitly. That is, the task is not to explicitly state whether people see, for instance, rows or columns in the stimulus material, but the grouping should, in principle, have the power to influence behavior on a different task. In other words, the effect should not depend on people's awareness of the grouping.

In fact, the traditional view in Gestalt psychology held that perceptual organization, including grouping, occurs preattentively (Treisman, 1982; for an overview on perceptual organization and visual attention see Kimchi, 2009). Later, however, empirical research challenged this view (e.g., Mack, Tang, Tuma, Kahn, & Rock, 1992). But Moore and Egeth (1997) claimed to have shown that grouping without attention is possible. In a task in which participants had to judge which of two lines was longer, illusions could be induced by manipulations of background elements that were based on grouping principles to elicit the Ponzo illusion or the Mueller-Lyer illusion. Despite the occurrence of the illusion, the participants could not report the pattern of the elements in the background. But the approach by Moore and Egeth was criticized because the background elements were not completely task-irrelevant. For true situations of *inattention* (according to Mack et al., 1992), the unattended elements need to be different from the target items and need to be task-irrelevant. In the following, a lasting debate on the occurrence of grouping without attention was started.

The current state of evidence led Kimchi (2009) to conclude that "some forms of grouping and figure–ground segmentation can occur without attention, whereas other forms of organization require controlled attentional processing, depending on the processes involved in the organization and the conditions prevailing for each process" (p. 30). Grouping of columns versus rows by color similarity, for instance, can occur under inattention as was demonstrated by Russell

[2] Note that the above enlisted citations and selected examples are not meant to be an extensive review on display effects, rather they are an exemplary selection. Apart from different aspects of displays that can be manipulated, there is also research on very specific applications (e.g., the design of front-of-package food labels in research on consumer behavior; for a review, see Hawley et al., 2013).

and Driver (2005). In their task, the grouping was applied to circles in the background. These elements were completely task-irrelevant but they influenced participants' behavior on the main task (change detection task) even though people were not aware of them. When explicitly asked about it, participants could not reliably report the pattern. This distinction between explicit and implicit measures explains the diverging conclusions reached by Mack et al. (1992) in comparison to Moore and Egeth (1997) and Russell and Driver (see also Kimchi & Razpurker-Apfeld, 2004, and Shomstein, Kimchi, Hammer, & Behrmann, 2010, for evidence speaking in favor of grouping without attention).

Kimchi (2009) concluded that grouping of columns versus rows by color similarity is possible without attention and so is grouping of shape. However, when grouping of shape involves element segregation and therefore figure–ground relations between groups need to be resolved, effects of inattention (on implicit measures) are no longer detected (see Kimchi, 2009, for more information on the debate on grouping without attention).

To summarize, there is evidence that grouping by Gestalt principles is fairly automatic. Hence, we used the principles of common region, similarity, and proximity to provoke impressions of a row-wise versus column-wise organization of the information matrix.

If perceptual manipulations based on the Gestalt principles influenced decision behavior despite the absence of differential processing costs, one would expect participants to adopt a cue- or option-wise search pattern depending on the highlighted aspect. Moreover, since we designed our task such that all the strategies of interest (i.e., TTB and different versions of WADD) performed well, we expect that people adapt their choice rule accordingly. That is, as mentioned in Section 1, the different decision strategies are associated with different search rules: TTB implies cue-wise search and compensatory strategies are usually associated with option-wise search. Therefore, we expect our participants to develop a non-compensatory strategy (TTB) when the information is grouped according to cues and a compensatory strategy (WADD/EQW) when the information is grouped according to options (but see Jarvenpaa, 1989, and Senter & Wedell, 1999).

2. Experiments 1, 2, and 3: hidden information with Mouselab paradigm

Experiments 1 through 3 investigate purely perceptual display effects with hidden information; that is, the information was not openly displayed but needed to be acquired with a mouse device (Mouselab paradigm; Johnson, Payne, Schkade, & Bettman, 1989). The three experiments only differed in sample size and type of manipulation that was used (see below). Experiment 2 is an almost exact replication of Experiment 1 with a larger sample size in order to increase the power and with a more intense version of the perceptual manipulation used in the first experiment. Experiment 3 was a conceptual replication of Experiments 1 and 2 with a different perceptual manipulation (based on proximity). The three experiments were conducted in a temporal sequence corresponding to their number but due to the similarity of the experiments and the results, we will present them simultaneously.

2.1. Methods

2.1.1. Task and design

In Experiments 1 through 3, participants had to identify the best among four options in a multi-cue inference task with four cues (see details in Section 2.1.2). The information presentation was manipulated such that either the options or the cues were highlighted. We applied different colors to the background of the matrix containing the information (color manipulation; Experiments 1 and 2) or spaced the cells of the matrix differently (proximity manipulation; Experiment 3) to induce the impression of either rows or columns in a Gestalt-like manner. The highlighting of rows versus columns was varied between-subjects.

2.1.2. Materials and procedure

Experiments 1, 2, and 3 followed the same procedure. Participants were greeted and seated at one of six computers in separate cubicles in our lab. They signed a consent form, read the instructions on the screen and after completing a practice trial, started the decision experiment. All experiments consisted of 80 decision trials.

The task was to identify the best of the four available options in each trial by acquiring cue information and drawing inferences about the options. The goal was to maximize the points on one's fictitious account. The options in the task were four poker players. The cues were four experts who provided information about the poker players in the form of “yes” versus “no” bets. “Yes” meant that the expert thought that the respective player had good chances of winning; “no” meant that he did not credit the player good chances. An expert could also say “yes” to more than one player or to none at all.

The task was presented in a matrix format. The cue information was hidden in the matrix cells and could be revealed by clicking on the cells. Participants were allowed to acquire as many pieces of information as they liked but they could not indicate their decision before having acquired at least one piece of information. They could also reacquire information (the information was covered up again as soon as the mouse click was released). But the cue information was costly; for each piece of acquired information, 2% of the achieved outcome in a given trial was subtracted from that outcome before it was added to the participant's account. The 2% costs were also allocated to pieces of information that were reacquired. For loss trials (i.e., in some trials even the best option had a negative outcome), no cue costs were subtracted. The statistical environment determining the outcome values was partially compensatory.[3]

The experts (cues) were presented in the rows of the matrix in descending order of their validity (top to bottom) and participants were informed about this setup in the instructions. The players (options) were presented in the columns. The display containing the matrix looked rather different between the two conditions of each experiment. In Experiment 1, bars from light to dark blue highlighted the four rows of the matrix in the Row Condition. In the Column Condition, the same colors were used to highlight the four columns of the matrix (Fig. 1). The display in Experiment 2 highlighted rows and columns even more by extending the common regions to the cue names and option names, respectively (see Fig. 2). Also, the common regions were now separated by a gap. In Experiment 3, the principle of proximity was used for grouping as depicted in Fig. 3.

After the 80 decision trials in either the Row or the Column Condition, participants completed a post-experimental interview questioning them about their awareness of the manipulation. Finally, participants completed math tasks, which were assessed to pilot an unrelated research idea.

2.1.3. Participants

Fifty-four participants completed Experiment 1. Twenty-two of them were female and their mean age was 22 years ($SD = 4$). Experiment 2 had 102 participants (66 females, mean age = 21 years [$SD = 5$]) and Experiment 3 was completed by 84 participants (63 females, mean age = 21 years [$SD = 2$]). The majority of participants in each of the

[3] To compute the criterion value of each option, the information of Cue 1 through Cue 4 was weighted as follows in all three experiments: $122^*c_1 + 84^*c_2 + 59^*c_3 + 44^*c_4$, with c_1 to c_4 being 1 (“yes”) or −1 (“no”). When information was integrated, as with WADD, accuracy was higher than for TTB. But WADD requires more information and therefore induces higher information costs than TTB. Overall, a partially compensatory version of WADD performed best if only the required information was acquired rather than all information. The performance of the strategies of interest (TTB and three versions of the WADD strategy, which differed in the strength of their compensatory characteristic) was within approx. 10% difference.

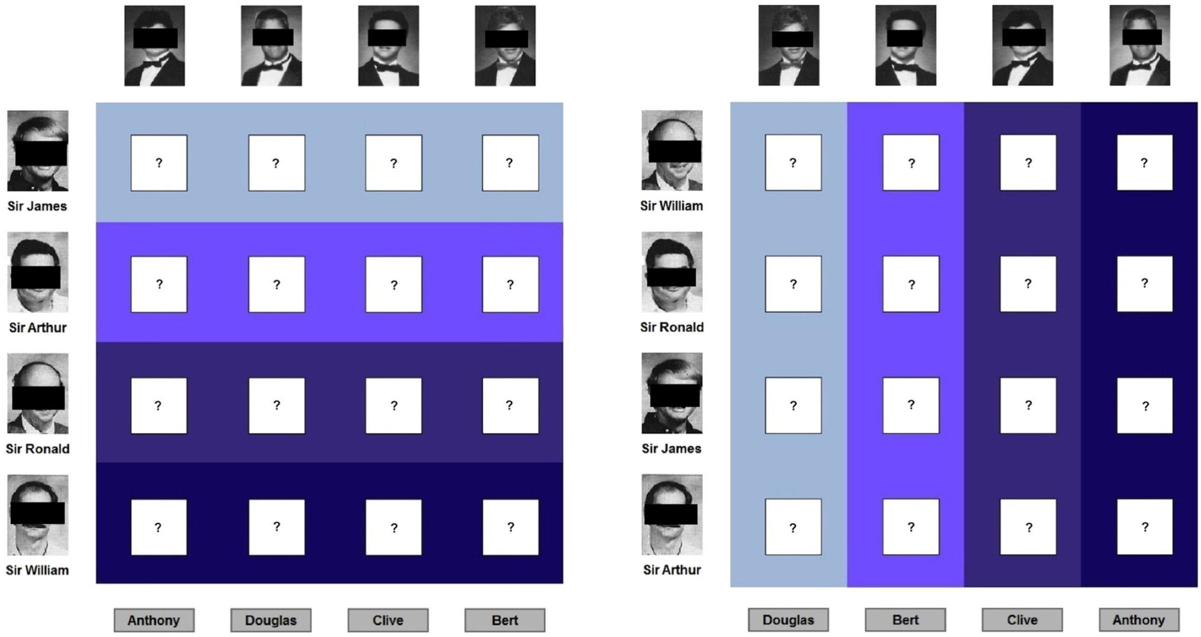

Fig. 1. The displays of the Row (left) and the Column Condition (right) in Experiment 1 (original faces not disguised).

experiments were students of the University of Mannheim. Participation was compensated with a fixed and an additional small performance-contingent amount of money.

2.2. Analyses and statistical hypotheses

The sequence of acquired information was traced and turned into Payne's (1976) search index (SI), which is a measure of relative cue- versus option-wise search for information (ranging from -1 to $+1$, respectively). For the classification of decision strategies, an outcome-based maximum likelihood classification method was used (Bröder & Schiffer, 2003). The 80 items in the experiments were constructed such that the different strategies of interest made the same choice predictions on some of the items but that for a combination of certain items, each strategy differed in its predictions from all other strategies. By comparing these strategy predictions to a participant's actual choices, each participant can be classified as a user of a certain strategy or he remains unclassified if he shows an unsystematic pattern of choices.

These two measures, the SI and the classification based on choices, relate to our hypotheses. We expect the participants to search in the

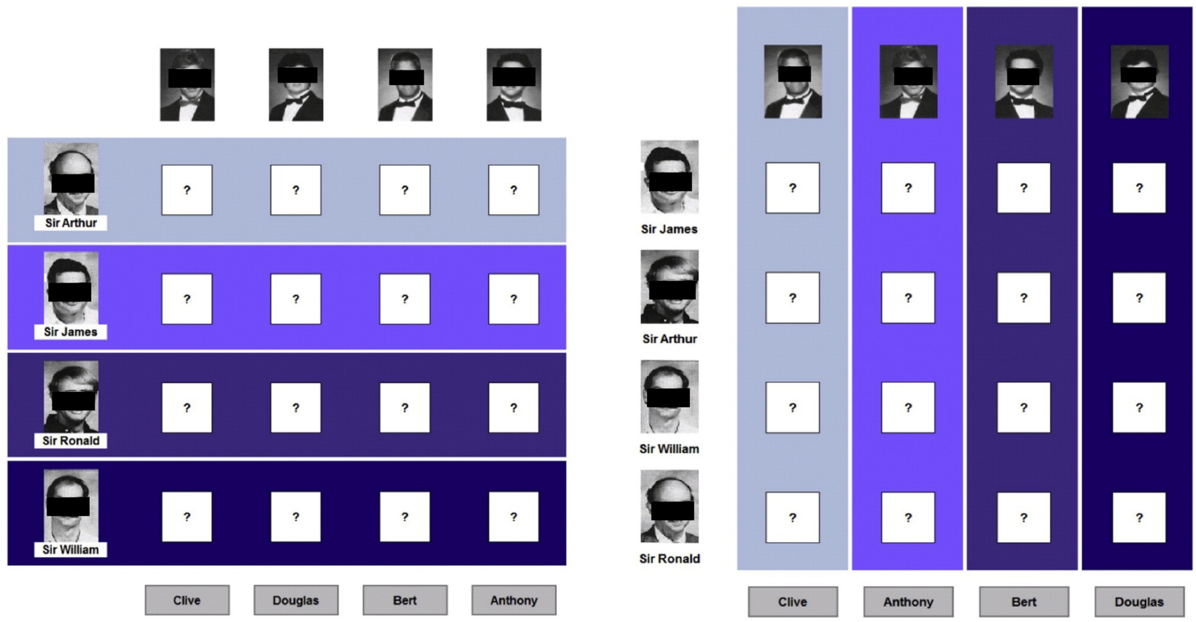

Fig. 2. The displays of the Row (left) and the Column Condition (right) in Experiment 2 (original faces not disguised).

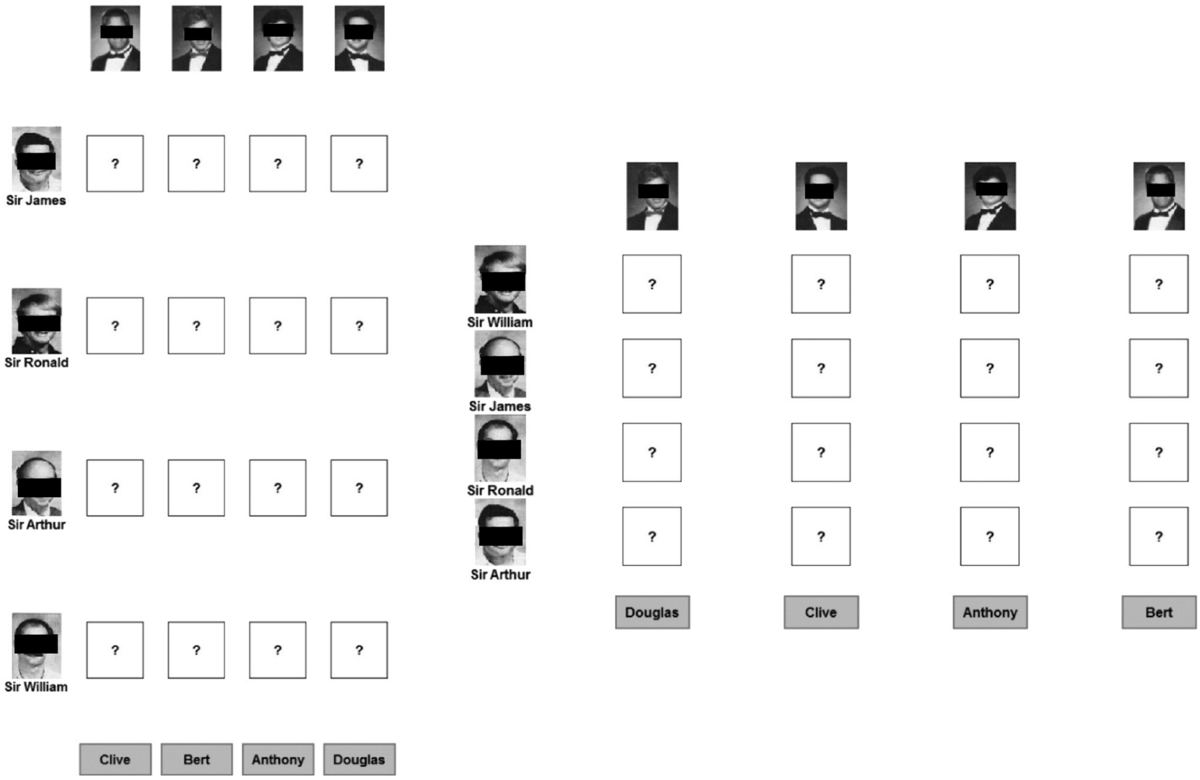

Fig. 3. The displays of the Row (left) and the Column Condition (right) in Experiment 3 (original faces not disguised).

direction of the highlighted concept; in other words, we expect them to use the colored bars (Experiments 1 & 2) and the difference in proximity (Experiment 3) as a guide for their search behavior. In terms of the SI this means that we expect negative numbers (cue-wise search) in the Row Conditions and positive numbers (option-wise search) in the Column Conditions. As explained above, these different search patterns are associated with different classes of decision strategies. In accordance with these strategy models, we expect more TTB users in the Row than in the Column Condition but more users of a compensatory strategy in the Column than in the Row Condition. However, there is also evidence by Jarvenpaa (1989) and Senter and Wedell (1999) suggesting that the link between search pattern and choice rule might be weaker than suggested in the strategy models.

2.3. Results

2.3.1. Information search behavior

Information search did not differ between the Row and Column Conditions in any of the three experiments (see Table 1). Due to the small sample, Experiment 1 has a rather low power of 0.57 (post-hoc power-analysis for independent sample *t*-test [one-tailed], Cohen's $d = 0.5$, $n_1 = 27$, $n_2 = 27$, $\alpha = 0.05$). In order to reach a power of .80, a larger sample was collected in Experiment 2. To achieve this goal, data of 102 participants were collected (a-priori power analysis for independent sample *t*-test [one-tailed], Cohen's $d = 0.5$, $\alpha = 0.05$, exact power = .81). Finally, Experiment 3 had a power of .73 (post-hoc power-analysis for independent

Table 1
Analysis of search behavior in Experiments 1, 2, and 3.

	Experiment 1		Experiment 2		Experiment 3	
	Experimental condition		Experimental condition		Experimental condition	
	Row $n = 27$	Column $n = 27$	Row $n = 51$	Column $n = 51$	Row $n = 42$	Column $n = 42$
M_{SI} (*SD*)	−0.29 (0.32)	−0.17 (0.55)	0.04 (0.48)	−0.04 (0.42)	−0.06 (0.46)	0.04 (0.52)
Mdn_{SI}	−0.26	−0.41	0.00	−0.03	0.00	0.04
t-Test	$t(41.81) = -1.00$, $p = .325$, Cohen's $d = 0.28$[a]		$t(97.95) = 0.93$, $p = .356$, Cohen's $d = 0.18$		$t(80.89) = -0.98$, $p = .328$, Cohen's $d = 0.22$	
U-test	$U = 379$, $z = 0.25$, $p = .802$, $r = .03$		$U = 1176.5$, $z = -0.83$, $p = .407$, $r = .08$		$U = 977.5$, $z = 0.85$, $p = .393$, $r = .09$	
BF[b]	3.14		4.38		3.82	

Note. Results did not differ when only classified participants were included (see Table 2 on strategy classification). Only the BF for Experiment 1 fell below 3 after reducing the sample to the classified participants (BF = 2.65).

[a] Data in one of the groups is not normally distributed.

[b] Scaled JSZ Bayes Factor computed on http://pcl.missouri.edu/bayesfactor with the scale factor, *r*, left at the default of 1.0 (for details, see Rouder et al., 2009). BF < 1 means evidence for H_1, 1 < BF < 3.2 means evidence (for H_0) that is not worth more than a bare mention, 3.2 < BF < 10 means substantial evidence in favor of H_0, 10 < BF means strong evidence in favor of H_0, a BF above 32 means very strong evidence and a BF above 100 stands for decisive evidence (categories according to Jeffreys, 1961).

sample t-test [one-tailed], Cohen's $d = 0.5$, $n_1 = 42$, $n_2 = 42$, $\alpha = 0.05$).

The power in Experiment 2 is decent; that is, if there is an effect (of medium size), the chance of observing it is admissible. In order to achieve an even higher power, we pooled the three experiments and compared the information search behavior in all three Row Conditions to the search behavior in all three Column Conditions. With a total of 240 participants this yielded a power of 99% (post-hoc power-analysis for independent sample t-test [one-tailed], Cohen's $d = 0.5$, $n_1 = 120$, $n_2 = 120$, $\alpha = 0.05$). With the probability of missing a difference (of medium effect size) as low as 1%, no difference was detected ($M_{\text{Row}} = -0.07$ [$SD_{\text{Row}} = 0.46$], $M_{\text{Column}} = -0.04$ 0.04 [$SD_{\text{Column}} = 0.49$; distribution not normal], $t(237.13) = -0.47$, $p = .319$ [one-tailed], $d = 0.06$; $U = 7385.00$, $z = 0.34$, $p = .366$ [one-tailed], $r = .02$).

However, an alternative way of showing that there is no difference is the Bayes Factor (BF). In fact, it is not possible to express evidence *for* the null hypothesis (no difference between the conditions) with a conventional significance test. BFs, however, can state evidence for either of the hypotheses, the alternative or the null (Rouder, Speckman, Sun, Morey, & Iverson, 2009). We used the default t-test for two-samples on the Web-based program (http://pcl.missouri.edu/bayesfactor) by Rouder and colleagues with the JSZ prior which serves as an objective prior for one and two-sample cases. For the computation of the BF in the case of a two-sample t-test, there are two models, a null model and an effect model. Both models contain parameters for the grand mean and the variance around the grand mean, and priors on both of these parameters are uninformative. The effect model additionally contains a parameter for effect size with a Cauchy prior on it. The Cauchy is broad and is suitable if one does not know much about the effect size. The resulting BF is above 3 in favor of the null model in all three experiments. This means that there is *substantial evidence* that the information search patterns did indeed not differ between the Row and Column Conditions. The BF rises to 8.85 when all three experiments are pooled.

One could argue, though, that after participants get familiar with the task, they follow the search pattern that matches the decision rule they are applying and which does not have to be influenced by the manipulation (see results on strategy selection below). Therefore, if there is an effect of the display, it may only emerge in the beginning when participants are unfamiliar with the task (cf. Orquin, Bagger, & Mueller Loose, 2013) and did not yet routinize a specific strategy. However, also when analyzing only the first three of 80 trials, there is no effect of the display manipulation on information search behavior. Fig. 4 corroborates these results and shows the development of the SI in the two conditions over the whole Experiments 1, 2, and 3.

2.3.2. Choices

The second hypothesis concerned the selection of a decision strategy. Classifying participants according to their choices and comparing strategy use between the Row and the Column Conditions again revealed no effect of the manipulation (see Table 2). In order to increase the power, we again pooled the three experiments, but again there was no influence of the manipulation ($\text{TTB}_{\text{Row}} = 15$ [19.7%], Compensatory $\text{strategies}_{\text{Row}} = 61$ [80.3%], $\text{TTB}_{\text{Column}} = 20$ [24.4%], Compensatory $\text{strategies}_{\text{Column}} = 62$ [75.6%], $\chi^2(1) = 0.50$, $p = .482$, Cramér's $V = .056$).

2.3.3. Match of information search behavior and choices

The results in Appendix A (Table A.1) show that, in general, the process data fit the outcome-based strategy classification. That is, participants who were classified as users of TTB searched more cue-wise, searched for less information, and needed less time for their decisions compared to participants who were classified as users of either WADD or EQW.

2.3.4. Post-experimental interview

In the post-experimental tasks, participants had to indicate whether they had noticed a pattern in the background of the decision task. In Experiment 1, only 13 participants (24%) gave a positive response. In a forced choice task with four options (see Fig. 5), 37 participants (69%) correctly differentiated whether they had been confronted with rows or columns and out of these, 26 (48% of total) succeeded in picking the correct color pattern.

In Experiment 2, 21 participants (21%) gave a positive response to the question whether they had noticed a pattern. In the forced choice task, 76 participants (75%) correctly differentiated whether they had been confronted with rows or columns and out of these, 50 (49% of total) succeeded in picking the correct color pattern. Finally, in Experiment 3, 35 participants (42%) gave a positive response to the question

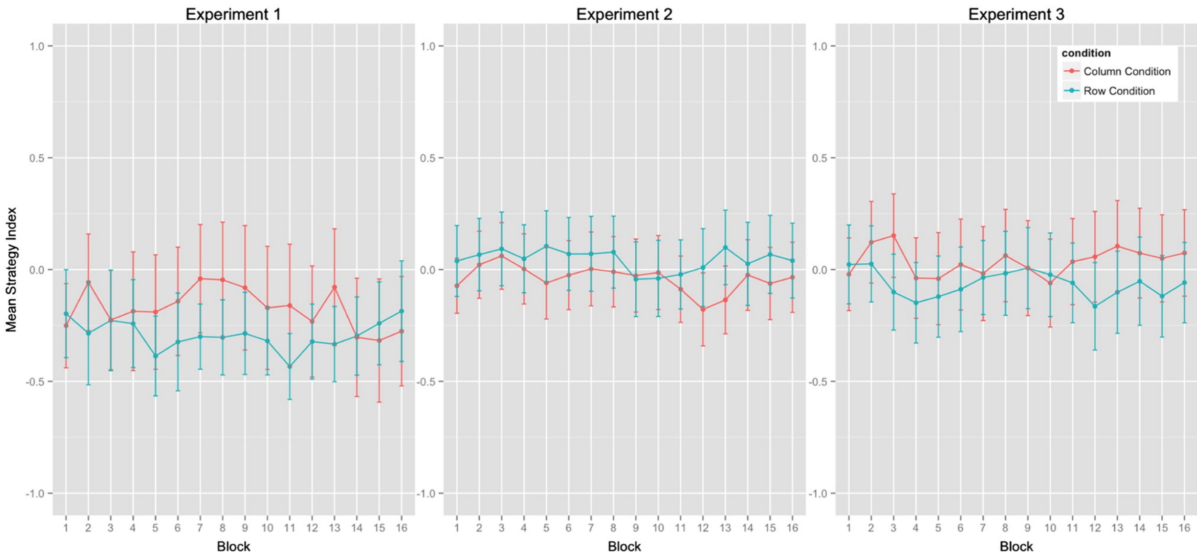

Fig. 4. Experiments 1 (left), 2 (middle), and 3 (right). Development of the SI over the total of 80 decision trials in blocks of 5 trials. Error bars represent 95% CI.

Table 2
Analysis of choices in Experiments 1, 2, and 3.

Experiment condition	TTB users[a]	Compensatory decision makers[a]	Unclassified[b]	χ^2(df), p[c]
Experiment 1				$\chi^2(1) = 0.75$, $p = .386$,
Row	4 (22.2%)	14 (77.8%)	9	Cramér's $V = .141$
Column	7 (35.0%)	13 (65.0%)	7	
Experiment 2				$\chi^2(1) = 0.09$, $p = .768$,
Row	8 (25.0%)	24 (75.0%)	19 [d]	Cramér's $V = .037$
Column	7 (21.9%)	25 (78.1%)	19	
Experiment 3				$\chi^2(1) = 0.74$, $p = .390$,
Row	3 (11.5%)	23 (88.5%)	16 [d]	Cramér's $V = .115$ [e]
Column	6 (20.0%)	24 (80.0%)	12 [f]	

[a] Percentages are strategy users (out of all classified participants) per condition.
[b] If there was more than 40% error for the best fitting strategy, the participant remained unclassified. Mean error of all classified participants was 23% in Experiment 1, 24% in Experiment 2, and 25% in Experiment 3.
[c] Does not include unclassified participants.
[d] Out of these, two participants could not be classified because the likelihoods for the use of TTB and one of the compensatory strategies were equal.
[e] 50% of cells had minimum expected frequencies below 5; Fisher's exact test, $p = .481$, odds ratio = 0.53.
[f] Out of these, one participant could not be classified because the likelihoods for the use of TTB and one of the compensatory strategies were equal.

whether they had noticed any kind of grouping of the cells in the decision task and 65 participants (77%) chose correctly in the forced choice task in which two patterns were presented; that is, row-wise and column-wise grouped cells.

Whether participants noticed a pattern or not did not make a difference with respect to the effect of our manipulations (see results in Appendix B): In Experiment 1, the search patterns did not differ between the Row and the Column Conditions, neither for those who indicated to have noticed a pattern nor for those who did not notice a pattern in the background of the task. Also the strategy use did not differ between the two conditions, neither for those who noticed nor for those who did not notice a pattern. The same was true for Experiment 2; the results did not differ depending on whether a subject indicated to have noticed a pattern or not. And also in Experiment 3, whether the participants had noticed any kind of grouping or not did not affect the results.

2.4. Discussion

In short, in Experiments 1 to 3, the perceptual manipulations of the display did not influence participants' decision behavior at all. Neither search patterns nor decisions differed when the focus was laid upon the cues versus the options. This was true for each experiment and even for a highly powered one-tailed t-test conducted for the entire sample. Since accepting the null hypothesis is problematic in the Fisherian tradition of null hypothesis testing, a Bayesian analysis confirmed the result and provided substantial evidence for the null hypothesis over the alternative. At first glance, this consistent negative result and the absence of even a descriptive trend clearly speak against the ubiquity of perceptual influences on decision behavior.

But several issues might be discussed with respect to the validity of this conclusion. It might be that participants showed rather inconsistent behavior, for instance, in the way they acquired information. The SI's focus on cue- versus option-wise search might not be able to capture the search patterns and this might have resulted in the SI values close to zero. However, we observed that participants' search and decision rules matched as predicted in the strategy models. That is, the SI showed the expected difference between TTB users and those who used WADD or EQW. But while TTB users had a clearly negative SI indicating cue-wise search behavior, and while EQW users searched rather option-wise as indicated by a positive SI, WADD users also searched rather cue-wise or were close to neutral with respect to the two dimensions (SI close to 0). This systematic pattern of results speaks against the concern that the SI was invalidated due to inconsistent behavior with respect to cue- versus option-wise search.

A further concern might arise from the observation that many participants indicated that they were not aware of a pattern in the background of the display. However, as introduced in the beginning, there is evidence that Gestalt principles influence behavior even without attention (Kimchi & Razpurker-Apfeld, 2004; Moore & Egeth, 1997; Russell & Driver, 2005; Shomstein et al., 2010) and therefore, awareness is not necessary. Furthermore, when participants aware and unaware of the display structure were analyzed separately, there was still no consistent effect, not even a consistent descriptive trend.

To conclude, in Mouselab experiments, perceptual grouping does not influence the decision behavior. If there are no differential processing costs for different strategies induced by the display manipulation, there is apparently no influence. However, there were general information acquisition costs in our experiments. Importantly, these general costs did not differ between the conditions in Experiments 1, 2, and 3. That is, in both conditions of our previous experiments, more than perception and attention had to be invested by participants because they had to move the mouse and needed to click on the desired information in order to acquire it. Franco-Watkins and Johnson (2011) showed a decrease in the number of acquisitions and a decrease in duration of attendance to acquired information over the course of a Mouselab experiment (i.e., closed information board). These effects did not occur with the open information board and they suggest higher costs (transaction costs as Franco-Watkins & Johnson, 2011, called them) for closed information boards. In addition, in our experiments, the information search caused monetary costs. Because of these costs, participants may have wanted to reduce the number of clicks and may therefore have searched strategically, in a manner that allowed early exclusion of unwanted options. Hence it may be that as soon as there is any kind of cost for information search in general (i.e., monetary, mouse clicks, etc.), strategic aspects might be very strong and might override subtle aspects such as perceptual manipulations.

Therefore, we added a fourth experiment with the goal of investigating whether purely perceptual grouping manipulations are effective in situations with purely perceptual search for information where no search costs except eye movements are involved. In order to get rid of monetary and mouse-clicking costs, we used an open information board and traced participants' search behavior with an eye-tracking

Fig. 5. The four options of the forced-choice task in the post-experimental interview in Experiments 1, 2, and 4 (eye tracking experiment; see below).

device. With this setup there is no cost of getting the information; neither monetary nor physical (apart from moving one's gaze over the display). If indeed search costs highlighted strategic aspects of information search, which predominated subtler effects, the effect of perceptual grouping—if it exists—should emerge with an open information board where information comes for free.

3. Experiment 4: open information board with eye tracking

Experiment 4 is the final attempt to observe display effects of grouping information in a purely perceptual way. We stripped the task of any costs that might highlight strategic aspects in information acquisition. With this setup, all information is present for free during the whole decision phase. Thereby we eliminated the minimal motor (and time) costs resulting due to the necessity to click on the information cells—costs that may have worked against a subtle effect of perceptual grouping.

In the current experiment, the open information board was a color-manipulated matrix like that in Experiment 2. If the manipulation of the display influences people's decision behavior in this setting, it means that grouping of information does only influence people in tasks with purely perceptual information search but it does not have an influence anymore as soon as additional factors such as motor actions (like the ones resulting from the use of a mouse) or monetary costs are added.

3.1. Methods

3.1.1. Materials and procedure

Apart from the use of an open information board and eye tracking, the experiment was almost identical to Experiment 2. The same color manipulation of the display was used (see Fig. 2) and also the task and story were the same. However, instead of having to click on the matrix cells in order to get the information, participants just had to look at the cells containing “yes” or “no” hints.

In each session, one participant and either one or two experimenters were present. Upon arrival, participants signed a consent form and indicated whether they wore glasses, contact lenses, or mascara. These details were recorded as possible explanatory factors in case of poor gaze data quality. Next, participants were seated in front of the eye-tracking device (SMI, RED500, 500 Hz sampling rate, binocular tracking). The experiment was presented on a 1680×1050 pixel screen.

After the participants' position was adjusted such that tracking was possible for the whole area of the screen, gaze recording was calibrated. The calibration and validation procedure was followed by the instructions for the decision task and if the participants had no more questions after a practice trial, they started with the first of 80 decision trials. The items were the same as in Experiments 1 to 3, but the payoff structure differed. There were no monetary cue costs anymore and therefore, the payoff structure[4] was changed to be less compensatory in order not to put TTB at a clear disadvantage when all the information was displayed for free.

As before, the display color manipulation was between-subjects and after 80 decision trials, participants completed the same post-experimental interview as in the previous experiments. Then participants completed the math tasks also presented after Experiments 1 to 3. Finally, all participants continued with a second, unrelated eye tracking experiment.

3.1.2. Participants

Sixty participants completed the eye tracking experiment. Six participants were excluded; one participant was excluded because, after the experiment, the participant told the experimenter to be informed about the task and the decision strategies. Five participants were excluded because of lacking quality of gaze data (see Section 3.3.1). Therefore, 54 participants remained in the final sample (34 females, mean age = 21 years [$SD = 6$]). The majority of participants were students of the University of Mannheim. Each of the five best performing participants won 10 Euros. In addition, every participant was reimbursed for the second unrelated eye tracking task.

[4] Payoff structure in the eye tracking experiment: $94^*c_1 + 58^*c_2 + 30^*c_3 + 22^*c_4$. To prevent that people remembered exact criterion values for specific patterns, we added a random number from the range of -5 to $+5$ to each outcome value.

Table 3
Analysis of search behavior in Experiment 4.

	All trials	
	Experimental condition	
	Row $n = 25$	Column $n = 29$
M_{SI} (*SD*)	0.20 (0.20)	0.21 (0.13)
Mdn_{SI}	0.23	0.22
t-Test	$t(40.84) = -0.27$, $p = .791$, Cohen's $d = 0.08$.	
U-test	$U = 369$, $z = 0.11$, $p = .910$, $r = .02$	
BF[a]	4.74	

[a] See note on BF in Table 1.

3.2. Analyses and statistical hypotheses

Again, Payne's (1976) SI was used to quantify information search behavior. However, the sequence was not computed from clicks on cells but from fixations.[5] Each cell was an individual AOI (each AOI was 100×100 pixels). When participants placed subsequent fixations on two AOIs in the same row, a cue-wise transition was counted. When subsequent fixations occurred on two AOIs in the same column, an option-wise transition was counted (if there were fixations on whitespace in between, they were ignored). The SI was computed from these transitions. The procedure for the strategy classification was identical to the one in Experiments 1 to 3 and so were the hypotheses concerning search behavior and strategy selection.

3.3. Results

3.3.1. Quality checks for gaze data

As a first criterion for exclusion, we checked the validity of the calibration and excluded four participants because of x- or y-deviations above 1.0°. Second, we checked the amount of available data per trial. For most of the remaining participants, there was only 0 or 1 trial for which the total duration of all events (fixations or saccades) accounted for less than 60% of the trial duration. However, for one participant, this was the case in more than half of the trials. This participant was excluded resulting in a final sample of 54 participants.

3.3.2. Information search behavior

Also with the open information board, information search did not differ between the Row and Column Conditions (see Table 3). The same is true for the search behavior in the first three decision trials. The development of the SI over the whole experiment is depicted in Fig. 6 and descriptively shows that the search pattern was unaffected by the perceptual manipulation.

3.3.3. Choices

Again as in the previous experiments, also the decision behavior did not differ between the Row and the Column Conditions (see Table 4).

[5] We used SMI's BeGaze (version 3.0) software to detect events in the gaze data (high speed event detection: Saccade detection parameters: min. duration = 22 ms, peak velocity threshold = 40°/s, min. fixation duration = 50 ms. Peak velocity window: 20% to 80% of saccade length). For each decision trial, the first fixation was excluded.

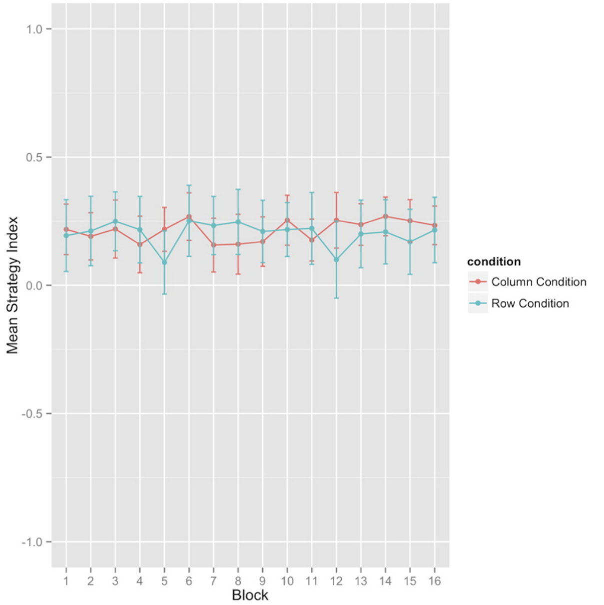

Fig. 6. Development of the SI over the total of 80 decision trials in blocks of 5 trials in Experiment 4. Error bars represent 95% CI.

3.3.4. Match of information search behavior and choices

Also in the eye tracking experiment, the process measures differed between the strategy classes in the direction predicted by the models (see Appendix A; Table A.2), at least descriptively. Not all differences reached the conventional level of significance and most of the effect sizes were smaller than those in Experiments 1 to 3 with the closed Mouselab paradigm. Also, the typical cue-wise information search pattern for TTB users was not observed.

It must be pointed out, though, that the results for TTB users are based on seven participants only. This low rate of TTB users in Experiment 4 is not surprising, however, given the setup of the task. Situations in which information is provided for free are not the ones in which TTB was thought to find application (Gigerenzer & Todd, 1999). The fact that we did not observe the typical information search process for TTB might be due to a lack of the necessity to invest resources (money, time, energy etc.). If the information is all readily available "at a glance" and easy to compare and integrate, then why should people ignore it (cf. Söllner, Bröder, & Hilbig, 2013)?

Moreover, the SI might just not be able to properly capture the information acquisition process in eye tracking studies with openly displayed information. Shi, Wedel, and Pieters (2013) criticized the SI as a measure of information search in eye tracking studies and showed that people switch between cue- and option-wise transitions once every less than 2 s. They argue that the situation in such eye tracking experiments differs from the typical Mouselab situation, for which the SI was developed, because the latter requires hand movement to acquire information and therefore represents more deliberate processes. However, we argue that, given the manipulation and for reasons of comparability to the results of Experiments 1 to 3, the SI is still an appropriate measure to test our hypothesis on search behavior.

Table 4
Analysis of choices in Experiment 4.

Experimental condition	TTB users	Compensatory decision makers	Unclassified[a]	χ^2(df), p[b]
Row	4 (16.0%)	21 (84.0%)	0	$\chi^2(1) = 0.38, p = .537$,
Column	3 (10.3%)	26 (89.7%)	0	Cramér's $V = .084$[c]

[a] If there was more than 40% error for the best fitting strategy, the participant remained unclassified. Mean error of all classified participants was 12%.
[b] Does not include the category "Unclassified".
[c] 50% of cells had minimum expected frequencies below 5; Fisher's exact test, $p = .692$, odds ratio = 1.64.

3.3.5. Post-experimental interview

Eleven participants (20%) responded positively to whether they had noticed a pattern in the background of the decision task. In the forced choice task with four options (see Fig. 4), 44 participants (81%) correctly differentiated whether they had been confronted with rows or columns although only 23 (43%) succeeded in picking the correct color pattern. As in the previous experiments, the results did not differ for participants who indicated having noticed a pattern and those who did not (see results in Appendix B).

4. General discussion

In short, none of the perceptual manipulations (color and proximity) had an effect on decision behavior; neither with a closed information board in the Mouselab paradigm nor with an open information board which eliminated all explicit (monetary) as well as presumably most implicit general search costs (mouse movements) in the task. Moreover, neither participants who did not notice the manipulation nor those who did were influenced by the perceptual manipulation. For identical information and when there are no opportunity costs for mismatching strategies, perceptual manipulations to displays do not influence strategy selection in multi-attribute tasks, thus seriously qualifying the "established fact" of display effects stated by Payne et al. (1993).

The lack of influence of the perceptual grouping manipulation on the decision rule is not as surprising (cf. Jarvenpaa, 1989, and Senter & Wedell, 1999) as the lack of impact on the search behavior, however. As mentioned in the beginning, Schkade and Kleinmuntz (1994) already showed that different aspects of displays influence different phases of a decision. The manipulation of organization, like our manipulations can be best described, does not so much influence the evaluation but rather the acquisition phase. But—also contrary to speculations on diverging results in risky choice due to Gestalt-like effects (see Brandstätter & Gussmack, 2013; Pachur et al., 2013)—we could not find support for effects on information acquisition in a multi-cue inference task. In fact, information search behavior was not even influenced by the display manipulation in the first few trials when participants started with the completely unfamiliar task and when display effects were shown to exert a stronger influence than after repeated decisions (Orquin et al., 2013).

Due to the use of different process tracing approaches, the requirements for information acquisition in Experiments 1 to 3 differed from those in Experiment 4 (cf. Franco-Watkins & Johnson, 2011). However, a perceptual manipulation focusing on cues or options did not influence decision behavior whether mouse movements were required (Experiments 1 to 3) or whether information could be acquired at nothing but the cost of eye movements (Experiment 4). Moreover, when the information was openly presented, also the relation of the strategies (compensatory vs. non-compensatory), specifically, of the decision rule, to the decision process was not as pronounced as in the Mouselab setting with hidden information. It seems that the open presentation of information invites for an overall evaluation of options.

Previously observed effects of grouping of information like the ones shown by Bettman and Kakkar (1977) and Jarvenpaa (1989) thus seem to crucially depend on the induced processing costs. Decision makers adapt their strategies to the information display if this adaptation saves costs. As long as there are no differential opportunity costs for different strategies, information display manipulations leave decision makers unaffected. This result is in accordance with the idea of cost–benefit tradeoffs (Beach & Mitchell, 1978), but it seems to deviate from the findings by Bröder et al. (2013) who showed effects of differential guidance of attention on the development of decision routines.

Even though their manipulation was free of opportunity costs, there is one crucial difference between their and our experiments: They manipulated the feedback display, whereas we manipulated the task display itself. Therefore, the influence in Bröder et al.'s experiment cannot have been the result of perceptual influences that guided the information search. Rather, the highlighting of the cue information or the option itself in the *feedback* may have been used as a hint for what to focus on in the *task*. Hence, the shift of attention was semantically mediated. There cannot have been any direct visual guidance for the decision behavior because the task display was "neutral" and identical across conditions.

Another finding that seems to conflict with our results is the evidence for the influence on search behavior exerted by the switching of rows and columns in matrices of multi-attribute tasks. The review and own experiments by Scherndl, Schulte-Mecklenbeck, and Kühberger (2013, July) revealed that in an early reading and screening phase, search behavior is more attribute-wise when attributes are presented in rows than when they are presented in columns. Therefore, the effect of the rows-versus-columns manipulation seems to stem from people predominantly searching row-wise, no matter how the information is oriented. The effect is not due to a change in behavior, but due to (at least partially) *constant* behavior on changed displays. That is, routines (such as reading directions) may affect information search behavior even though they are irrelevant for the task at hand.

But even though we did not observe any effect of perceptual grouping manipulations on decision behavior, we also did not observe strong evidence for the null hypothesis as quantified by the Bayes Factor (BF) in each single experiment. But when we pooled the three Mouselab experiments, we got a BF of 8.83 signifying substantial evidence for the null hypothesis. The mediocre evidence in individual experiments is surprising given that the descriptive difference we observed for information search (on the SI measure) was very low or virtually nonexistent. In Experiment 2, in which we increased the sample size in order to achieve a good power, we observed an SI difference between the two grouping conditions of 0.08, but still the BF only amounted to 4.38. Thus, these results show the importance of adequate sample sizes: Even for results that seem quite clear on the descriptive level and even if the significance tests support that conclusion, the amount of evidence for the hypothesis in question (in our case the null) might not be decisive. However, one conceptual advantage of the Bayesian approach is the possibility to combine evidence from different, but similar experiments in order to increase the diagnosticity of the data. Nevertheless, the results from the single experiments underline the necessity to obtain diagnostic data also for a Bayesian analysis.

So we did not detect any effect of perceptual grouping on decision behavior. One critical note on our results might be that the Mouselab paradigm is too blunt to detect strategy differences. However, the findings by Bröder et al. (2013) show that the paradigm we used is suitable to investigate effects of even subtle influences. In fact, we used the exact same paradigm and cover story as Bröder et al. in their Experiment 1 (see their Fig. 1) with which they showed that a subtle manipulation of the feedback display strongly influenced whether participants developed a strategy routine or an option routine.

The fact that the information board setup used here is suitable for investigating strategy shifts due to various kinds of costs or environmental payoff structures was also shown by abundant research conducted in the fast and frugal heuristics tradition (e.g., general processing costs due to divided attention: Bröder & Schiffer, 2003; other costs or payoff structure: e.g., Bröder, 2000a; Newell & Shanks, 2003; Söllner et al., 2013). Hence, our finding that perceptual grouping did not influence search behavior cannot be attributed to the insensitivity of the Mouselab paradigm to detect influences, since many manipulations that *did* change costs have been shown to affect behavior in this paradigm.

5. Conclusion

The results of four experiments relying on manipulations based on Gestalt principles strongly suggest that purely perceptual grouping manipulations of information displays in multi-attribute decision tasks do not influence strategy selection or even information acquisition. Previous results showing display effects on strategy selection are probably grounded in the opportunity costs of applying strategies deviating from the one suggested by the display manipulation. To conclude, our experiments show one boundary condition of display effects. At least with the manipulations we used, people showed no sign of following suggestions for strategy selection cued by completely task-irrelevant perceptual manipulations of the display. Hence, effort–accuracy frameworks (Beach & Mitchell, 1978; Johnson & Payne, 1985) are currently sufficient to account for display effects as reported in the literature. According to our results, no additional "bias" of merely perceptual nature has to be explained.

Appendix A

Table A.1
Process variables and strategies in Experiments 1, 2, and 3.

	Experiment 1		Experiment 2		Experiment 3	
	Strategy classification		Strategy classification		Strategy classification	
	TTB	WADD & EQW	TTB	WADD & EQW	TTB	WADD & EQW
	$n = 11$	$n = 27$	$n = 15$	$n = 49$	$n = 9$	$n = 47$
M_{SI} (SD)	−0.45 (0.42)	−0.23 (0.50)	−0.47 (0.32)	0.12 (0.48)	−0.45 (0.35)	0.10 (0.52)
Mdn_{SI}	−0.53	−0.49	−0.65	0.19	−0.52	0.17
SI: U-test	$U = 191$, $z = 1.37$, $p = .171$, $r = .22$[a]		$U = 621$, $z = 4.02$, $p < .001$, $r = .50$[b]		$U = 340$, $z = 2.87$, $p = .004$, $r = .38$[c]	
M_{NUMBER}[d] (SD)	4.5 (2.1)	9.3 (3.7)	3.5 (2.1)	9.2 (2.0)	4.3 (2.0)	9.2 (2.8)
Mdn_{NUMBER}	5.2	8.9	2.5	8.9	4.8	8.3
NUMBER: U-test	$U = 275$, $z = 4.07$, $p < .001$, $r = .66$		$U = 708$, $z = 5.40$, $p < .001$, $r = .67$		$U = 400$, $z = 4.21$, $p < .001$, $r = .56$	
M_{TIME} (SD)	5796 ms (2927)	9871 ms (3437)	5275 ms (1888)	10,404 ms (2592)	5813 ms (2537)	10,445 ms (3195)
Mdn_{TIME}	4844 ms	8378 ms	4687 ms	9967 ms	4710 ms	9972 ms
TIME: U-test	$U = 264$, $z = 3.72$, $p < .001$, $r = .60$		$U = 696$, $z = 5.21$, $p < .001$, $r = .65$		$U = 372$, $z = 3.58$, $p < .001$, $r = .48$	

Note. Nonparametric tests were chosen because, in most of the groups, the data were not normally distributed.
[a] When looking at the strategies in a more fine-grained categorization it becomes obvious that this lack of difference in the SI between TTB and the compensatory strategies stems from the WADD users who (contrary to the EQW users) adopted a rather cue-wise search pattern; SI: Mdn_{TTB} ($n = 11$) = −0.53, Mdn_{WADD} ($n = 19$) = −0.49, Mdn_{EQW} ($n = 8$) = −0.05.
[b] SI for more detailed strategy classification in Experiment 2: Mdn_{TTB} ($n = 15$) = −0.65, Mdn_{WADD} ($n = 27$) = −0.13, Mdn_{EQW} ($n = 22$) = 0.53.
[c] SI for more detailed strategy classification in Experiment 3: Mdn_{TTB} ($n = 9$) = −0.52, Mdn_{WADD} ($n = 19$) = −0.31, Mdn_{EQW} ($n = 28$) = 0.50.
[d] Includes re-acquisitions.

Table A.2
Process variables and strategies in Experiment 4.

	Experiment 4	
	Strategy classification	
	TTB	WADD & EQW
	$n = 7$	$n = 47$
M_{SI} (*SD*)[a]	0.02 (0.18)	0.24 (0.14)
Mdn_{SI}	0.01	0.23
SI: *t*-Test	$t(7.20) = -2.99$, $p = .020$, Cohen's $d = 1.31$	
SI: *U*-test	$U = 272$, $z = 2.77$, $p = .006$, $r = .38$	
M_{NUMBER}[b] (*SD*)	10.4 (5.8)	12.6 (4.1)
Mdn_{NUMBER}	9.0	12.3
NUMBER: *t*-Test	$t(6.92) = -0.99$, $p = .356$, Cohen's $d = 0.45$[c]	
NUMBER: *U*-test	$U = 230$, $z = 1.69$, $p = .092$, $r = .23$	
M_{TIME} (*SD*)	5165 ms (2830)	6390 ms (1798)
Mdn_{TIME}	4416 ms	6405 ms
TIME: *t*-Test	$t(6.74) = -1.11$, $p = .304$, Cohen's $d = 0.53$[c]	
TIME: *U*-test	$U = 252$, $z = 2.25$, $p = .024$, $r = .31$	

[a] SI for more detailed strategy classification: Mdn_{TTB} ($n = 7$) = 0.01, Mdn_{WADD} ($n = 39$) = 0.23, Mdn_{EQW} ($n = 8$) = 0.32.
[b] Includes re-acquisitions. Each entry into an AOI (with fixation on that AOI) is counted; several subsequent fixations within the same AOI are counted as one.
[c] Data in one of the groups is not normally distributed.

Appendix B

Table B.1
Analysis of search behavior of participants who noticed a pattern in the background of the task (Experiments 1, 2, & 4) or any kind of grouping of the cells in the decision task (Experiment 3).

Experiment condition	M_{SI} (*SD*)	Mdn_{SI}	*t*-Test	*U*-test	BF[a]
Experiment 1			$t(9.37) = -0.28$, $p = .784$, Cohen's $d = 0.16$[b]	$U = 23$, $z = 0.29$, $p = .775$, $r = .08$	2.67
Row: $n = 6$	−0.45 (0.38)	−0.37			
Column: $n = 7$	−0.40 (0.29)	−0.53			
Experiment 2			$t(17.43) = 0.59$, $p = .562$, Cohen's $d = 0.26$	$U = 42$, $z = -0.72$, $p = .469$, $r = .16$	2.80
Row: $n = 8$	0.14 (0.40)	0.27			
Column: $n = 13$	0.02 (0.50)	0.11			
Experiment 3			$t(28.45) = -0.90$, $p = .375$, Cohen's $d = 0.31$	$U = 174$, $z = 0.80$, $p = .424$, $r = .14$	2.84
Row: $n = 15$	−0.18 (0.52)	−0.23			
Column: $n = 20$	−0.02 (0.47)	−0.04			
Experiment 4			$t(2.16) = -0.07$, $p = .947$, Cohen's $d = 0.07$	$U = 8$, $z = -0.82$, $p = .414$, $r = .25$	2.40
Row: $n = 3$	0.10 (0.31)	0.24			
Column: $n = 8$	0.12 (0.10)	0.13			

[a] See note about BF in Table 1.
[b] Data in one of the groups is not normally distributed.

Table B.2
Analysis of search behavior of participants who did not notice a pattern in the background of the task (Experiments 1, 2, & 4) or any kind of grouping of the cells in the decision task (Experiment 3).

Experiment condition	M_{SI} (*SD*)	Mdn_{SI}	*t*-Test	*U*-test	BF[a]
Experiment 1			$t(27.39) = -1.05$, $p = .305$, Cohen's $d = 0.35$	$U = 227$, $z = 0.44$, $p = .657$, $r = .07$	2.70
Row: $n = 21$	−0.25 (0.29)	−0.24			
Column: $n = 20$	−0.09 (0.60)	−0.22			
Experiment 2			$t(77.92) = 0.87$, $p = .388$, Cohen's $d = 0.19$	$U = 748.5$, $z = -0.65$, $p = .517$, $r = .07$	4.15
Row: $n = 43$	0.03 (0.50)	−0.02			
Column: $n = 38$	−0.06 (0.39)	−0.06			
Experiment 3			$t(38.10) = -0.70$, $p = .487$, Cohen's $d = 0.21$	$U = 335$, $z = 0.76$, $p = .445$, $r = .11$	3.75
Row: $n = 27$	0.00 (0.42)	0.04			
Column: $n = 22$	0.10 (0.56)	0.13			
Experiment 4			$t(37.18) = -0.75$, $p = .459$, Cohen's $d = 0.23$	$U = 263$, $z = 0.78$, $p = .437$, $r = .12$	3.47
Row: $n = 22$	0.22 (0.18)	0.23			
Column: $n = 21$	0.25 (0.13)	0.26			

[a] See note about BF in Table 1.

ANOVAs with the factors Pattern and Condition and with SI as the dependent variable yielded the same pattern of results: Whether participants noticed the manipulation or not had no influence on their search behavior (Experiment 1: the main effects Pattern and Condition and the interaction of the two factors were all $p > .05$ [$\eta^2_p = 0.061$, $\eta^2_p = 0.011$, and $\eta^2_p = 0.003$, for Pattern, Condition, and their interaction, respectively]; Experiment 2: all *ps* > .05 [$\eta^2_p = 0.007$, $\eta^2_p = 0.008$, and $\eta^2_p = 0.000$, for Pattern, Condition, and their interaction, respectively]; Experiment 3: all *ps* > .05 [$\eta^2_p = 0.023$, $\eta^2_p = 0.017$, and $\eta^2_p = 0.001$, for Pattern, Condition, and their interaction, respectively]). Only in Experiment 4 (*ps* for Condition and the interaction > .05 [$\eta^2_p = 0.003$ and $\eta^2_p = 0.001$, for Condition and the interaction, respectively]), there was a significant effect of Pattern with those who had noticed the manipulation showing a lower, though still positive, SI than those who did not notice the manipulation ($p = .046$, $\eta^2_p = 0.077$). However, this is not an effect due to the row versus column manipulation. If noticing the manipulation had led to different effects of the manipulation, we would have observed significant interactions. This was clearly not the case.

Table B.3
Analysis of decisions of participants who noticed a pattern in the background of the task (Experiments 1, 2, & 4) or any kind of grouping of the cells in the decision task (Experiment 3).

Experiment condition	TTB users[a]	Compensatory decision makers[a]	χ^2(df), p[b]
Experiment 1			$\chi^2(1) = 1.10$, $p = .294$, Cramér's $V = .350$[c]
Row	3 (75.0%)	1 (25.0%)	
Column	2 (40.0%)	3 (60.0%)	
Experiment 2			$\chi^2(1) = 1.54$, $p = .215$, Cramér's $V = .320$[d]
Row	0 (0.0%)	6 (100.0%)	
Column	2 (22.2%)	7 (77.8%)	
Experiment 3			$\chi^2(1) = 2.41$, $p = .121$, Cramér's $V = .299$[e]
Row	1 (8.3%)	11 (91.7%)	
Column	5 (33.3%)	10 (66.7%)	
Experiment 4			$\chi^2(1) = 2.93$, $p = .087$, Cramér's $V = .516$[f]
Row	1 (33.3%)	2 (66.7%)	
Column	0 (0.0%)	8 (100.0%)	

[a] Percentages are strategy users (out of all classified participants) per condition.
[b] Does not include unclassified participants.
[c] 100% of cells had minimum expected frequencies below 5; Fisher's exact test, $p = .524$, odds ratio = 3.76.
[d] 50% of cells had minimum expected frequencies below 5; Fisher's exact test, $p = .486$, odds ratio = 0.
[e] 50% of cells had minimum expected frequencies below 5; Fisher's exact test, $p = .182$, odds ratio = 0.19.
[f] 75% of cells had minimum expected frequencies below 5; Fisher's exact test, $p = .273$, odds ratio = Inf.

Table B.4
Analysis of decisions of participants who did not notice a pattern in the background of the task (Experiments 1, 2, & 4) or any kind of grouping of the cells in the decision task (Experiment 3).

Experiment condition	TTB users[a]	Compensatory decision makers[a]	χ^2(df), p[b]
Experiment 1			$\chi^2(1) = 3.03$, $p = .082$, Cramér's $V = .323$[c]
Row	1 (7.1%)	13 (92.9%)	
Column	5 (33.3%)	10 (66.7%)	
Experiment 2			$\chi^2(1) = 0.51$, $p = .475$, Cramér's $V = .102$
Row	8 (30.8%)	18 (69.2%)	
Column	5 (21.7%)	18 (78.3%)	
Experiment 3			$\chi^2(1) = 0.45$, $p = .501$, Cramér's $V = .125$[d]
Row	2 (14.3%)	12 (85.7%)	
Column	1 (6.7%)	14 (93.3%)	
Experiment 4			$\chi^2(1) = 0.00$, $p = .951$, Cramér's $V = .009$[e]
Row	3 (13.6%)	19 (86.4%)	
Column	3 (14.3%)	18 (85.7%)	

[a] Percentages are strategy users (out of all classified participants) per condition.
[b] Does not include unclassified participants.
[c] 50% of cells had minimum expected frequencies below 5; Fisher's exact test, $p = .169$, odds ratio = 0.16.
[d] 50% of cells had minimum expected frequencies below 5; Fisher's exact test, $p = .598$, odds ratio = 2.27.
[e] 50% of cells had minimum expected frequencies below 5; Fisher's exact test, $p = 1.00$, odds ratio = 0.95.

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Manuscript 2

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A new task format for investigating information search and organization in multiattribute decisions

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Abstract In research on multiattribute decisions, information is typically preorganized in a well-structured manner (e.g., in attributes-by-options matrices). Participants can therefore conveniently identify the information needed for the decision strategy they are using. However, in everyday decision situations, we often face information that is not well-structured; that is, we not only have to search for, but we also need to organize the information. This latter aspect—subjective information organization—has so far largely been neglected in decision research. The few exceptions used crude experimental manipulations, and the assessment of subjective organization suffered from laborious methodology and a lack of objectiveness. We introduce a new task format to overcome these methodological issues, and we provide an organization index (OI) to assess subjective organization of information objectively and automatically. The OI makes it possible to assess information organization on the same scale as the strategy index (SI) typically used for assessing information search behavior. A simulation study shows that the OI has a similar distribution as the SI but that the two indices are a priori largely independent. In a validation experiment with instructed strategy use, we demonstrate the usefulness of the task to trace decision processes in multicue inference situations.

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Imagine that you are about to assemble a research team for your next project. From all the candidates who applied, you need to identify those who will be most suitable for your team. How do you proceed? Usually, you get information about the applicants such as CVs, letters of recommendation, and certificates. The information about the applicants' skills can be used to infer how suitable the applicants are. This is a typical example of a multicue inference task: Cues (aspects of the CVs) provide information about different options (the job candidates), among which the decision maker needs to identify the best one(s). Further examples of multicue inference situations are diagnostic situations, in which the cues are symptoms and the options are different diseases or disorders. As a final example, information about companies may be used to infer which company's shares to invest one's money in. These kinds of tasks exist in the domain of preferences and of inferences. In the former domain, the information units are usually referred to as *attribute information,* and in the latter, they are referred to as *cue information*. Since we used an inference task in our experiment, we will generally use the term cue information unless we refer to previous research from the domain of preferences.

Different strategies and factors have been investigated to describe how the decision maker may use cue information and to identify influences on the selection of a decision strategy, respectively (Bröder, 2000b, 2003; Gigerenzer, Todd, & the ABC Research Group, 1999; Payne, Bettman, & Johnson, 1988, 1993; Svenson, 1979). The influence of time pressure (see, e.g., Payne et al., 1988; Rieskamp & Hoffrage, 1999; see Bröder, 2000b, for different results) and information costs (see, e.g., Bröder, 2000b, 2003; Newell & Shanks, 2003) on strategy selection are among the most investigated factors. The decision strategies investigated with multicue decisions differ in the amount of information considered as well as in additional aspects, which we will introduce below. These strategies are presumably more conveniently applied to well-structured than to unorganized information (see, e.g., Bettman, 1975, on processability). However, this step in the decision process—structuring information to increase processability—has so far not gotten much attention in research on decision strategies. One reason is probably that no standardized and easy-to-use research tools exist.

The goal of the new task presented here is to overcome this issue. We introduce a task format for the investigation of decision strategies in multicue decision tasks, a format that is based on and extends the commonly used Mouselab paradigm (Johnson, Payne, Schkade, & Bettman, 1989) but which is more flexible than the latter. In the Mouselab paradigm, decision-relevant information is hidden in boxes on the screen and can be acquired with the mouse device. This method allows tracking the information-acquisition process. In addition to the typically investigated variables choice, information search, and decision time, our task makes it possible to assess the subjective organization of information in a standardized manner. The new index we introduce quantifies subjective organization on the same scale as the *strategy index* (SI) that is often used for characterizing information search (Payne, 1976). Hence, we develop a paradigm in which search and organization can be investigated both simultaneously and independently from each other. Furthermore, the analysis of subjective organization is less laborious and more objective in comparison with previous approaches. With this task, we would like to shift attention to an aspect of the decision process that is oftentimes skipped, by providing participants with preorganized information. However, we argue that the subjective organization of information might provide valuable insights into the decision process in information-based decisions.

Before we present this new task format, we discuss the importance of spatial organization of information and continue with an overview of decision strategies for multicue decisions and of methods commonly used to investigate those. We then summarize previous research on information presentation format and on information organization. Thereafter, we introduce the new task for tracing information-organization behavior in multicue decisions and the organization index. With simulations, we show that important requirements for the new index are met. Next, we present a validation study with the new task and discuss the results, focusing on the importance of information organization for the application of decision strategies. Finally, we discuss limitations and possible future developments of the task, which make it possible to measure information organization with fewer restrictions, and might therefore provide further insight into how information is used in multicue decisions.

Information organization, decision strategies, and previous research approaches

Information organization

The way we organize information can be much more than just finding a place for things. According to Kirsh (1995) the way we organize items in space "is an integral part of the way we think, plan and behave" (p. 31). The idea behind this is that organization (in space) is used to reduce time and cognitive effort needed for a task. In addition, reorganizing information can help accentuate categories, and it facilitates visual search; that is, it gets easier to find information and to keep track of it (Kirsh, 1995).

Whenever we cannot freely organize the space around us, we might adapt by using different strategies. For instance, Ballard, Hayhoe, and Pelz (1995) showed that eye movements are adjusted and used to economically deal with tasks. The authors investigated eye movements in a hand–eye coordination task, in which a block configuration model had to be copied. In this task, participants seemed to follow an online information-acquisition strategy to save working memory costs (i.e., looking back to the required information right before the information is needed). However, when the costs for the online strategy were increased by shifting the separate sections in the task further apart, participants relied more on working memory, which was reflected in fewer eye movements back to the area containing the model information that had to be copied. Similarly, Russo (1977) showed that the spatial arrangement of information can facilitate its use. By making price information more processable, higher performance (amount of money saved) was achieved. Importantly, making the information content more comparable by using unit prices alone was not as effective as when these unit prices were spatially assembled in a list rather than being tagged to the supermarket shelves.

In sum, the studies by Ballard et al. (1995) and Russo (1977) highlight influences of spatial arrangements on strategy use and on performance. In addition, the considerations by Kirsh (1995) emphasize that we spatially arrange items in a meaningful way that relates to the task at hand. These results and considerations suggest that the spatial arrangement or organization of information might be highly relevant for information-based decisions. Particularly, the idea of organizing information in order to save working memory might be central for the application of decision strategies in multicue decisions.

Decision strategies

Strategies for multicue inference tasks differ in terms of the amount and the sequence of information search as well as in their choice predictions. According to the fast and frugal heuristics framework (Gigerenzer et al., 1999), the decision maker selects a strategy that is adaptive in the given situation. The strategies are typically divided into two broad categories: noncompensatory and compensatory strategies (see, e.g., Payne et al., 1988; Svenson, 1979). With a noncompensatory strategy (e.g., the *Take the Best* [TTB] heuristic; Gigerenzer & Goldstein, 1996), the less important cues are ignored; the decision is based on the most important reason, and no tradeoffs are made. In other words, for assembling a research team, a team leader using TTB identifies the information or skill he deems most important to identify a good team member—for instance, experience with the research topic—and compares the applicants on that skill. Only if there is more than one remaining applicant who excels on the specific skill, will the team leader compare the remaining applicants on the second most important skill. This procedure is continued until a decision can be made. Compensatory strategies, however, integrate less important cues and trade them off against more important ones. So, if the project leader applies a compensatory strategy such as the *Weighted Additive Rule* (WADD; Payne et al., 1988) or the *Equal Weight Rule* (EQW; Dawes, 1979), he will integrate all available information about each applicant (by first weighting each piece of information by its importance, in the case of WADD) and will then choose the applicant with the highest sum.

Investigating decision strategies Two different approaches are commonly used to investigate what type of strategy a decision maker applied: the outcome-based approach and process tracing (see, e.g., Bröder, 2000a; Svenson, 1979). The former approach focuses on the choices people make. With items for which different strategies predict different choices, the comparison of a person's actual choices with the strategy predictions makes it possible to identify the strategy the given person most likely used (see, e.g., Bröder, 2002, 2010; Bröder & Schiffer, 2003; Lee & Cummins, 2004; see also Rieskamp & Hoffrage, 1999). The other approach, process tracing, focuses on information search. The strategies described above may not just differ in their pattern of predicted choices but they especially differ in their information search and stopping rule. Whereas TTB prescribes cue-wise search for information, the compensatory WADD and EQW are usually associated with more option-wise search patterns (see, e.g., Bettman & Zins, 1979; Payne et al., 1988), and the latter strategies use (almost) all available information, whereas TTB stops information search as soon as a discriminating cue is found. The information search process is typically investigated with the Mouselab paradigm (Johnson et al., 1989), with eyetracking (e.g., Franco-Watkins & Johnson, 2011; Lohse & Johnson, 1996), or with verbal protocols (see, e.g., Jarvenpaa, 1989, 1990; Payne, 1976; Stone & Schkade, 1991; see Schulte-Mecklenbeck, Kühberger, & Ranyard, 2011, for a recent overview on process tracing approaches).

These approaches have the advantage of providing standardized methods for investigating decision strategies. However, this advantage comes with the cost of necessitating well-structured information presentation. Specifically, information is typically provided in a preorganized manner, for instance, in a cues-by-options matrix (for an example, see Fig. 1 in Bröder, Glöckner, Betsch, Link, & Ettlin, 2013). In the Mouselab paradigm, the information in the cells of the matrix is hidden, and participants need to click on the cells in order to acquire

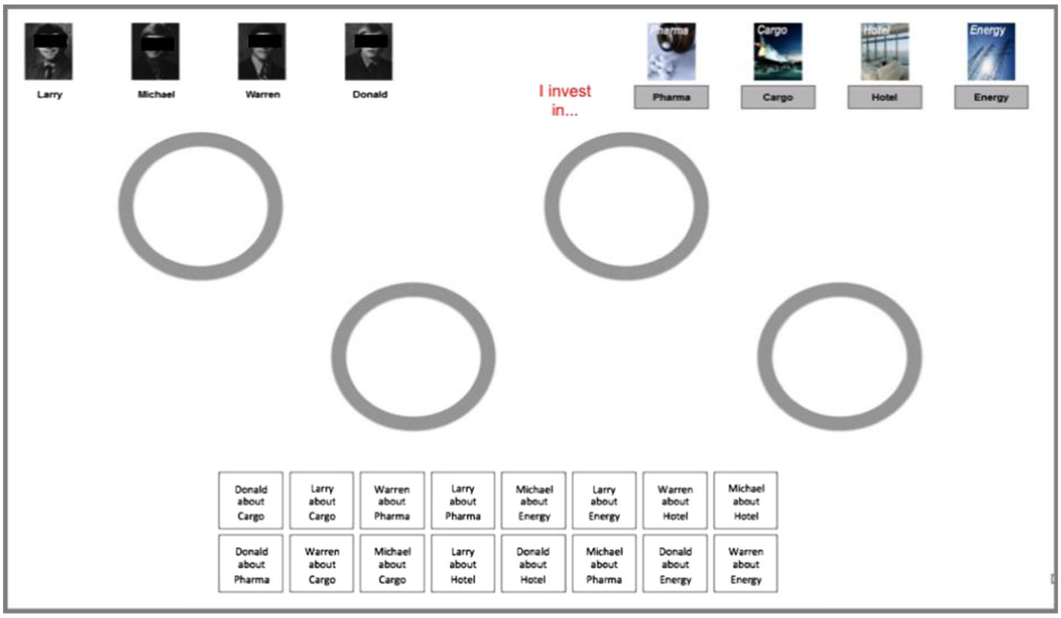

Fig. 1 Example of the SOT: Details about the screen and the task are explained in the text

the information. Also, when eyetracking is applied, information is often provided in a matrix format—either with open information cells or with hidden information that is revealed as soon as the participant places a fixation on a cell (see Franco-Watkins & Johnson, 2011). The problem with this format is that the information search pattern applied to matrices may be influenced by the typical reading direction (Scherndl, Schulte-Mecklenbeck, & Kühberger, 2013). That is, when the attributes describing different choice options are presented in the rows of a matrix, search is more attribute-wise than when the attributes are presented in the columns. Furthermore, we rarely encounter information in matrices in everyday decision situations. The matrix format is rather an exception, which is used, for instance, in consumer reports. But other formats were also used in process tracing studies that applied methods such as eyetracking, flashlight, or mouse-response trajectories (see, e.g., Koop & Johnson, 2013; Schulte-Mecklenbeck, Murphy, & Hutzler, 2011; Visschers, Hess, & Siegrist, 2010). However, sometimes we even have to gather information from various different sources. Therefore, we do not only have to search for information, we also have to organize it by ourselves.

When introducing subjective information organization in multicue decision tasks, two main questions emerge. First, how does the organization of information influence the selection of decision strategies? And second, (how) do people organize information differently when they use different strategies with diverse information search and decision rules? In other words, is subjective organization of information used to reduce the costs of strategy application? Many years ago, decision scientists already addressed these issues (Coupey, 1994; Coupey & DeMoranville, 1996); however, research on the topic is still scarce, and previous approaches seem problematic. This is mainly because of crude manipulations, a lack of standardized methods to assess subjective information organization, and a lack of quantifiable measures of subjective organization.

Previous approaches to investigating presentation format effects and subjective organization

The impact of information organization in multiattribute decisions has been investigated in two ways. The first approach confronted participants with different formats of preorganized information and assessed parameters of information search, decision quality, and confidence as the dependent variables. In this line of research, participants did not have the opportunity to organize the information by themselves. In the second approach, participants were given the opportunity to organize the given information, and this subjective organization was investigated both as a dependent variable and as a mediator to parameters of decision quality. We will characterize both approaches in turn.

The influence of information presentation format on decision behavior Bettman and Kakkar (1977) took a first step toward understanding effects of information presentation format on decision behavior. In a multiattribute preference task, the authors showed that participants who received information that was organized according to brands (alternatives) more often searched in an alternative-wise (option-wise) manner and that those who received the information ordered according to attributes searched instead in an attribute-wise (cue-wise) manner. So even though the same information was presented to all of the participants, their information acquisition patterns strongly differed depending on the presentation format.

This finding is not very surprising, however, given that the grouping of information in a brand- versus attribute-wise manner was manipulated using different booklets; that is, in the Brand Condition, there was a separate booklet for each brand containing all attribute information on a specific brand. In the Attribute Condition, the setup was analogous, with a separate booklet for each attribute. Therefore, acquiring information along the dimension according to which it was grouped (i.e., looking through one booklet after the next) was faster and more convenient than using a search strategy deviating from this pattern. Specifically, if a participant in the Brand Condition wanted to search for information in an attribute-wise manner, she had to switch booklets after each piece of information she gathered. Hence, the manipulation affected not only the saliency of the brand versus attribute dimensions, it also entailed high opportunity costs for applying a search strategy that mismatched the format.

Bettman and Zins (1979) continued this line of research by not only focusing on the presentation format but by considering the format *and* the task someone intended to apply. According to their task–format congruence hypothesis, for a given task and information format, "the degree of congruence between the processing characterizing the task and that encouraged by the format affects performance" (Bettman & Zins, 1979, p. 143; see also Vessey, 1991, on the idea of cognitive fit). The authors tested the congruency idea by providing specific strategy instructions (*tasks*), which differed with regard to whether option- or cue-wise processing was required, and by combining them with different *formats* (i.e., brand, attribute, and matrix format). The resulting conditions differed in their degree of congruence. According to the task–format congruence hypothesis, a task requiring brand-wise processing, for instance, should be easiest with the matrix, next easiest with the brand format, and hardest with the attribute format. In accordance with the hypothesis, participants adapted the decision time as a function of congruency (Experiments 1 and 2). Accuracy was not affected

(Experiments 1 and 2), though. In addition, there was some support for the effect on subjective reactions (e.g., confidence, Experiment 2). But when participants had to choose a format for a specific strategy instruction, the majority preferred the matrix format, and there was no matching of format to the task (Experiments 1 and 2).

Again, when considering the formats provided, this finding is not surprising. The matrix was the only format with which all of the provided information was visible at once, on a single sheet of paper. The brand and attribute formats were such that each brand and each attribute, respectively, was described on a single sheet of paper on a tacked stack. But after eliminating the matrix format in a third experiment, the congruence hypothesis for format choice was not supported. In this final experiment, with one single decision trial, the results for decision time were not in line with the congruence hypothesis anymore, nor were the results for subjective reactions. To sum up, the support for the task–format congruence hypothesis was mixed, and as with Bettman and Kakkar's (1977) experiment, the manipulation was rather crude and entailed opportunity costs for mismatching search strategies.

Investigating subjective information organization Coupey (1994) extended this work by giving people the opportunity to organize the provided information in a user-defined manner by simply providing participants with pen and paper. Participants' notes were coded according to what kind of *restructuring* (i.e., changes to the information display) participants applied (i.e., whether they used editing, rearranging, etc.) and these coded notes provided the basis for the evaluation of the hypotheses. In the tradition of the cost–benefit idea (e.g., Beach & Mitchell, 1978; Payne et al., 1993), Coupey hypothesized that people would evaluate the costs and benefits of restructuring; that is, when restructuring is made easy by providing scratch paper, people will use the opportunity to restructure the display to facilitate the application of a more normative, alternative-based compensatory strategy. However, when the restructuring needs to be done in working memory, participants would rather rely on a simpler, noncompensatory strategy than restructure the information in their heads to be able to apply a compensatory strategy. This was indeed the case: Of the participants provided with scratch paper, 94 % used an alternative-based strategy, compared with only 40 % of those who were not allowed to take notes. In addition, the amount of restructuring depended on how well-structured the initial display was.

Coupey's (1994; see also Coupey & DeMoranville, 1996) approach was certainly a step forward with respect to the investigation of information organization. However, we argue that apart from being extremely laborious, the method based on participants' notes also entails a high degree of subjectivity because of the necessity of coding. A further line of research related to information organization is the investigation of information usage in quasinaturalistic risky choice decisions, with the active information search paradigm of Huber and colleagues (Huber, Wider, & Huber, 1997). Here, the focus is on what kind of information is asked for in a decision task when no information is provided in addition to the basic scenario. But as with most approaches, there is no separation of search sequence and information organization.

There is a general lack of standardized methods to elicit and a lack of measures to quantify subjective organization. However, we consider the organization of information an important aspect of the decision process that needs decision researchers' attention. Especially nowadays, information is widely available and easily accessible for most of us. That is, whenever we want, or need, to make an information-based decision, we not only have to search for information, but we also have to filter and then organize it in order to be able to conveniently apply a decision rule. The new task we introduce was developed to make information organization assessable and analyzable in a more convenient and standardized manner.

A new tool: The search and organization task (SOT)

Our new tool is based on the Mouselab paradigm, with the addition that not only information acquisition and choices but also subjective organization of information can be assessed and analyzed. We provide an index that quantifies information organization on the same scale as Payne's (1976) index for information search, which is commonly used to assess information-acquisition patterns. Therefore, information organization becomes readily measurable.

With the SOT, a participant who starts working on a decision task sees a display that may look like the screenshot in Fig. 1. In the top left corner of the display, four cues are presented. In the example, these are four brokers who are ordered according to their importance, from left to right, with the leftmost broker being the one with the best predictions. In the top right corner, four choice options (here, market segments) are presented; their order of presentation is newly randomized for each decision trial. The 16 pieces of cue information, which result from fully crossing the four cues and the four options, are presented in the two rows of boxes in the lower half of the screen and are arranged in random order. As in the Mouselab paradigm, the information is hidden. The participants' task is to identify the best market segment in several decision trials. In each trial, they start with a display that looks like the screen in Fig. 1. In order to make the inference decision, the participants can then acquire information from the brokers about the options by clicking on the piece of information (in the bottom rows) they are interested in. In this first step, the information label in the box that was clicked on disappears. In a next step, the participant needs to click into one of the four circles in the middle of the screen. Then the information label as well as the value of the information (“yes”/”no”) appears in that spot. With this basic version of the task, the only restriction is that a maximum number of four pieces of information fits into each of the circles. The participants are free to acquire information in any order they like and also to organize or group it in any way they desire (within the four circles). After each decision, the cue information for the next trial is hidden in a new random order in the two rows in the lower half of the screen. Again, participants are free to search and organize according to any preferred sequence and pattern, respectively.

In contrast to some Mouselab setups, once acquired, the information in the SOT remains visible for the whole duration of a trial. Because of this difference, reacquisitions cannot be analyzed with the SOT. However, investigating benefits and strategies of spatial layout is only useful for visible information. Eyetracking may be used to reveal how people make use of the information after it has been organized in the circles.

In addition to search order, amount of acquired information, choices, and decision times that are usually registered and analyzed in Mouselab or eyetracking studies, the SOT allows the assessment of subjective organization via the arrangement of information in the circles. That is, for each decision trial, the sequence in which the information is clicked on in the two bottom rows can be turned into Payne’s (1976) strategy index, SI. The SI is a measure of relative cue- versus option-wise search for information and is computed as the number of option-wise transitions minus the number of cue-wise transitions divided by the sum of the two numbers. It is measured on a scale from –1 (cue-wise search) to +1 (option-wise search). Our newly introduced organization index, OI, allows quantifying information organization on the same scale as the SI, ranging from –1 (cue-wise grouping) to +1 (option-wise grouping). The OI is computed as follows:

$$OI = \frac{\left[\left[\sum_{j=1}^{4}\left(\max\left(SameOption_{circle\ \ j}\right)-1\right)\right]-\left[\sum_{j=1}^{4}\left(\max\left(SameCue_{circle\ \ j}\right)-1\right)\right]\right]}{\left[\left[\sum_{j=1}^{4}\left(\max\left(SameOption_{circle\ \ j}\right)-1\right)\right]+\left[\sum_{j=1}^{4}\left(\max\left(SameCue_{circle\ \ j}\right)-1\right)\right]\right]}$$

with max($SameOption_{circle\ j}$) as the maximum number of pieces of information describing the same option in circle j and with max($SameCue_{circle\ j}$) being the analogous value for cues. Subtracting 1 from each maximum count is necessary for scaling the index from –1 to +1. In the Appendix (see supplemental material), we provide R (R Core Team, 2013) code for the computation of the OI for one decision trial (code for a task with four options and four cues; examples of how to input data are provided with the code).

Hence, it is not necessary to code or classify messy notes on scratchpads, as in Coupey’s (1994) approach. Rather, information organization is directly assessed and automatically computed in each decision trial. Of course, our standardization comes with the limitation of restricting the organization to a cue-wise versus option-wise grouping. But we argue that these are probably the most relevant dimensions, and since the number of cases of the two dimensions is equal and is also equal to the number of circles, there is no a priori bias toward either of the two dimensions. In addition, we argue that the disadvantage of this limitation is outweighed by the advantage of standardization and objectivity.

Flexibility of the SOT The above-outlined explanation describes the basic version of the SOT to illustrate its logic. In fact, the task can be adjusted and modified in many ways. First, the *payoff environment* can be manipulated. This influences the adaptivity of the different decision strategies. Second, the *search environment* can be manipulated. Instead of leaving the sequence of information acquisition to the participant, one can predefine an acquisition sequence. For instance, with an option-wise restriction, participants are forced to acquire all information about one option after the next. Alternatively, search can be restricted accordingly in a cue-wise manner. Finally, the researcher can manipulate the *organization environment*. The organization environment may be changed by restricting the possibilities for the grouping of information (e.g., again in an option- or cue-wise manner) or by using a different display. Needless to say, the display depicted in Fig. 1 is only one example of an arbitrary arrangement of elements. For our initial studies, we used circles, to avoid any resemblance to the usual matrix format. However, as long as the basic idea of spatial grouping of elements is maintained, there is no restriction to the actual design of the display (see the General Discussion).

In summary, the SOT is flexible and allows for far subtler format manipulations than have been used in previous studies (see, e.g., Bettman & Kakkar, 1977; Bettman & Zins, 1979). Furthermore, the method is standardized and automatic, and does not need to be coded by the researcher. Finally, the OI is an objective measure for information organization that is comparable to the SI measure for assessing information search. In the remainder of the article, we will present simulations and a validation study that show that basic requirements for the OI are fulfilled and that people seem to be able to make use of the possibility to organize information in multicue inference tasks.

The organization index: A simulation study

An important requirement for the OI is its a priori independence from the SI. In other words, certain sequences of search should not be associated statistically with specific patterns of subjective organization. Hence, artificial correlations should be ruled out. To investigate this issue, we conducted a simulation study, generating 100,000 random trials of information search and organization sampled from the population of all combinations possible with four cues and four options. The function *sample()* in R (R Core Team, 2013) was used to first determine the number of information pieces acquired by a simulated decisionmaker in a trial [x = sample(1:16,1)] and then to sample the x items from all information pieces [y = sample(1:16,x)].

For each of these samples, the SI was computed. The resulting distribution of SIs is depicted in Fig. 2A. As expected for a representative random sample from the whole distribution of possible search patterns, the mean SI is zero; that is, neither cue- (negative numbers) nor option-wise (positive numbers; M_{SI} = 0.00, Mdn_{SI} = 0.00, 1st Quartile$_{SI}$ = –0.33, 3rd Quartile$_{SI}$ = 0.33). Importantly, the expected value of the SI is zero only in symmetric cases with the same number of options and cues (Böckenholt & Hynan, 1994). Although the *display* of information in our example is asymmetric (2 rows, 8 columns), the information *structure* is symmetric (4 by 4), and the latter aspect is relevant for the SI distribution.

In a second step, the random samples generated to compute the SI were randomly placed into n slots of the 16 slots representing the 16 positions in the four circles provided to organize information in each simulated trial. Again, we used *sample()* to randomly distribute the previously drawn samples to the 16 slots. From this, the OI was computed for each of the 100,000 samples. The resulting distribution of OIs can be seen in Fig. 2B. As with the SI, the mean OI is zero; that is, again random with respect to cue- (negative numbers) versus option-wise (positive numbers) grouping of information (M_{OI} = 0.00, Mdn_{OI} = 0.00, 1st Quartile$_{OI}$ = –0.20, 3rd Quartile$_{OI}$ = 0.20). In addition to being unbiased, both distributions show a similar shape, and both are symmetrical.

As mentioned above, the two measures should not be a priori correlated. This requirement is largely fulfilled (r = 0.10, R^2 = 0.01, Kendall's rank-order correlation coefficient τ = 0.06; see Fig. 3). This means, when we observe that participants' information search and organization behavior is correlated, it will not be an artifact of the indices, but it will rather indicate a true behavioral matching of search and organization. So the SI does not restrict the possible OI values. But of course, there are certain cases for which the SI and OI are restricted. For instance, when only one piece of information is acquired, both indices need to be 0. Also, when only two pieces of the same cue (option) are acquired, for instance, then the SI is always –1 (1) and the OI can only assume the values 0 or –1 (1).

Validation experiment

After checking the requirements for the OI, we conducted an empirical validation study of the SOT. We investigated information search and organization behavior with the instructed use of decision strategies. In one of the two between-subjects conditions, participants were instructed to use the compensatory EQW rule (n = 31); in the other condition, participants were instructed to use the noncompensatory TTB heuristic (n = 32). Hence, corresponding to the instructions for the decision strategies, we expect more option-wise search in the EQW Condition and more cue-wise search in the TTB Condition. If Bettman and Zins' (1979) task–format congruence hypothesis (see also Vessey's, 1991, cognitive fit

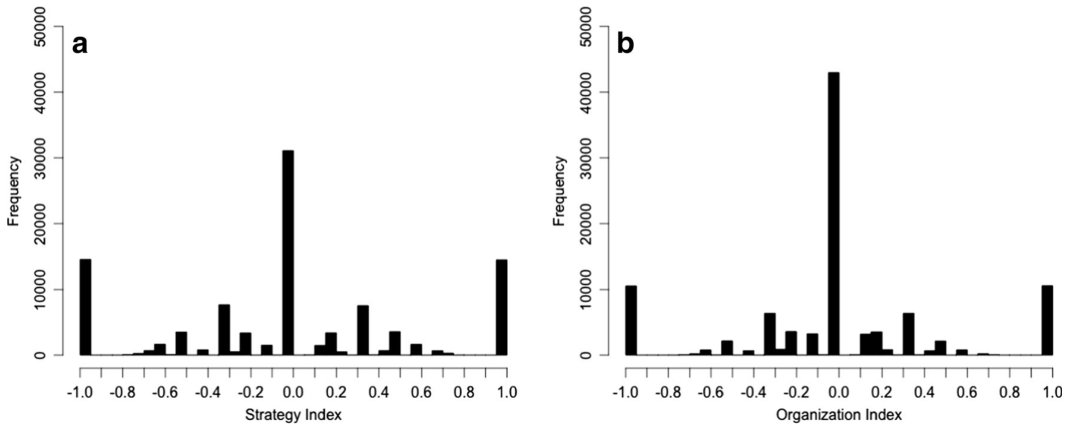

Fig. 2 (A) Simulated SI. (B) Simulated OI

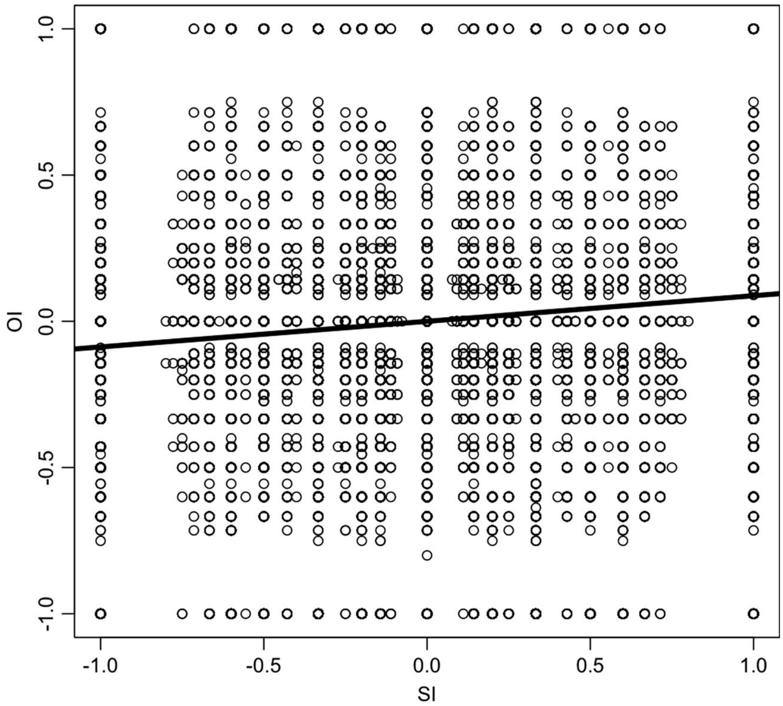

Fig. 3 Scatterplot showing the relation of the SI and the OI (simulations)

hypothesis) holds, we also expect participants to organize the information in a way that best suits the strategy. Hence, in this validation study, we expect a high correspondence between SI and OI.

Method

Participants Sixty-three people [19 male; M_{Age} = 23 years (SD_{Age} = 5)] participated in the experiment in our laboratory at the University of Mannheim. The majority of the participants were students, with a few exceptions of employed people; the majority of the students were majoring in psychology. A chocolate bar was offered for participation. In addition, students could acquire course credits. The participants were randomly assigned to one of the two conditions (EQW or TTB Condition). Because of lower than chance level performance and because of a lack of compliance with respect to the use of the instructed strategy, we excluded 4 participants (see the Manipulation Check below). The remaining sample size allows for a statistical power > .90 to detect large effect sizes (d = .80, Cohen, 1988) in a t-test with α = .05.

Materials and procedure Upon their arrival, participants were greeted, they signed a consent form informing them about their rights and duties as participants, and they were brought to one of six individual cubicles with a computer. After the experimenter had settled them and started the program, the participants worked through the decision task on their own.

For the validation experiment, the setup on the screen was basically identical to the one in Fig. 1, but the task content differed: The cues (top left) were four friends (Paul, Lars, Mike, & Jan) providing advice (in terms of "yes" and "no" hints) about the options (top right), namely, vehicles for traveling. The participants were put back in the year 1894 and were told that Phileas Fogg had just traveled around the world in 80 days. The participants' task was to challenge Mr. Fogg and to travel around the world within half of that time. Therefore, they needed to identify the fastest vehicle (among sailing ship, steam train, carriage, and hot-air balloon) in each of 40 decision trials. Whenever they chose one of the slower vehicles for the upcoming route, they lost a day. The participants in the EQW Condition were told that their friends were all equally experienced and that it was best to choose the vehicle that was favored by a majority of their friends. In the TTB Condition, they were informed that their friends had different levels of experience with traveling around the world and that the friends were ordered accordingly, from left to right, with the most experienced friend being the one in the left corner. Participants were informed that they would achieve their goal by following the advice of the friend who was presented on the extreme left. Only if that friend could not decide between certain options, then the friend who was to the first friend's right should be asked for advice on the options between which the first friend could not decide. The procedure should be continued in this manner when the second friend's opinion still did not lead to a decision.

After the instructions about the task and about the nature of the SOT, the participants completed a practice trial before working through 40 decision trials. The 40 items were constructed such that 100 % accuracy could be achieved in each condition if the participants applied the instructed strategy. For half of the items, EQW and TTB made identical predictions, but the two strategies' predictions differed for the other half of the items. The items were separated into four blocks, each containing an equal number of discriminating and nondiscriminating items (the separation into blocks was not obvious to participants). Within each of these blocks, the items were presented in random order. The pictures of the four options on the top right were randomized after each decision and so were the four cue patterns of each item. Therefore, there was no option or position of an option on the screen that was systematically preferred by either of the strategies. Depending on choice accuracy, the journey took 40 to 80 days.

After each decision, participants got feedback about the outcome of all four options and about the number of days their journey had taken so far. The feedback was binary: Each choice was associated with either one additional day of travel (winning option) or two additional days (the three losing options). For eight predefined items, participants were asked for a confidence rating after indicating their decision and before they got feedback. However, since this measure was assessed for piloting reasons for further studies and is not of relevance for the purpose of introducing the SOT, we will not take the confidence ratings into account in this article. After finishing the experiment, participants got the chance to provide verbal feedback to the experimenter about their experience, difficulties, or any other issues related to the task. Finally, those who were interested in the background and the goal of the experiment were informed about the details before they left the laboratory.

Hypotheses We expected a negative SI in the TTB Condition and a rather positive SI in the EQW Condition. But since the strategy instruction implied the search rule (as well as the stopping and the decision rule) for both of the strategies, this is a manipulation check rather than a true hypothesis. That is, the TTB instruction clearly described a cue-wise search pattern. The instruction for EQW, however, described option-wise integration (decision rule) but did not explicitly prescribe any specific search pattern. With respect to the organization of information, we hypothesized that participants would group the information in a manner matching the search rule of the instructed strategy (i.e., both patterns were expected to be either more cue-wise or rather option-wise). This would also facilitate the application of the instructed decision rules in the respective conditions, because the information that is needed in close temporal proximity would be grouped in close spatial proximity.

Results

Manipulation check When the strategy instructions were followed, all 40 decisions could be made correctly, resulting in a score of 40 days. With four options per decision trial, chance level performance was at 25 % correct answers. Sixteen correct answers was the lowest score that was significantly different from chance (Binomial test, $p_0 = 0.25$, $p_{\text{success}} = 0.40$, $p = .042$) and participants who achieved 15 or fewer correct answers (i.e., a score of [15*1 day + 25*2 days =] 65 days or more) were therefore excluded. This was the case for 3 participants who all had been assigned to the TTB Condition.

In a next step, the adherence rates to both strategies were examined, and participants who made more choices in accordance with the TTB heuristic when they were in the EQW Condition, or vice versa, were excluded. This led to the exclusion of 1 more participant in the TTB Condition. Therefore, the final sample consisted of 31 participants in the EQW Condition and 28 participants in the TTB Condition whose choices were generally in line with the instructed strategy. In this sample, the overall mean score for number of days taken for the journey was 45.5 (*SD* = 7.3; *Mdn* = 42), which corresponds to a mean of 5.5 incorrect choices [13.8 %; *Mdn* = 2 incorrect choices (5 %)]. In the EQW Condition, the mean score was 45.5 days (*SD* = 7.9, *Mdn* = 41) and also in the TTB Condition, the mean score was 45.5 days (*SD* = 6.7, *Mdn* = 42).

Finally, the number of acquired pieces of information should be 16 in (almost) every decision trial for EQW. For TTB, however, the expected mean number of acquisitions for the 40 decisions was 8.5. Participants in the TTB Condition indeed acquired a mean of 8.6 pieces of information (*SD* = 2.5; *Mdn* = 8.6). In the EQW Condition, the mean number of acquired pieces of information was somewhat lower than expected (*M* = 10.9; *SD* = 3.9; *Mdn* = 12.0). Note, however, that certain cue constellations allow applying the EQW decision rule even if not all pieces of information have been uncovered (e.g., one need not uncover the last cue of an option with three negative cue values if there is a rival option with two already uncovered positive values).

Information search As expected, the SI differed between the two conditions [Fig. 4 (left panel); *Mdn* = 0.07, Median test (for all Median tests, ties with the sample Median were put into the category of observations that were lower than the Median), $\chi^2(1) = 37.63$, $p < .001$, Cramér's $V = .799$]. A nonparametric procedure was chosen because the distribution of the SI and OI in the groups was not normal or symmetrical. But the means (bootstrapped 95 % CI) showed the same pattern as the nonparametric results.

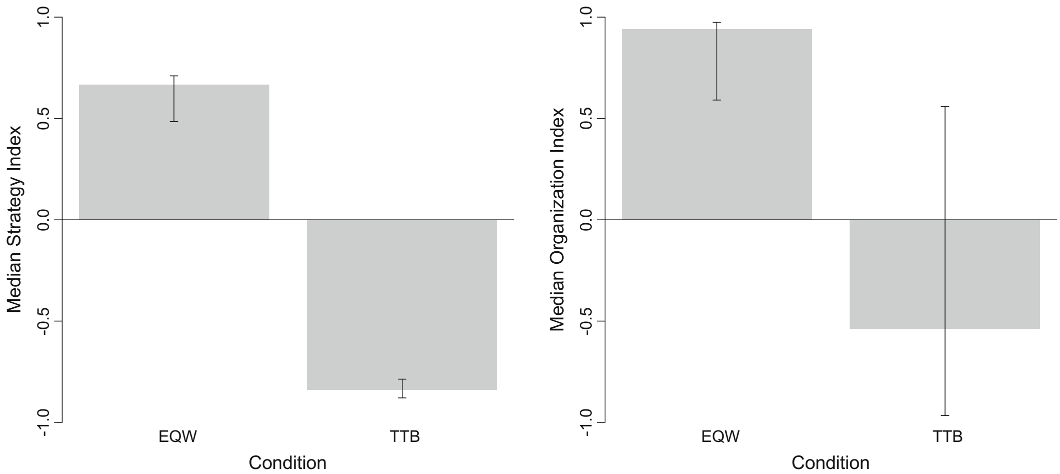

Fig. 4 Median SI (left) and Median OI (right) for the EQW and TTB Conditions; error bars represent bootstrapped 95 % CI (2,000 samples)

The information search pattern in the EQW Condition was in accordance with the expected option-wise search pattern: The Median SI in the EQW Condition was positive (0.67) and differed significantly from zero [one-sample Sign test (for all Sign tests, values equal to zero, i.e., equal to the Median tested under the null, were eliminated from the sample), $\eta_0 = 0$, $n = 31$, $s = 28$, $p < .001$]. Also in the TTB Condition, the information search pattern was in line with the expected (and in this case specifically instructed) search rule for the strategy. The Median SI in the TTB Condition (–0.84) clearly indicated cue-wise search for information (one-sample Sign test, $\eta_0 = 0$, $n = 28$, $s = 2$, $p < .001$).

Information organization The OI also differed between the two conditions [Fig. 4 (right panel); $Mdn = 0.59$, Median test, $\chi^2(1) = 6.17$, $p = .013$, Cramér's $V = .323$]. The information organization pattern in the EQW Condition was in accordance with the expected option-wise organization: The Median OI in the EQW Condition was positive and differed significantly from zero [one-sample Sign test, $\eta_0 = 0$, $Mdn_{n\ =\ 26} = 0.96$ ($Mdn_{n\ =\ 31} = 0.94$; 5 participants' OIs were zero), $s = 23$, $p < .001$]. In the TTB Condition, the OI showed the hypothesized negative sign indicating cue-wise grouping, but was not significantly different from zero [one-sample Sign test, $\eta_0 = 0$, $Mdn_{n\ =\ 27} = –0.70$ ($Mdn_{n\ =\ 28} = –0.54$; 1 participant's OI was zero), $s = 11$, $p = .442$].

As expected, the two process measures, SI and OI, were positively correlated in the sample, Kendall's rank-order correlation coefficient $\tau = .44$, $z = 4.90$, $p < .001$ (one-tailed). That is, participants searched for and organized information in a similar manner. This was true for EQW as well as for TTB users: Within each of the conditions, this positive relation was preserved [EQW Condition, Kendall's rank-order correlation coefficient $\tau = 0.24$, $z = 1.88$, $p = .030$ (one-tailed); TTB Condition, Kendall's rank-order correlation coefficient $\tau = 0.24$, $z = 1.76$, $p = .039$ (one-tailed)].

General discussion

The following quote by Kirsh (1995) highlights an important aspect of information organization that we try to tap into with the SOT.

> One of the most obvious and compelling ways of using space […] is to lay down items for assembly, in the order in which they are to be put together, touched, handed off, or otherwise used. Space naturally encodes linear orders, and higher orders if the agent has an encoding system in mind. The obvious virtue of encoding orderings in the world is to *offload memory.* (p. 51)

Information organization may tell us something about how information is used. The burden on working memory may be relieved, since the decision maker does not have to keep all the information in mind if he arranges information in a way that facilitates the application of a strategy.

Indeed, the validation experiment with instructed strategy use showed the expected difference in information organization behavior depending on the type of strategy (compensatory vs. noncompensatory). That is, participants organized the information according to how it was needed for the instructed decision strategy and such that it matched their information search behavior. Because of the grouping into categories, only the locations of the groups or chunks rather than the locations of up to 16 pieces of information need to be kept in mind (cf. Kirsh, 1995). Looking back and using the organized information should then become much more convenient than if the decision maker had to either gather the information from a random organization or if he just memorized it (cf. Ballard et al., 1995).

But for all that, the very act of organizing information is effortful and takes some time. So the question is whether the organization of information is as helpful as to justify the costs it entails (see Coupey, 1994, on the cost–benefit tradeoff for information restructuring). This seems to be the case for a compensatory strategy: The results for the OI were clear-cut in the EQW Condition, in which participants organized information matching the strategy (in Bettman and Zins' [1979] terminology, they created a congruent situation). But in the TTB Condition, even though people searched for and organized information similarly, the pattern of organization was not as clear-cut as expected. This result suggests that the benefit of information organization is not equal for all strategies, and benefits of organizing information may be small for strategies that are very frugal.

The compensatory strategies integrate information, and it seems plausible that visual grouping of information helps to reduce the cognitive costs of integration and hence of applying a compensatory strategy. Noncompensatory strategies such as TTB do not integrate any information. In the case of four options, the four values of the most important cue need to be compared, for a start. As soon as the decision maker is clear on the next step (decision vs. which information to search for from the second-most-valid cue), the values of the first cue are not needed anymore. However, for TTB the sequence of information search should be highly relevant because of its clearly defined search rule. It will therefore be interesting to investigate whether, with the SOT, the search patterns are in accordance with the strategy models when the strategies are not instructed, a finding that was indeed observed with the Mouselab paradigm (see, e.g., Bröder & Schiffer, 2003). In addition, one could hypothesize that for TTB users, organization could become more relevant if they were restricted in their information search in a manner that is not favorable to the application of TTB.

To get back to the introductory example, if you as a team leader needed to decide which applicants to employ, you might actively search for information in addition to what you got from the applicants themselves. But a lot of information will already have been provided by the applicants, and it will therefore be ordered in an option-wise (or applicant-wise) manner. That is, for instance, in a job interview situation, you encounter one candidate after the next. However, if you intend to apply a noncompensatory strategy, you might just jot down the relevant information in order to be able to compare it for the different job candidates. In other words, information organization may be a relevant part of the decision process—especially when the decision maker has no or little control over the sequence in which she gets access to the information she is interested in. With the SOT, we provide a tool to investigate this aspect of the decision process.

Comparison with previous research

Our results are in accordance with the task–format congruence hypothesis (Bettman & Zins, 1979; see also Vessey, 1991). We observed that participants matched their information organization behavior to the instructed strategy. Bettman and Zins (1979) did not observe this kind of matching in their studies when participants were allowed to choose a format for a given task. However, as mentioned previously, their format manipulation was rather crude. In contrast to the screen we provided, their brand-wise and attribute-wise formats did not allow participants to see all information at once. When the only format that actually displayed all the information on a single sheet (i.e., the matrix format) was taken out of the choice set, they still did not observe matching. However, they used only very few trials (i.e., a single decision in Experiment 3). In our experiment, participants went through 40 decisions and had time to develop their organization behavior and to routinize the decision process.

Finally, in comparison with Coupey's (1994) research, there is one crucial difference between her and our conclusions worth highlighting: Whereas Coupey argued that the possibility to take notes and restructure information promotes the use of compensatory strategies, we concluded that people adapt their organization behavior to their strategy. The next step would be to test this with self-selected strategy use; that is, to investigate whether people still learn an adaptive strategy and organize the information accordingly or whether they jump to compensatory strategies.

SOT: Limitations and outlook

Providing four circles for information organization may be viewed as a restriction of the method proposed here. We argue that this restriction is outweighed by the benefit of not having to code and categorize participants' notes, which makes the SOT more standardized and objective than previous approaches. However, the circles prestructure the space for information organization, and differences in the kind of structuring applied to information have been shown to have an impact on decision behavior. For instance, different kinds of structuring have an impact on the pattern of information acquisition in risky choice (for discussions, see Brandstätter & Gussmack, 2013; Pachur, Hertwig, Gigerenzer, & Brandstätter, 2013; see also the section on "The influence of information presentation format on decision behavior" in this article). Note that in the literature just mentioned, the effect of structuring is reflected in information-acquisition behavior (i.e., in search patterns). The prestructuring in the SOT, however, concerns information organization *after* acquisition. Although we argue that the prestructuring in circles does not introduce any bias toward either options or cues, it may nevertheless introduce a demand effect toward grouping the information according to one of these two dimensions rather than in any other way. If the research focus is on cues and options and the comparison of organization and search, we argue that the prestructuring is appropriate and may yield less noisy data.

However, a future plan is to develop a version without circles or any other kind of structure. In this general version, people will be free to organize information on the screen in any way they like. Instead of the OI that we used in the prestructured version of the SOT, some distance-based index (DI) could be computed in this general version of the SOT. The DI could be based on the Euclidean distances between pieces of information. This general version of the SOT will reveal more about the importance of options and cues for participants' subjective organization and about the question of how space is used when no structures are provided to suggest organizational patterns. However, the present version of the SOT is the first step in validating this new standardized method for the assessment of subjective organization. It keeps the strong focus on cues and options that has been present in previous research. The results of the validation study reveal that the OI captures an aspect of the decision process that differs from information search (as captured in the SI).

Problems may arise when the number of cues and options is increased. Given that the researcher wants to provide enough space for all of the information to be acquired and organized, the number of circles has to be identical to the number of options and cues. The number of options and cues should in turn be the same, in order to preserve symmetry and to not introduce a bias toward either of the dimensions. A to-be-developed version of the SOT without circles would provide more flexibility for this kind of variation and less demand effects.

Furthermore, the way the hidden information is provided can be varied. We chose labels with the structure "Cue X about Option Y" (e.g., "Mike about Carriage") for the information boxes. One could argue that this order (cue first, option second) influences people's information search and organization behavior. In the present study, we chose this labeling because it seemed natural with the content we used in the task. For future versions, different setups would be possible—for instance, allowing participants to collect the desired information by directly clicking the option name and the cue name in the display, in any order.

Conclusion

We do not always get information in a well-structured manner, and sometimes we cannot get it in the preferred sequence. These are aspects of a decision situation that so far have not gotten the attention they deserve. As, for example, research by Bettman and Kakkar (1977), Bettman and Zins (1979), and Coupey (1994; Coupey & DeMoranville, 1996) shows, the effect of information organization has not been completely neglected. Nevertheless, the studies in this area have been surprisingly rare and have suffered from a cumbersome methodology.

With the SOT, we provide a useful new research tool. The new task does not require coding and categorization of notes. It retains the advantages of the Mouselab paradigm and adds to those the possibility of investigating subjective information organization. The OI provides an objective measure for information organization, which is computed online during the experiment. Our simulations, as well as the validation study, revealed promising results. The OI fulfills the necessary requirements as an objective quantification of information organization, which is comparable to the widely used SI measure for information search. And at least with the instructed use of strategies, the OI reveals the expected differences in information organization between users of a compensatory and users of a noncompensatory strategy. To conclude, the new task can be flexibly adapted to tackle various research questions concerning information organization, and we hope that decision researchers find it useful for doing so.

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Manuscript 3

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Strategy-Compatible Information Organization is not Generally Preferred in Multi-Attribute Decisions

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Abstract

In two experiments using a recently developed task format to assess subjective information organization in multi-attribute decisions, we investigated whether people organize information such that it mirrors the process of a strategy learned from feedback. We manipulated the performance of the decision strategies (via the payoff environment) and the information acquisition (free search or beneficial or unbeneficial restriction of search) and examined whether people organized information in a strategy-compatible manner. Surprisingly, independent of the strategy used, participants generally preferred to group information by choice options; the difference in information organization between different classes of strategies was minor. In addition, search behavior influenced organization behavior. We conclude that information organization does not mirror the decision process for all strategies and consider a possible explanation for the observed pattern. Finally, we focus on the link between processes and choices in decision strategies and discuss limits of process tracing data for predicting choices.

Keywords: Information organization; Multi-attribute decisions; Process tracing; Decision strategy; Decision making

PsycINFO classification: 2340

Strategy-Compatible Information Organization is not Generally Preferred in Multi-Attribute Decisions

1. Introduction

Good organization simplifies many tasks. For instance, cooks lay out the ingredients and the tools in a particular order, namely such that the task “in the high tempo phases of cooking is both simplified and reduced“ (Kirsh, 1995, p. 35). Also when repairing something, taking apart and laying out the individual pieces such that they reflect the order in which they need to be put back together may simplify the task (Kirsh, 1995). For one thing, laying out the required objects and tools makes it more convenient to reach them *physically*. But there is also a *mental* aspect. Kirsh (1995) argued that restructuring is often done to support cognition: “to reduce the cost of visual search, to make it easier to notice, identify and remember items, and, of course, to simplify one’s representation of the task” (p. 41).

Do people also use the advantages of optimally arranged information in multi-attribute decisions? The aspect of information organization has been largely neglected in research on multi-attribute inferences, with a few exceptions (see Ettlin, Bröder, & Henninger, in press, for a brief overview). The goal of the current article is to fill this gap by investigating whether people make use of the possibility to organize information spatially when taking information-based decisions such as multi-attribute inferences. We approach this question by applying a recently developed task format with which the researcher may assess participants’ information organization—an aspect that was lost on most previous task formats used in multi-attribute decision research.

1.1 Information Organization in Multi-Attribute Decisions

In multi-attribute inference tasks, different attributes or *cues* provide information about different choice *options*. For instance, symptoms (cues) are indicators for diseases (options). But not all symptoms are equally valid as predictors. Fever, for instance, is linked to various different diseases from influenza to chickenpox to typhus as well as various other ones. But the typical rash is a much more valid indicator for chickenpox. Such cues can be used in different ways to reach a decision, for instance, a diagnosis, and depending on the task and situation, an adaptive decision maker should use them in different ways, that is, he should use different *strategies* (Gigerenzer, Todd, & the ABC Research Group, 1999; Payne, Bettman, & Johnson, 1993). These strategies are composed of different building blocks (e.g., a search rule, a stopping rule, and a decision rule). Furthermore, they are either *non-compensatory* and do therefore not integrate and tradeoff information from different cues against each other, or they are *compensatory* and therefore they integrate information from different cues.

One prototypical non-compensatory strategy, the Take-the-Best heuristic (TTB), proceeds in a *cue-wise* manner. It starts information search with the most valid cue (e.g., the most predictive symptom) and continues along the validity hierarchy. The most valid cue that discriminates among the possible choice options (e.g., among two different possible diagnoses), determines the decision (Gigerenzer & Goldstein, 1996). The compensatory strategies need more information and are typically represented by the Weighted Additive rule (WADD; e.g., Payne, Bettman, & Johnson, 1988) and the Equal Weight rule (EQW or Dawes' Rule; Dawes, 1979). These strategies integrate all available information for each option (i.e., the procedure is rather *option-wise*) and choose the option favored by a higher number of cues either by giving all cue information equal weight (EQW) or by weighting the cue information by a measure of the cues' validities before computing the sum for each option (WADD).

In the following, we will focus on one often-highlighted distinction between non-compensatory and compensatory strategies that we introduced above: the cue-wise and option-wise information search of non-compensatory and compensatory strategies, respectively (see Payne et al., 1988, 1993). TTB proceeds in a cue-wise manner in information acquisition. WADD and EQW both integrate information in an option-wise manner, and usually, researchers also assume that the search sequence matches this integration (but see Bröder, 2000, for a critique). This distinction suggests that different information organizations match the representation of these two different classes of strategies.

1.2 Previous Research on the Impact of Information Organization on Strategy Use

One central finding of previous research on information organization is that information search is adapted to the display (Bettman & Kakkar, 1977; Jarvenpaa, 1989; Schkade & Kleinmuntz, 1994). Second, if there is a mismatch between the display and the instructed strategy, people either take longer and may feel less confident (Bettman & Zins, 1979) or they still adapt their search to the display and only apply the decision rule according to the instructed strategy (Jarvenpaa, 1989). Third, with hard-to-process formats, people may sometimes end up with inferior decisions (specifically, this was shown in the consumer realm: consumers spent more money with hard-to-process formats [Russo, 1977]).

This previous research on information organization, however, mainly focused on pre-organized information rather than on participants' own subjective organizations. The importance of information organization for cognition has long since been investigated and discussed, though. For instance, Cafferty, DeNisi, and Williams (1986) showed that the way information is blocked when it is presented (i.e., option-wise, cue-wise, or mixed) influences the organization of information in memory (assessed with a clustering index applied to participants' free recall protocols). This indicates that subjective information organization may reflect memory representations. And, as mentioned above, Kirsh (1995) suggested that structuring may serve cognition. He mentioned "ways of using spatial arrangements to informationally jig or structure the environment" in order to direct attention properly (p. 39). Moreover, researchers commonly trace the search process in multi-attribute decisions to learn more about how people deal with information in those tasks. The above results and contemplations impose the addition of subjective information organization to the repertoire of measures in process tracing studies. The subjective way of organizing information may reveal more on how decision makers represent information.

As mentioned above, subjective information organization has been largely neglected in research on multi-attribute decisions. In rare exceptions, it has been assessed, though, with laborious and subjective rating methods (Coupey, 1994; Coupey & DeMoranville, 1996; see a more extensive discussion in Ettlin et al., in press). For instance, Coupey (1994) provided her participants with scratch paper and presented matrices with different degrees of structure in them. The notes participants took were the basis for Coupey's analyses. Coders categorized the notes into different classes of restructuring (i.e., changes to the information display). In short, the method was laborious and the subjective organization of information could not easily be expressed in a single index (but see Coupey & DeMoranville, 1996, for a relative measure of different types of restructuring).

The search and organization task (SOT; Ettlin et al., in press) remedies these problems by providing a computerized task to assess subjective information organization and with it an objective measure, the organization index (OI), to quantify subjective information organization. Importantly, the quantification allows for a direct comparison to information search, an aspect of the decision process researchers are typically interested in in multi-attribute decisions. Specifically, the SOT is based on the idea of the Mouselab paradigm (Willemsen & Johnson, 2011), which is often used with multi-attribute decisions and which allows assessing the decision rule and tracing information search and stop as well as other process measures. The novelty of the SOT is the possibility to assess and quantify information *organization*. In the SOT, the search direction can be quantified with Payne's (1976) search index (SI), which is also often used in Mouselab studies. Information organization can be quantified with the organization index (OI) specifically developed for the new task format.

The two indices have similar distributions and both focus on the two dimensions *cues* and *options*. For both indices, negative numbers indicate more cue-wise patterns (i.e., search and organization, respectively) and positive numbers indicate rather option-wise patterns.

1.2.1 The search and organization task.

The original version of the SOT is shown in the upper panel of Figure 1. In that example, four brokers on the top left represent the cues. In our experiments, the cues are arranged according to their performance with the leftmost broker being the one who provides the best predictions. The four market segments on the top right represent the options; their position is randomized anew after each decision. The 16 pieces of cue information (4 brokers * 4 options) are presented in the boxes in the lower half of the screen. In fact, only the labels are presented there, the information is still hidden. In order to get the information, the participants need to click on the label of the information they are interested in and then need to click into one of the four circles[1] in the center of the screen. The label as well as the value of the information will then appear in this spot. Participants can acquire as many pieces of information as they like, in any sequence, and they can organize it in any way they want with the only restriction that a maximum of four pieces of information fits within each circle. When the participants think they have enough information to take a decision, they can indicate their choice by clicking on one of the market segments in the upper right corner.

In Ettlin et al. (in press), we showed that, with instructed strategy use in the SOT, people not only search but also organize information such that the pattern matches the decision strategy (for TTB users, the search rule was in fact instructed). Above all, for information organization, we observed a clear preference for option-wise grouping for EQW

[1] See Ettlin et al. (in press) for explanations on the use of four circles as a template for information organization. In a nutshell, separable groups of information are necessary to compute the organization index that quantifies information organization, and the number of circles corresponds to the number of options, which needs to be identical to the number of cues (to avoid bias).

users and more cue-wise grouping for TTB users; the latter result was not as distinct as the former, however. We speculated that this might be due to the fact that compensatory strategies need to integrate information while TTB just compares (little) information stepwise. Under normal circumstances without adverse influences, it may just not be necessary for TTB users to organize information in a strategy-compatible manner. We will further investigate this issue in the current article and with spontaneous rather than instructed strategy use. Of particular interest is the question whether people use organization to compensate for disadvantageous restrictions of the possible search order.

1.3 The Importance of Strategy-Compatible Information Organization

Specifically, we will investigate whether people use spatial organizations to support the application of an acquired strategy in multi-attribute inference decisions; that is, whether they support their task representation by organizing information to map the decision process. So do participants organize information more cue-wise when non-compensatory strategies are more adaptive and more option-wise when compensatory strategies are better in terms of payoff? Senter and Wedell (1999) showed that acquired strategies could be applied with search rules deviating from the one assumed in the strategy model. That is, different information acquisition patterns do not necessarily result in shifts of strategy use, nonetheless they may “lead to different mental representations of the information that facilitate the use of certain strategies” (p. 429), and as discussed above, there is evidence that presenting information grouped by cues versus by options indeed leads to different memory representations (Cafferty et al., 1986). These findings strongly suggest that decision makers would preferably organize information in a strategy compatible manner.

A strategy-compatible information organization may not always be of the same relevance, however. In Ettlin et al. (in press), we discussed that the relevance of proper information organization may depend on the decision strategy. However, strategy use was instructed since the study targeted at the validation of the SOT method. This might have created experimental demands. In the present experiments, participants learn a strategy through feedback, rather than being instructed, and, additionally, we will focus on environmental aspects that may influence the relevance of a strategy-compatible information organization. Specifically, we manipulate the information acquisition sequence (cf. Senter & Wedell, 1999). The goal of manipulating such an external factor is to investigate whether unbeneficial restrictions increase the importance of information organization and whether decision makers therefore make use of the opportunity to organize the information in such a manner as to achieve a strategy-compatible representation of information—regardless of the strategy used. In other words, is information organization really important for the decision makers' task representation? With two experiments, we will demonstrate that there is an impact of search on organization, but, surprisingly, the relation between information organization and the decision strategy (i.e., choice) is barely affected. However, information organization is not random, rather there is a general preference for grouping together the information of individual options. To wrap up, we will provide a possible explanation for this observation and we will discuss the role of information organization for different strategy classes. Finally, we will discuss the limits of process tracing studies; that is, limits concerning the link between the decision process and the actual choices (cf. Bröder, 2000; Schulte-Mecklenbeck & Kühberger, 2014).

2. Experiment 1

The goal of the first experiment was to demonstrate that subjective information organization represents the process of decision strategies, especially under adverse influences. We investigated how decision makers organized information in multi-attribute inferences when strategy use was not instructed but when the best strategy could be learned from outcome feedback and we manipulated the acquisition sequence such that it was either compatible or incompatible with the optimal strategy. Compatibility should support and incompatibility should work against a coherent task representation. This manipulation should therefore influence the importance of a strategy-compatible information organization. Especially when the manipulation of the *acquisition* sequence hampers a coherent task representation by separating pieces of information that would have to be integrated or compared, decision makers should use the opportunity of *organizing* information in a strategy-compatible manner in order to compensate the unbeneficial restriction of the acquisition sequence. Under these conditions, also more frugal strategies like TTB may show a clear preference for a strategy-compatible information organization.

2.1 Methods

2.1.1 Task and conditions.

The decision task we used in this as well as in the following experiment was a multi-attribute inference task with four options and four cues. Four market segments (Hotel, Cargo, Energy, and Pharmaceutical Industry) represented the options and the four cues were brokers (Michael, Larry, Warren, and Donald) who provided information about the market segments. The information was either a positive (“yes”) or a negative (“no”) comment on a specific segment and meant that the broker either recommended to invest in the respective segment or advised against it, respectively. The brokers’ advice was of different quality and, on the screen, the brokers were ordered according to their performance. We informed participants about this aspect of the task.

The participants’ task was to choose the best market segment for investment in each decision trial. Their goal was to maximize the points on their fictitious accounts. To infer the best segment, they could use as much information from the brokers as they liked. Participants got feedback after each decision in which they were informed about the outcome values of all four options and about the number of points they had accumulated up to that point.

We implemented that decision task in the search and organization task (SOT; Ettlin et al., in press). As mentioned above, its main achievement is the easy assessment and quantification of information organization. The original version of the task is shown in the upper half of Figure 1. There are different aspects that can be varied in the SOT: the payoff environment, the search environment, and the organization environment. In our experiments, we manipulated the former two. The manipulation of the payoff environment influences the adaptivity of the decision strategies and is expressed via the outcome values of the four options, which are provided as feedback after a choice. TTB performs best in a non-compensatory payoff environment but in compensatory environments, WADD or EQW are more profitable. The second aspect, the search environment, can be manipulated, for instance, by restricting information acquisition in a particular manner. This version of the SOT is shown in the lower half of Figure 1. Instead of 16 boxes with labels, only one box is displayed with the label of the information that can currently be acquired.

In Experiment 1, the payoff environment was either non-compensatory or strictly compensatory.[2] In addition, there were three different search environments. Either participants could search for information in any sequence they liked (original version of the SOT, upper panel in Fig. 1) or the information acquisition sequence was restricted to be either cue-wise or option-wise (lower panel in Fig. 1). That is, with the cue-wise restriction, the information stemming from the broker on the very left about the first option to the left, then about the second, third, and fourth option was provided, before the information from the

[2] The non-compensatory payoff structure was $44*c_1 + 19*c_2 + 6*c_3 + 2*c_4$ where the c's need to be replaced by either +1 or –1 depending on the cue value which can be either positive or negative, respectively. In the compensatory environment, the payoff structure was $32*c_1 + 30*c_2 + 27*c_3 + 25*c_4$. In each decision trial, the criterion value for each of the four options was determined by these equations. However, we added a random integer to each outcome in order to lower the chances that people just learned criterion values by heart instead of using a rule (ranges of random integers differed between types of options; max. range = –3 to +3 depending on the number of possible rank order switches of the options).

broker second to the left was provided about all four options in order, and so on. With the option-wise restriction, the sequence was analogous but the information from each cue, one after the next from left to right, was presented about one option after the next.

2.1.1.1 Design.

Fully crossing the two factors payoff environment and search environment resulted in six conditions: Two mismatching conditions in which the restriction of the acquisition sequence was incompatible with the adaptive strategy, two matching conditions in which the restriction of the acquisition sequence was compatible with the adaptive strategy, and two unrestricted conditions. Specifically, the mismatching conditions were the option-wise restriction combined with the non-compensatory payoff environment (NonC fixed – mismatching) and the cue-wise restriction with the compensatory payoff environment (Comp fixed – mismatching). The matching conditions were the cue-wise restriction in combination with the non-compensatory payoff environment (NonC fixed – matching) and the option-wise restriction with the compensatory payoff environment (Comp fixed – matching). Finally, there was the non-compensatory (NonC – free) and the compensatory (Comp – free) payoff environment with unrestricted, participant-determined information search.

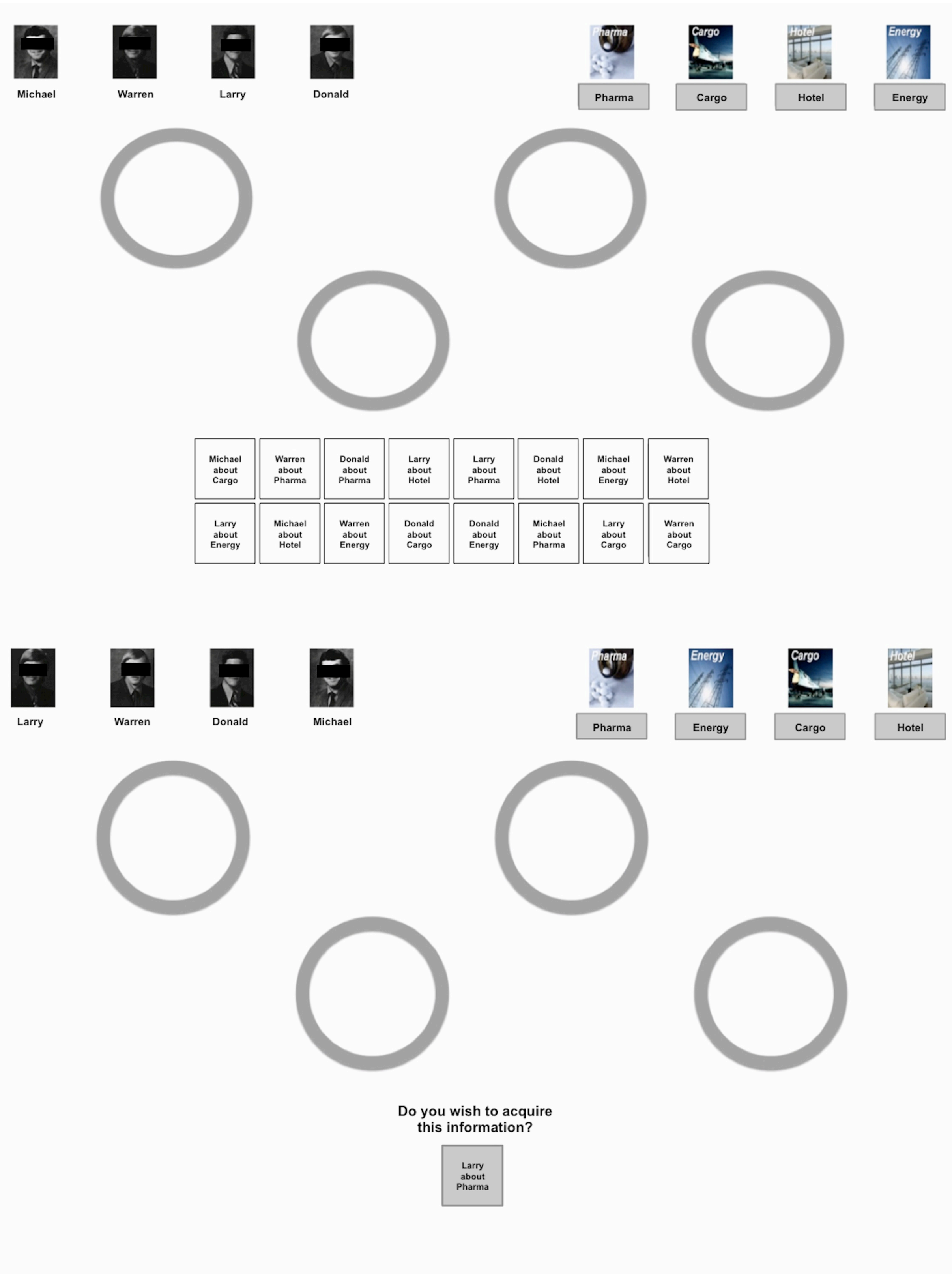

Figure 1. The SOT in its original version (upper panel) and in a modified version with a restricted search environment (lower panel). In our experiments, the language was German and the faces were not disguised.

2.1.2 Procedure.

The experiment took place in a laboratory with six individual cubicles containing one computer each. Upon arrival, the experimenter accompanied each participant to one of the cubicles where he or she signed a consent form. Participants were randomly assigned to one of the six experimental conditions.

After the experimenter had started the experiment, participants worked through the instructions on their own and completed 50 decision trials. Subsequently, participants worked through math tasks that were administered to investigate an unrelated research question. After completing the experiment, participants enlisted if they were interested in getting a debriefing email. Before leaving, they were paid 3 € or got the course credits for participation and, in addition, everyone received a maximum of 4.40 € depending on their performance in the 50 decision trials.

2.1.3 Participants.

Twenty-two participants partook in each condition, resulting in a sample of 132 participants.[3] The majority were students from the University of Mannheim. Ninety-nine (75%) were female and their mean age was 21 years (*SD* = 4).

2.1.4 Measures.

To identify the strategy that best matched each participant's pattern of choices, we used the outcome-based maximum-likelihood classification method by Bröder and Schiffer (2003). With this method, each participant is classified as user of the strategy for which the pattern of actual choices made by that particular participant is most likely. We used 50 items

[3] Four data files were lost. The files were overwritten because subject numbers were accidentally used twice on identical computers.

of different types such that the investigated strategies (TTB, WADD, EQW) all predicted different answer patterns and could thus be separated from one another.

As process measures, specifically to quantify information search and organization, we used Payne's search index (SI; 1976) and the organization index (OI; Ettlin et al., in press), respectively. The SI is a measure of relative option- versus cue-wise transitions in information search. An option-wise transition results if two pieces of information about the same option are inspected in sequence; a cue-wise transition results if two pieces of information stemming from the same cue are inspected in sequence. The SI is computed as the difference of the number of option-wise and cue-wise transitions within a trial, divided by the sum of these two numbers. Positive numbers (max. +1) indicate predominantly option-wise search and negative numbers (min. –1) mean that cue-wise search predominates.

The OI assesses what kind of information (cues or options) is predominantly grouped together. That is, in each of the four circles the maximum number of same options and same cues is identified. Then the sums of these values are computed for options and cues separately, after one was subtracted from each maximum in order to scale the index from –1 to +1. The sums for cues is subtracted from the sums for options and divided by the sum of these two individual sums:

$$OI = \frac{\left[\!\left[\left[\!\left[\sum_{j=1}^{4} (\max(SameOption_{circle\ j}) - 1) \right]\!\right] - \left[\!\left[\sum_{j=1}^{4} (\max(SameCue_{circle\ j}) - 1) \right]\!\right] \right]\!\right]}{\left[\!\left[\left[\!\left[\sum_{j=1}^{4} (\max(SameOption_{circle\ j}) - 1) \right]\!\right] + \left[\!\left[\sum_{j=1}^{4} (\max(SameCue_{circle\ j}) - 1) \right]\!\right] \right]\!\right]} \qquad (1)$$

$\max(SameOption_{circle\ j})$ is the maximum number of pieces of information describing the same option in circle j and $\max(SameCue_{circle\ j})$ is the analogous value for cues. The OI comprises the same range as the SI (-1 to 1), and positive numbers denote more option-wise grouping of information while negative numbers stand for cue-wise grouping. The two indices, SI and OI, are comparable in further aspects as well: For random search and organization the sampling means of SI and OI are both zero, given the number of cues and the number of options in the task are identical. Moreover, the two indices have very similar distributions, and their a priori correlation is negligible (see Ettlin et al., in press).

2.1.5 Hypotheses.

2.1.5.1 Strategy hypothesis.

Based on previous research we expect that people learn to use the adaptive strategy when the inference task is presented with the SOT like they do when inference tasks are presented with the Mouselab paradigm (e.g., Bröder & Schiffer, 2003, 2006; Rieskamp & Otto, 2006). That is, we hypothesize that the majority of participants in the non-compensatory environments will use TTB and the majority of participants in the compensatory environments will use a compensatory strategy (WADD/EQW).

2.1.5.2 Search hypothesis.

Concerning information search, we expect that, when information search is unrestricted, it will be matched to the adaptive strategy. We will analyze this hypothesis as well as further hypotheses concerning process measures conditional on strategy classification rather than on experimental condition because the payoff environments of the experimental conditions should influence strategy selection, but the process measures should depend on the actually selected strategy. That is, we hypothesize that TTB users will have a more negative SI (indicating cue-wise information search) than compensatory decision makers who (are supposed to) integrate information option-wise.

2.1.5.3 Organization hypothesis.

Finally, we expect that in all six conditions, the organization of information will be matched to the chosen strategy such that information needed in close temporal proximity (given a specific strategy) is organized in close spatial proximity. This means that we expect identical signs for the SI and OI and spontaneous matching of search and organization to the adaptive strategy in the two conditions with unrestricted information search (NonC – free and Comp – free). In the two matching conditions (NonC fixed – matching and Comp fixed – matching), we also expect identical signs for the SI and OI. In the two mismatching conditions (NonC fixed – mismatching and Comp fixed – mismatching), however, we expect opposite signs for the SI and OI. In other words, we expect that participants use the possibility to organize information to compensate for the strategy-incompatible search sequence in order to support a coherent representation of the task. In fact, we expect the effect of strategy on organization to be largest between these two mismatching conditions; that is, between the TTB users in the NonC fixed – mismatching Condition and the WADD/EQW users in the Comp fixed – mismatching Condition. Due to the strategy-incompatible search restrictions in these conditions, the adaptive strategy should become less convenient to apply than in the two matching and the two free search conditions. However, with the help of a strategy-compatible information organization, the strategy-incompatible search restrictions can be compensated. In other words, the strategy-incompatible search restrictions should increase the importance of a strategy-compatible information organization.

2.2 Results

2.2.1 Outcome-based strategy classification: Test of the strategy hypothesis.

As expected, there were more TTB users in the conditions with the non-compensatory payoff environment than in the ones with the compensatory payoff environment. These results are shown in Table 1.

Table 1

Outcome-based strategy classification for Experiment 1

	Strategy Classification[a]		χ^2-Test
	TTB (%) [b]	WADD/EQW (%) [b]	
Non-compensatory payoff Conditions	36 (75.0%)	12 (25.0%)	$\chi^2(1) = 60.85$, $p < .001$, Cramér's $V = .747$
Compensatory payoff Conditions	2 (3.3%)	59 (96.7%)	

Note. [a] If the deviation from the best fitting strategy (application error) was higher than 30% in total or the error due to the choice of the strategy incompatible option (in contrast to an error due to the choice of a dominated option) was higher than 20%, the participant was labeled *unclassified*. This was the case for 20 participants. In addition, three participants were omitted from the above analysis because they had the same likelihoods for TTB and a version of WADD and could therefore not be classified. The mean error for the application of the strategy for which each of the remaining participants was classified was 10%.

[b] Percentages are users of a particular strategy within a particular condition.

2.2.2 Information search: Test of the search hypothesis.

As hypothesized, if participants were free to acquire information in any sequence they liked, those who were classified as TTB users engaged in a more cue-wise search pattern than those who were classified as users of a compensatory strategy (Table 2).[4]

[4] Here, as well as for all further analyses, we provide non-parametric tests if the assumptions regarding the distribution of the data were violated; otherwise we provide the parametric tests. Moreover, we report one-tailed tests for the analyses of our hypotheses but not for the post-hoc or exploratory analyses.

Table 2

Information search in Experiment 1 (only free search conditions)

	TTB users [a]	WADD/EQW users [b]
SI		
M	–0.60	0.01
(*SD*)	(0.29)	(0.57)
Mdn	–0.68	0.03
U-Test	$U = 294$, $z = 3.39$, $p < .001$ (one-tailed), $r = 0.55$	

Note. [a] This sub-sample includes all participants classified as TTB users and who were in the two conditions with free information search, $n = 17$.

[b] This sub-sample includes all participants classified as users of a WADD or EQW strategy and who were in the two conditions with free information search, $n = 21$.

2.2.3 Information organization: Test of the organization hypothesis.

Figure 2 depicts the organization index OI in each condition and shows that TTB users tended to organize less option-wise than users of compensatory strategies (except for the TTB users in the NonC fixed – mismatching Condition). The results in Table 3 reveal that, overall, the WADD/EQW users had a higher positive OI value than the TTB users. This reflects the expected difference in the OI between the strategies. Nevertheless, we did not observe cue-wise grouping for TTB users, like we had predicted, but we rather observed a general preference for option-wise information organization (see Fig. 3).

Moreover, the overall effect was not driven by the expected groups: We expected the largest difference between the OIs in the two mismatching Conditions. That is we expected a clearly negative OI (cue-wise grouping) for TTB users in the NonC fixed – mismatching

Condition and a clearly positive OI (option-wise grouping) for the WADD/EQW users in the Comp fixed – mismatching Condition (i.e., the focus is on those strategy users for whom the restrictions in the respective conditions really were strategy-incompatible). However, these were the only conditions for which the observed pattern disagreed with the expected one (Fig. 2; see also Fig. 3); that is, the OI for TTB users in the NonC fixed – mismatching Condition was even slightly *higher* rather than lower (*M* = 0.81 [*SD* = 0.52], *Mdn* = 0.99) than the OI for WADD/EQW users in the Comp fixed – mismatching Condition (*M* = 0.26 [*SD* = 0.90], *Mdn* = 0.88). Thus we did not observe the expected compensation behavior for the strategy-incompatible search restrictions.

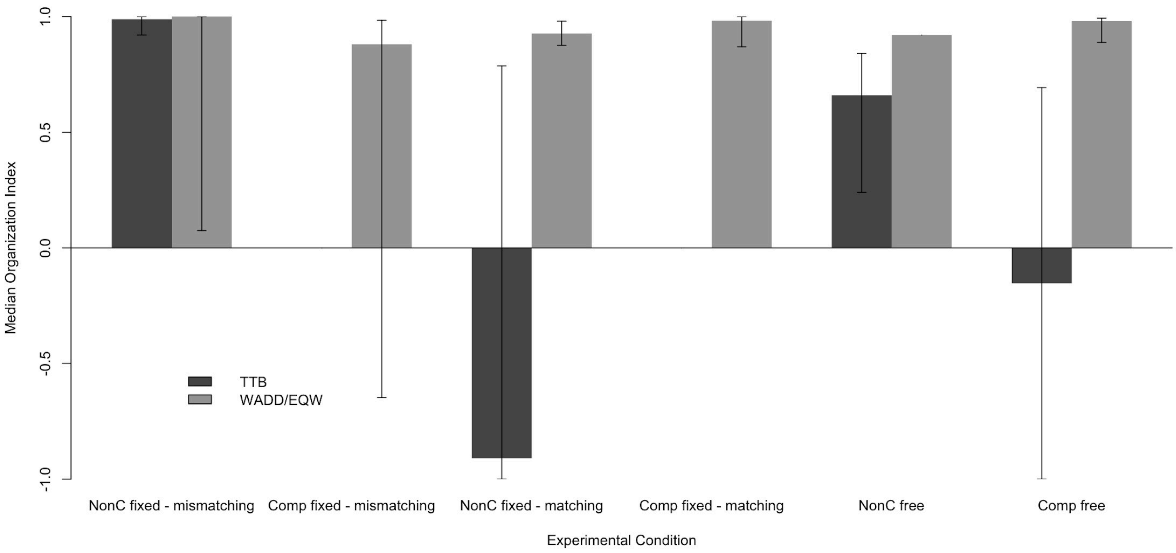

Figure 2. Median OI in each of the six experimental conditions; separately for TTB and WADD/EQW users. NonC fixed – mismatching = Condition with non-compensatory payoff environment and predetermined option-wise information acquisition (n_{TTB} = 11, $n_{\text{WADD/EQW}}$ = 6). Comp fixed – mismatching = Condition with compensatory payoff environment and predetermined cue-wise information acquisition (n_{TTB} = 0, $n_{\text{WADD/EQW}}$ = 21). NonC fixed – matching = Condition with non-compensatory payoff environment and predetermined cue-

wise information acquisition (n_{TTB} = 10, $n_{\text{WADD/EQW}}$ = 5). Comp fixed – matching = Condition with compensatory payoff environment and predetermined option-wise information acquisition (n_{TTB} = 0, $n_{\text{WADD/EQW}}$ = 18). NonC free = Condition with non-compensatory payoff environment and participant-determined information search (n_{TTB} = 15, $n_{\text{WADD/EQW}}$ = 1). Comp free = Condition with compensatory payoff environment and participant-determined information search (n_{TTB} = 2, $n_{\text{WADD/EQW}}$ = 20). Error bars represent bootstrapped 95% CI (percentiles; 10'000 samples).

Table 3

Information organization in Experiment 1: Comparison between strategy classes

	TTB users [a]	WADD/EQW users [b]
OI		
M	0.31	0.56
(*SD*)	(0.81)	(0.75)
Mdn	0.70	0.97
U-Test	U = 1831.5, z = 3.09, p = .001 (one-tailed), r = 0.30	

Note. [a] n = 38

[b] n = 71

Despite the general preference for option-wise information organization, Figure 3 reveals that there was still variance between the conditions. The three conditions with cue-wise information search (i.e., negative SIs; see Fig. 4 for the SIs in the two free search conditions, irrespective of strategy) show less option-wise grouping (i.e., have less positive

OIs) than the conditions with option-wise or only mildly cue-wise search. In other words, the organization may rather depend on the search, than the integration strategy.

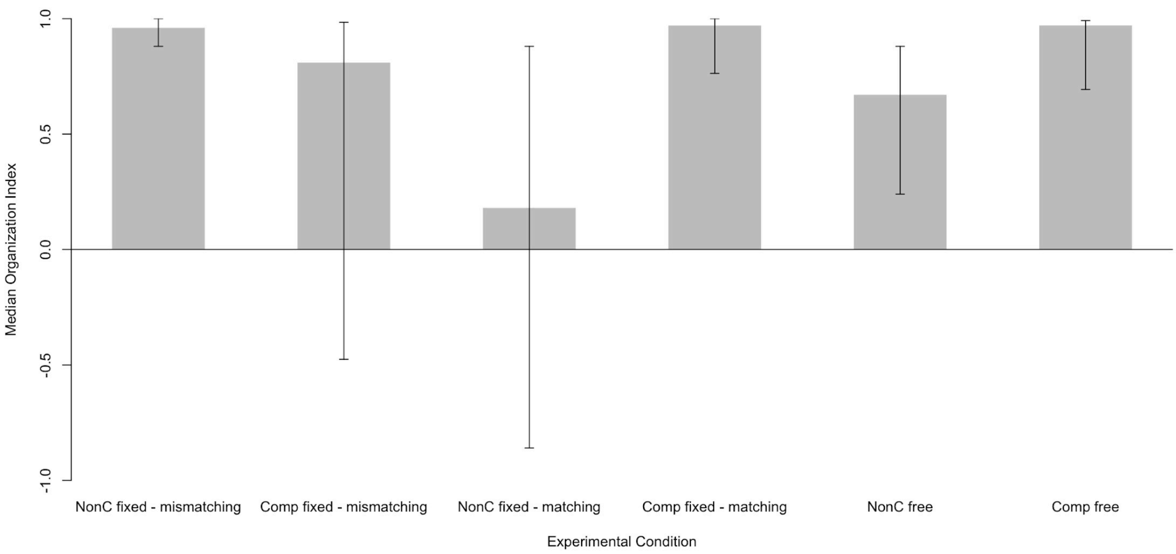

Figure 3. Median OI for each of the six experimental conditions (n = 22 in each condition). Error bars represent bootstrapped 95% CI (percentiles; 10’000 samples). For descriptions of labels of experimental conditions see Figure 2.

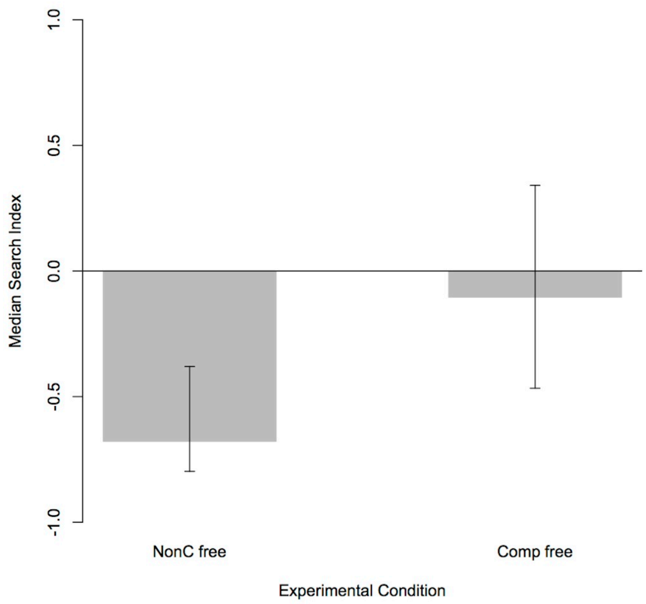

Figure 4. Median SI for the experimental conditions with participant-determined information search (n = 22 in each condition). Error bars represent bootstrapped 95% CI (percentiles; 10’000 samples). For descriptions of labels of experimental conditions see Figure 2.

2.2.4 Relationship between information search and organization: Unexpected influence on information organization.

Correlating the SI and the OI revealed that they were related: Participants who searched in a more cue-wise manner also organized in a less option-wise manner, Kendall τ = 0.32, p < .001. In other words, information search influenced information organization.

2.3 Discussion

To summarize, we observed a general preference for organizing information in an option-wise manner, which we had not predicted. Furthermore, there was a relation between search and organization, which we had not expected either. That is, participants who searched for information in a less cue- or more option-wise manner (either voluntarily or by fixed sequence) also organized information in a more option-wise manner. So information was partially just filled in the empty spaces, one after the next, the way it was acquired—regardless of the applied decision rule. And so in fact, some of the OIs for TTB users were negative (i.e., cue-wise organization; see Fig. 2, NonC fixed – matching Condition). However, the error bars cover a wide range; that is, there was a lot of variance in how the TTB users organized information. Nevertheless, the predicted correspondence between strategy and organization emerged, but was clearly not driven by the expected groups; that is, there was no sign of the expected difference between the OIs in the non-compensatory payoff environment with option-wise search restriction and the compensatory payoff environment with cue-wise search restriction. Especially, there was no attempt to compensate the strategy-incompatible restriction in information acquisition by TTB users in the non-compensatory payoff environment; they clearly organized information in a strategy-incompatible, option-wise manner. In short, the results for information organization differed from the expectations based on the assumption that the spatial organization of information is chosen to be most appropriate for applying the selected strategy.

The results for information search and adaptive strategy selection were in line with our expectations and former research (e.g., Bröder & Schiffer, 2003; Rieskamp & Otto, 2006), thus demonstrating that the new task is comparable to traditional Mouselab and does not induce completely different processes. Interestingly enough, participants succeeded in applying the adaptive strategy even in the conditions in which search was restricted in a strategy-incompatible manner and in which the TTB users also organized the information in an option-wise (i.e., strategy-incompatible) fashion. There seems to have been no need to compensate the strategy-incompatible acquisition restriction for TTB users (cf. Jarvenpaa, 1989, on matching search to the format and choice to the instructed strategy; see also Senter & Wedell, 1999).

For the WADD/EQW users, the story is different. They searched for information in a rather neutral way with respect to the dimensions cue- and option-wise, but they organized in a clearly option-wise manner. Those who were in the condition with a compensatory payoff structure and a fixed cue-wise acquisition sequence compensated for the strategy-incompatible restriction by organizing the information in a strategy-compatible, option-wise manner, even though their OI was not as high as the one of participants in compensatory payoff environments with a strategy-compatible restriction of information acquisition or with free search.

From this asymmetry we conclude that search and organization are likely to be of different importance for different strategies: While the SI was more extreme for the TTB users, the OI was more extreme for WADD/EQW users. This seems reasonable given the strategy models. TTB relies on the (cue-wise) acquisition sequence, which is a clearly specified building block of that strategy—but as was shown by TTB users confronted with an incompatible acquisition sequence, this sequence is not a necessity. Compensatory strategies, which do not have as clearly specified search sequences, but rather depend on (option-wise) integration, rely on option-wise grouping. Information integration may be done more effectively if all relevant information is visible “at a glance”. But then the question remains, why the TTB users would make the effort of organizing information in nearly the opposite way from what would be a strategy-compatible organization. Why do they not simply organize it strictly according to the acquisition sequence or just randomly?

Even tough we did not predict the general preference for option-wise grouping, it may be explained in a post-hoc manner: Decision makers appear to group the kind of information that builds the unit of the decision. That is, people eventually need to decide for one *option* and they therefore like to see the object they are choosing as a whole, even if they use a strategy that does not consider options holistically. Grouping the options allows for a final overall check of the choice. Furthermore, since TTB is a frugal strategy, the decision maker may easily keep the information in mind as she acquires it sequentially. In that case, the decision maker does not apply the strategy to the information once it is organized, but rather while she is acquiring and organizing it, and so the organization does not have to match the strategy but could serve other purposes (e.g., to verify one's choice; cf. Russo & Leclerc, 1994). And for the TTB users in the mismatching condition with a non-compensatory payoff structure, who also had a positive OI, it might not have been worthwhile to engage in organizing information in a manner deviating from the strategy-incompatibly restricted SI. Even if the incompatible restriction hampered strategy application during information acquisition, there was enough time to look back and forth a bit between the groups (circles on the screen) to gather the little information needed for TTB.

This is a post-hoc explanation for the general preference for option-wise information organization. However, if our idea on the role of information organization holds and if unlimited time and information held in working memory indeed lowered the importance of a strategy-compatible information organization, the general preference for option-wise grouping should disappear if those aspects were changed: If the information really needed to be gathered from the organized display, and if there was not enough time to look back and forth, the organization should be matched to the adaptive strategy, given information organization is indeed used as an aid to form a coherent task representation, especially also for the application of TTB.

We implemented these changes, time pressure and the necessity to read information off the screen because it is eliminated from working memory in Experiment 2. The goal was to increase the importance of a strategy-compatible information organization. Since for the critical decisions the information would not be available in working memory anymore, the only way to support the decision process was to organize information such that the grouping constituted a strategy-compatible representation of information. Given that decision makers assume that a strategy-compatible organization indeed simplifies the representation of the task, also TTB users should resolve to organize information in a strategy-compatible manner in the situation created in Experiment 2.

3. Experiment 2

In Experiment 1, users of compensatory strategies organized the information such that it was compatible with their strategy; that is, they organized information in an option-wise manner. Those who were classified as users of the TTB heuristic, however, did not organize information to be compatible with their strategy. In Experiment 2, we introduced time pressure and, most importantly, we also separated the decision from the information search and organization phase in order to make sure that the decisions could not be made with information held in working memory but that the information needed to be gathered from the screen. In this situation the potential relevance of a strategy-compatible information organization was therefore at a maximum. For the critical decisions in Experiment 2, participants needed to be quick to build a coherent task representation. They needed to be as fast and accurate as possible. If the decision maker took too long to apply her strategy, she missed the chance to answer, which had a negative impact on her outcome since she failed to increase her earnings.

3.1 Methods

3.1.1 Task and conditions.

The task displays in the second experiment were identical to the ones in Experiment 1 (Fig. 1), but the current experiment was divided into three distinct phases. The three phases had different purposes: Phase 1 was for participants to learn the best strategy; Phase 2 was to search and organize information for the decisions that would be taken in Phase 3. The Phases 2 and 3 implemented the separation of the search and organization (Phase 2) from the decision phase (Phase 3). This separation ensured that the decision maker would not hold the information needed for the decision in working memory but that he would have to gather it from the screen.

Specifically, Phase 1 consisted of the task already used in Experiment 1. It served as a training phase to acquire knowledge about the environment and establish a strategy. In Phase 2, we again presented 20 out of the 50 items of Phase 1, but this time, participants did not make decisions. Their task was to acquire and organize as much information as they would need to make a decision, then they should press the continue-button and work through the next trial. In the third and final phase, we showed the participants five out of the 20 items they had worked on in Phase 2, but with the information layout they had created themselves in the previous phase. Now they had to take a decision; they needed to click on one of the four options within five seconds, otherwise the trial would abort and the task would continue with the next of the five trials.

The items selected for Phase 3 were of those types that discriminated between TTB and compensatory strategies. That is, TTB would always choose a different option than the WADD strategy that was optimal in the conditions with a compensatory payoff environment. This ensured that correct answers for all five decisions in the third phase could only be reached with the adaptive strategy. That is, applying the more frugal TTB in the compensatory conditions, for instance, led to a bad outcome in terms of money earned. If this had not been the case, and knowledge about it had spread, it could have distorted our results.

We used a different set of 50 items than the one in Experiment 1 but again with a non-compensatory and a strictly compensatory payoff environment.[5] As before, there were two

[5] The non-compensatory payoff structure was $44*c_1 + 19*c_2 + 6*c_3 + 2*c_4$ where the c's need to be replaced by either +1 or –1 depending on the cue value which can be either positive or negative, respectively. In the compensatory environment, the payoff structure was $37*c_1 + 35*c_2 + 32*c_3 + 30*c_4$. In each decision trial, the criterion value for each of the four options was determined by these equations. However, we added a random integer between –2 and +2 to each outcome (or just between –1 and +1, depending on the number of possible

unrestricted search conditions, each with one of the two different payoff environments. But this time, we had just two conditions with restricted information acquisition, namely the mismatching ones; we omitted the matching conditions.

3.1.1.1 Design.

This resulted in a total of four conditions: the non-compensatory payoff environment with option-wise restricted information acquisition (NonC fixed – mismatching), the compensatory payoff environment with cue-wise restricted information acquisition (Comp fixed – mismatching), the non-compensatory payoff environment with participant-determined information search (NonC – free), and the compensatory payoff environment with participant-determined information search (Comp – free).

3.1.2 Procedure.

The experiment took place in the same laboratory with individual cubicles as Experiment 1. The participants signed the same kind of consent form when they arrived and were randomly assigned to one of the four experimental conditions. Then the experimenter started the experiment and each participant individually worked through the instructions and the task.

Each participant completed the three phases of the task described above. Before they started the second phase, they were informed about the details of Phases 2 and 3; that is, that they needed to search and organize information in the second phase but only had to take a decision for five out of these items in the third phase. They knew that they would see their own information organizations in Phase 3 and that they had to decide within five seconds and they also knew that their compensation would depend on the five decisions in that final phase.

After the decision task, participants registered if they wished to get a debriefing email and were reimbursed. In the current experiment, the payment was fully dependent upon the

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rank order switches of the options), in order to lower the chances that people just learned criterion values by heart instead of using a rule.

performance in the last five decision trials; participants got 1 € for each correct decision and correctness was determined by the choice corresponding to the adaptive strategy in the respective condition. In addition, participants could get course credits if needed.

3.1.3 Participants.

Sixty participants completed the experiment, resulting in 15 participants in each of the four conditions. They were students from the University of Mannheim, and 54 (90%) were female. Their mean age was 20 years (*SD* = 2).

3.1.4 Measures.

For strategy classification, we again used the outcome-based method described in the Methods section of Experiment 1. We used only the 50 items of Phase 1 to classify participants. As before, we used Payne's (1976) SI and the OI for the quantification of information search and organization, respectively.

3.1.5 Hypotheses.

3.1.5.1 Strategy hypothesis.

We expect that people adapt the strategy to the payoff environment. There should be more TTB users in the non-compensatory payoff environments than in the compensatory payoff environments.

3.1.5.2 Search hypothesis.

In the two conditions with free information search, we expect strategy-compatible search behavior; that is, more cue-wise search for TTB users than for users of a compensatory strategy.

3.1.5.3 Organization hypothesis.

For the organization of information, we expect different patterns for Phases 1 and 2. In Phase 1, we expect to replicate the results from Experiment 1. We expect an influence of information search on the organization of information and we expect an overall preference for an option-wise organization of information.

In Phase 2, however, we expect that participants organize the information such that it is compatible with their strategy. That is, we expect a negative OI (cue-wise organization) for TTB users and a positive OI (option-wise organization) for users of a compensatory strategy. This hypothesis differs from the one for Phase 1 because the circumstances of the decision differ: When it comes to the decisions in Phase 3, the information is not in working memory anymore unlike when the decision is taken immediately after information search and organization (as in Phase 1). All needs to be read from the display in Phase 3. Since participants know that they have to decide within a really short time (5 s), they should try to organize the information such that they quickly arrive at a coherent task representation in order to be able to apply their strategy (acquired in Phase 1) as conveniently and as quickly as possible. We therefore expect also TTB users to organize information in a strategy-compatible manner in Phase 2.

3.2 Results

3.2.1 Outcome-based strategy classification: Test of the strategy hypothesis.

As hypothesized, there were more TTB users in the non-compensatory payoff environments than in the compensatory ones (see Table 4).

Table 4

Outcome-based strategy classification for Experiment 2

	Strategy Classification[a]		χ^2-Test
	TTB (%) [b]	WADD/EQW (%) [b]	
Non-compensatory payoff Conditions	20 (74.1%)	7 (25.9%)	$\chi^2(1) = 18.27$, $p < .001$, Cramér's $V = .571$
Compensatory payoff Conditions	5 (17.2%)	24 (82.8%)	

Note. [a] If the deviation from the best fitting strategy (application error) was higher than 30% in total or the error due to the choice of the strategy incompatible option (in contrast to an error due to the choice of a dominated option) was higher than 20%, the participant was labeled *unclassified*. This was the case for two participants. In addition, two participants were omitted from the above analysis because they had the same likelihoods for TTB and a version of WADD and could therefore not be classified. The mean error for the application of the strategy for which each of the remaining participants was classified was 11%.

[b] Percentages are users of a particular strategy within a particular condition.

3.2.2 Information search: Test of the search hypothesis.

The information search behavior of TTB users and of those who were classified as users of a compensatory strategy showed the hypothesized difference. TTB users acquired information more cue-wise than those who were classified as WADD or EQW users. This was the case for both Phases 1 and 2 (Table 5).

Table 5

Information search (SI) in Experiment 2 (only free search conditions)

	TTB users [a]	WADD/EQW users [b]
SI: Phase 1		
M	–0.63	–0.21
(*SD*)	(0.34)	(0.55)
Mdn	–0.78	–0.32
U-Test	$U = 161$, $z = 2.44$, $p = .008$ (one-tailed), $r = 0.45$	
SI: Phase 2		
M	–0.73	–0.39
(*SD*)	(0.32)	(0.55)
Mdn	–0.87	–0.58
U-Test	$U = 156$, $z = 2.23$, $p = .013$ (one-tailed), $r = 0.41$	

Note. [a] This sub-sample includes all participants classified as TTB users and who were in the two conditions with free information search, $n = 15$.

[b] This sub-sample includes all participants classified as users of a WADD or EQW strategy and who were in the two conditions with free information search, $n = 14$.

3.2.3 Information organization: Test of the organization hypothesis.

First, we checked whether the difference between the OI values of the TTB users and the WADD/EQW users replicated. We compared all TTB users to all users of a compensatory strategy in the total sample. The descriptive statistics in Table 6 show a difference in the hypothesized direction. But the difference only reached the conventional level of significance in Phase 2. Nevertheless, all groups had positive OIs again; that is, the general preference for option-wise grouping of information replicated in both phases—also in the second phase in which we created circumstances that were expected to maximize the importance of a strategy-compatible information organization given it is used for the hypothesized purpose, namely to aid establishing a coherent task representation.

As in the first experiment, we expected to observe the strongest matching of information organization to the adaptive strategy in the two mismatching conditions (i.e., compensation for strategy-incompatible acquisition restrictions). But again, as in the first experiment, this was clearly not the case, neither in Phase 1 (TTB users in NonC fixed – mismatching Condition: $M = 0.47$ [$SD = 0.90$], $Mdn = 0.99$; WADD/EQW users in Comp fixed – mismatching Condition: $M = 0.31$ [$SD = 0.91$], $Mdn = 0.83$) nor in Phase 2 (TTB users in NonC fixed – mismatching Condition: $M = 0.30$ [$SD = 0.97$], $Mdn = 1.0$; WADD/EQW users in Comp fixed – mismatching Condition: $M = 0.40$ [$SD = 0.92$], $Mdn = 0.98$).

Table 6

Information organization (OI) in Experiment 2: Comparison between strategy classes

	TTB users [a]	WADD/EQW users [b]
OI: Phase 1		
M	0.25	0.50
(*SD*)	(0.69)	(0.77)
Mdn	0.34	0.96
U-Test	$U = 483.5$, $z = 1.58$, $p = .057$ (one-tailed), $r = 0.21$	
OI: Phase 2		
M	0.14	0.55
(*SD*)	(0.79)	(0.78)
Mdn	0.25	0.98
U-Test	$U = 497.5$, $z = 1.87$, $p = .031$ (one-tailed), $r = 0.25$	

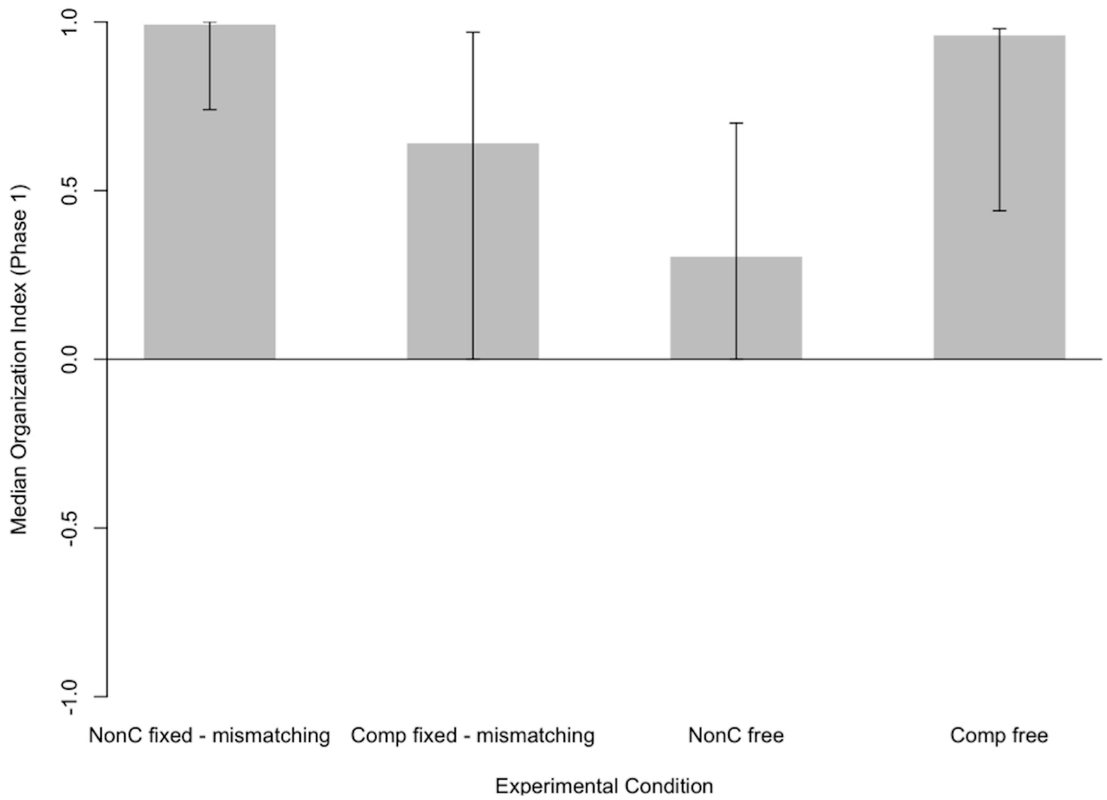
Note. [a] $n = 25$

[b] $n = 31$

As Figure 5 shows and as we already observed in Experiment 1, there was a clear preference for option-wise information organization; the OI was positive in all four conditions. In fact, the pattern of the bars is highly similar to the pattern of the four bars in Figure 3 that describe the same conditions. So again and despite the general preference for option-wise information organization, there was still variance between the conditions.

3.2.4 Relationship between information search and organization: Replication of the unexpected influence on information organization.

As in Experiment 1, this variance followed the variations of the SI (see Fig. 6 for the SIs in the two free conditions, irrespective of strategy). The influence of search on organization replicated in both phases (Phase 1: Kendall $\tau = 0.24$, $p = .009$; Phase 2: Kendall $\tau = 0.20$, $p = .038$).


Median Organization Index (Phase 1)
1.0
0.5
0.0
-0.5
-1.0
NonC fixed - mismatching
Comp fixed - mismatching
NonC free
Comp free
Experimental Condition

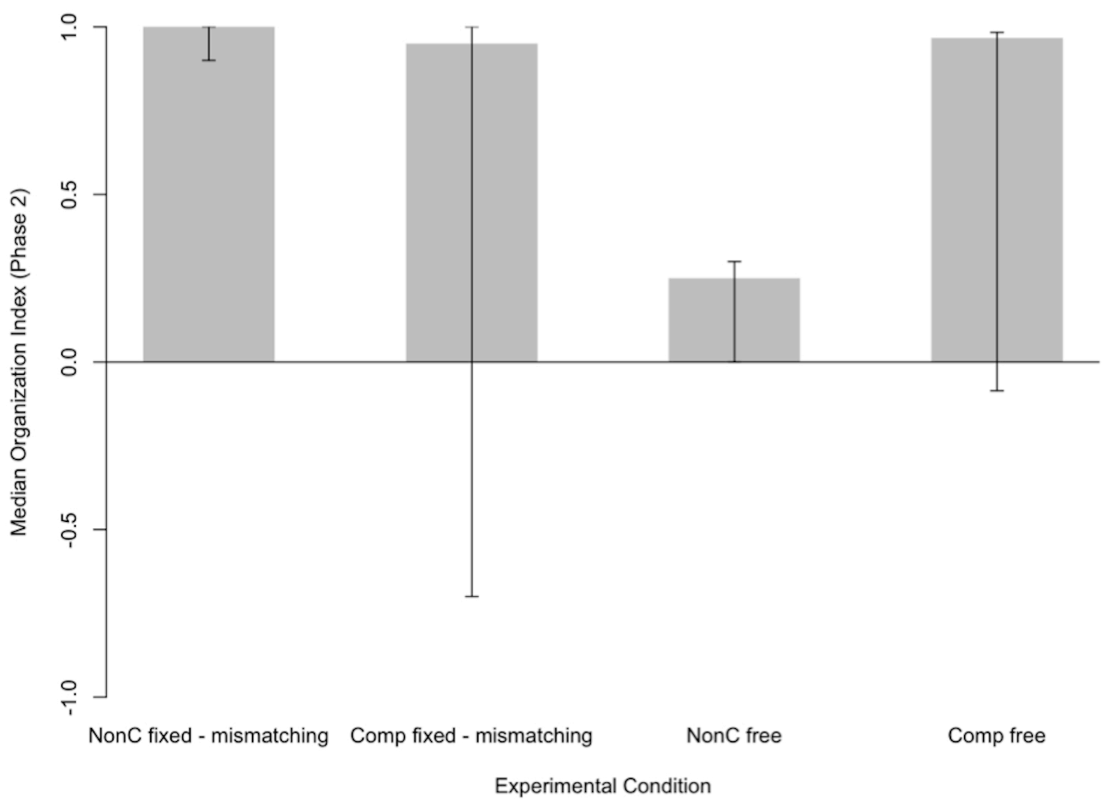

Median Organization Index (Phase 2)
1.0
0.5
0.0
-0.5
-1.0
NonC fixed - mismatching
Comp fixed - mismatching
NonC free
Comp free
Experimental Condition

Figure 5. Median OI for each of the four experimental conditions (*n* = 15 in each condition) for Phases 1 (upper graph) and 2 (lower graph) in Experiment 2. Error bars represent bootstrapped 95% CI (percentiles; 10’000 samples). NonC fixed – mismatching = Condition with non-compensatory payoff environment and predetermined option-wise information acquisition. Comp fixed – mismatching = Condition with compensatory payoff environment and predetermined cue-wise information acquisition. NonC free = Condition with non-compensatory payoff environment and participant-determined information search. Comp free = Condition with compensatory payoff environment and participant-determined information search.

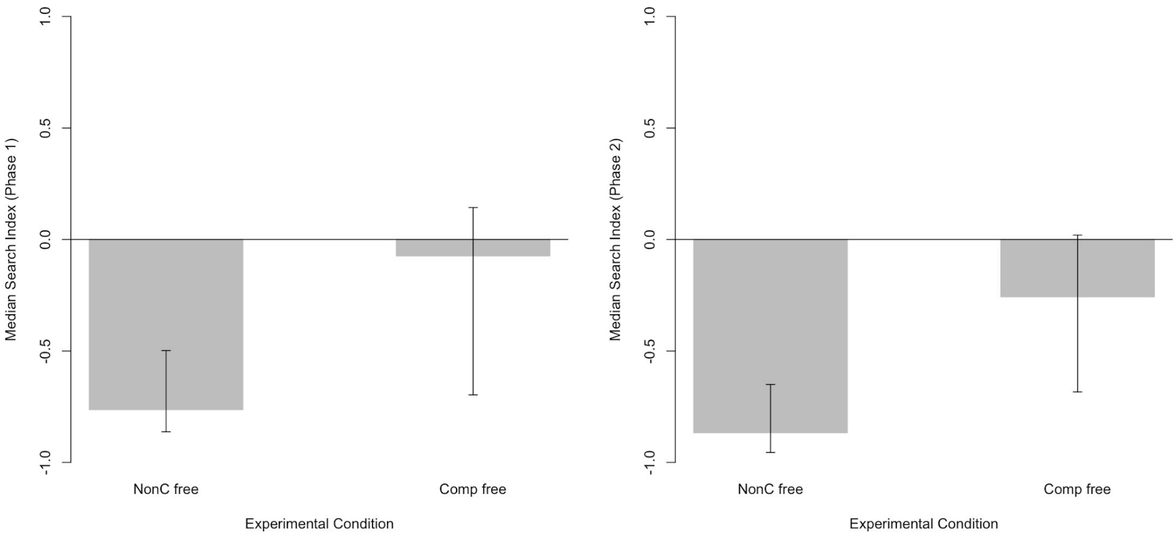


Figure 6. Median SI for the experimental conditions with participant-determined information search (*n* = 15 in each condition) for Phases 1 (left) and 2 (right) in Experiment 2. Error bars represent bootstrapped 95% CI (percentiles, 10’000 samples). For descriptions of labels of experimental condition see Figure 5.

3.2.5 Organization of information and strategy application error: Investigation of the ability to apply TTB with a strategy-incompatible organization.

In this second experiment, we created a situation that aimed at maximizing the importance of a strategy-compatible information organization. But even so, the TTB users stuck to their preference for a strategy-incompatible, option-wise information organization. That is, TTB users did not seem to have assumed that a strategy-compatible organization might support the application of TTB. And indeed, even though TTB users did not compensate the strategy-incompatible search restriction (NonC fixed – mismatching) by a strategy-compatible organization of information, they did not commit more errors when applying their strategy (n = 8, M = 5% [SD = 5], Mdn = 3%) than TTB users who could acquire information in any way they liked (TTB users in the NonC free Condition; n = 12, M = 8% [SD = 7], Mdn = 6%), U = 60, z = .94, p = .349, r = .21. Moreover, TTB users in general committed slightly fewer errors (n = 25, M = 9% [SD = 8], Mdn = 6%) in strategy application than those who used a compensatory strategy (WADD/EQW; n = 31, M = 12% [SD = 6], Mdn = 10%) even though only the latter ones used a strategy-compatible information organization, U = 513.5, z = 2.09, p = .037, r = .28.

4. Discussion

To summarize, Experiment 2 replicated the general preference for an option-wise information organization already observed in Experiment 1. Not even the prospect of having to take a decision under severe time pressure and the separation of information search and organization from the decision itself led TTB users to organize information in a cue-wise manner. And again the organization of information differed only slightly between participants who used TTB and those who used a compensatory strategy. As in the first experiment, information search behavior and information organization were related. Moreover, we did not detect a negative impact of a strategy-incompatible information organization for the application of TTB. This corroborates our previous conclusion that information organization might serve other purposes in the application of TTB rather than to support strategy application by mapping the information representation that matches TTB's search process. That is, option-wise organization of information with the use of TTB is not due to a lack of insight; it is not maladaptive. Finally, for users of compensatory strategies (WADD/EQW), we again observed a strategy-compatible, option-wise information organization. That is, the pattern is in accordance with our hypothesis that information organization mirrors the decision process, but it does not preclude verification behavior as suggested for TTB users.

5. General Discussion

Kirsh (1995) elaborated on the importance of organization and its role in supporting cognition. In the current article, we investigated whether decision makers support cognition in multi-attribute inferences by organizing information in a strategy-compatible manner. We observed that this was not the case for all strategy users. Only users of a compensatory strategy organized information in a strategy-compatible, option-wise manner. TTB users, however, also organized in an option-wise manner rather than in a strategy-compatible, cue-wise manner. In other words, there was a general preference for organizing information by grouping it by options.

We showed this preference for option-wise information organization in two experiments. There was a (descriptive) difference in information organization in the expected direction: TTB users tended to organize slightly less option-wise than compensatory decision makers. However, this difference was negligible and disappeared when information acquisition was restricted in a strategy-incompatible manner. That is, information organization depended on information search rather than on the decision strategy (i.e., choice rule). If the acquisition sequence was more cue-wise (by restriction or voluntarily), the information organization was less option-wise. However, these were only minor variations;

the general preference for an option-wise information organization clearly was the dominant result. Not even severe time pressure and ensuring that all information needed to be read off the display (and was not available in working memory) led to strategy-compatible information organization for all strategy classes. The general preference for option-wise information organization was imperturbable.

We focused on subjective information organization with the goal of learning more on how information is represented and used by decision makers in multi-attribute decisions. Probably due to the lack of an automatic and objective task and measure, there is barely any comparable research in that area. Coupey (1994; see also Coupey & DeMoranville, 1996) was a rare exception with her paper-and-pencil method to analyze subjective aspects of information restructuring (including rearrangements). In comparison to the SOT, Coupey's task was more laborious, less objective, and information organization could not be quantified to be then compared to a measure of information search. In the current article, we demonstrated that the SOT is not only applicable with instructed strategies (see Ettlin et al., in press), but that participants also succeed in selecting the adaptive strategy (according to the payoff structure) and that they spontaneously search for information in a strategy-compatible manner if they are free to do so, like it has been typically observed with the Mouselab paradigm (e.g., Bröder & Schiffer, 2003, 2006; Rieskamp & Otto, 2006). On the encouraging basis of this compatibility of the new task with former research, the hypotheses about the importance of information organization were clearly *not* corroborated. We did not observe strategy compatible organization in general—neither was there a spontaneous matching of organization to the TTB heuristic, nor did TTB users make use of the possibility to organize information in a strategy-compatible manner in order to compensate for strategy-incompatible search restrictions.

Nevertheless, TTB users did not commit more errors in applying their strategy than compensatory decision makers, even though the organization was compatible only for the latter group. More surprisingly, TTB users with a strategy-incompatible restriction of the acquisition sequence made no more errors in strategy application than TTB users in the participant-determined search condition with a non-compensatory environment. That is, strategy selection as well as strategy application were not affected by the restrictions. Therefore, the TTB users' behavior is not in conflict with the adaptive decision maker hypothesis (Payne et al., 1993). Furthermore, Senter and Wedell (1999) had already shown that strategy selection and the ability to apply a strategy were not affected when information acquisition was restricted to be cue- or option-wise, unless the decision makers had to make multiple judgments and the number of options was increased to five, respectively. We had indeed not expected that our restrictions would influence strategy selection, but rather that the restrictions incompatible with the adaptive strategy (given the payoff environment) would foster strategy-compatible information organization.

However, whether decision makers use search and decision rules the way they are assumed to correspond in the strategy models, is an empirical question (see Bröder, 2000, for a discussion of decision research methodology). That is, the search process and the choice might not be linked as strongly as typically assumed and therefore, there might be no need for compensation. Indeed, by presenting graphs with different kinds of groupings and by providing strategy instructions that either matched or mismatched the grouping pattern, Jarvenpaa (1989) demonstrated that participants may adapt search to the organization but might still adopt a deviating decision rule in case of a display–strategy mismatch. Moreover, there is evidence for dissociations of the decision process and the choices people make also with spontaneous strategy selection: Schulte-Mecklenbeck and Kühberger (2014) showed an aspect of the decision situation, redundancy of information, may impact choices but not the decision process (relative acquisitions of outcomes vs. probabilities in a risky choice task). Our results provide further evidence for the limits of process tracing methods to predict choices: The decision strategy, which was determined based on the choices participants made, and information organization were not compatible. The difference in information organization between TTB users and compensatory decision makers went in the hypothesized direction, however, TTB users did clearly not organize information in the predicted cue-wise manner that would match TTB's decision process.

As mentioned above, Senter and Wedell (1999) showed that acquisition restrictions only influenced strategy selection when participants had to make multiple judgments, and the ability to apply a strategy was influenced when the number of options was increased to five. In our experiments, however, with only four options and in which single choices rather than multiple judgments were required, the decision situation might have been simple enough not to render necessary the compensation of a strategy-incompatible restriction of information acquisition; that is, not to render it necessary for TTB users. But there was compensation by those who used a compensatory strategy, which are more information-intensive than TTB and information needs to be integrated rather than only compared. Compensatory decision makers consistently organized information in an option-wise manner, independent of whether there was an information acquisition restriction and of whether the restriction was strategy-compatible or not. So for more information-intensive strategies, information organization may indeed mirror the mental representation of the applied strategy.

This is not the case for TTB users. Nevertheless, TTB users did not place information randomly. Therefore, it is likely to serve a specific purpose. By organizing information in an option-wise manner, the decision maker ends up with groups of information representing the units of choice. That is, they have to choose one of the *options* rather than one of the cues. An option-wise information organization therefore allows to perceive the (to be) chosen option at a glance and the decision maker can verify her choice before definitely making the decision. This is in accordance with Russo and Leclerc's (1994) suggestion of a final verification stage. They defined three stages based on whether refixations of a previously seen alternative occurred. The third stage's criterion was the absence of refixations. This stage was interpreted as a validation stage in which single options were fixated prior to the announcement of the decision. This might reflect "a kind of review in which a tentative choice has been made and a last look at some alternatives finalizes that selection just prior to its announcement" (p. 277). The second stage contained not only refixations, especially, it also contained many comparisons between two and three options. Russo and Leclerc did not discriminate cue- and option-wise acquisition patterns. However, looking back and forth between options (i.e., the comparisons observed in Stage 2) may be considered as cue-wise comparisons, as comparisons of features of these options. In short, the gaze behavior observed in Stages 2 and 3 in Russo and Leclerc's study are compatible with our interpretation that participants might apply TTB during information acquisition and might then use the organization on the display to look at the (grouped) options in order to verify their decision. Furthermore, van Raaij (1977) divided the decision process into two phases and showed that with eye tracking as well as with information boards, the relative amount of cue-wise transitions is higher in the first phase but that of option-wise transitions is higher in the second phase (though, overall, the amount of option-wise transitions was always higher). This is again in accordance with our interpretation of our results.

6. Conclusion

As illustrated by his quote in the beginning of this article, Kirsh (1995) had argued that restructuring is often done to support cognition. For multi-attribute inferences, this statement does not hold for the idea that a strategy-compatible information organization might be relied upon to support a coherent task representation for facilitated strategy application—at least not for all kinds of strategies. That is, information organization may support cognition for the application of information-intensive compensatory strategies for which it mirrors the representation matching the option-wise integration process. However, for frugal strategies like TTB, this is not the case. But TTB users' information organization is not random and therefore likely serves other purposes. These results provide further evidence for limitations to the use of process information to draw conclusions about strategies (i.e., decisions). Nevertheless, the finding that information organization is not random reveals that it most likely is important for multi-attribute decision making, however, the determination of its exact role, especially for frugal strategies like TTB, needs further investigation.

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Strategy-Incompatible Information Displays Incur Only Subtle Processing Costs in Multi-Attribute Decisions: Evidence from Eye Tracking Data

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Abstract

Depending on the task, some organizations of objects or information are more helpful than others. When the decision process and the way information is organized are not compatible in multi-attribute decisions, it has been argued that decision making is hindered. But in the two eye tracking experiments presented in this article, there was only little influence of a strategy-incompatible information organization. Costs emerged only for very information-intensive, strictly compensatory strategies, but not for frugal strategies, and only on the process level (i.e., decision time and gaze behavior) but not on the choice level. The pattern of information presentation effects that emerges by contemplating the new results and previous research is largely in line with the idea of a processing cost continuum. But whether people are aware of subtle processing costs like the ones resulting from the current manipulation is subject to future research.

Keywords: information presentation; display effects; eye tracking; process tracing; strategy selection; decision making

Strategy-Incompatible Information Displays Incur Only Subtle Processing Costs in Multi-Attribute Decisions: Evidence from Eye Tracking Data

At the library, we find the book we are looking for because the books are organized in a systematic manner. Misplacing a book on the shelves renders its recovery extremely difficult. But even if items or information are not misplaced but simply organized differently, say less “conveniently”, we may have more trouble finding them. For instance, in our phone’s contacts list, we can easily find a specific contact in the alphabetic list by using the first few letters of the contact’s name. This does not work in the list of recent calls. However, if we want to contact someone whom we call all the time, it will be more convenient to use the recent calls list because the contact will be right toward the top. Thus, whether we rely on recency or the alphabet, we should use the correspondingly organized list. Organizations that match the task are helpful; unbeneficial organizations can cause costs such as a loss of time or higher effort. In the herein presented research, we investigated the negative effects caused by an information organization that does not mirror the process of the applied strategy in information-based decisions. Specifically, we aimed at identifying potential costs of a strategy-incompatible information organization in multi-attribute decisions.

For multi-attribute decisions, in which a set of choice options (e.g., financial investment options) are described by a number of different cues (e.g., information on former performance, expert opinions etc.), there is ample evidence that the way information is presented influences the decision behavior (Bettman & Kakkar, 1977; Bettman & Zins, 1979; Jarvenpaa, 1989; Russo, 1977; Schkade & Kleinmuntz, 1994; for a summary, see Payne, Bettman, & Johnson, 1993). However, such effects only occur when the information presentation supports a specific way of acquiring the information and hinders deviating proceedings (i.e., strategies); without differential processing costs for the application of different strategies, decision behavior is not affected by information presentation (Ettlin & Bröder, 2015b). When participants organize information themselves, however, only users of strategies that integrate information in a compensatory manner were observed to organize information in a strategy-compatible manner (i.e., congruent with the proceeding of the decision strategy; Ettlin & Bröder, 2015a). Thus, for the latter result to be in line with the above processing cost explanation for information presentation effects, we need to show that, with the display used in those experiments, the compensatory strategies, which are more complex per se, but not a non-compensatory heuristic, would have suffered from increased processing costs if participants had organized the information in a strategy-incompatible manner. In other words, the goal was to investigate whether the application of more complex strategies is more susceptible to information presentation manipulations than the application of a frugal heuristic.

Multi-Attribute Decisions: The Decision Strategies

In multi-attribute decisions, the task is to identify the best available option by relying on information provided by cues. These cues differ in how valid they are; that is, in how good they are for identifying the best option. For instance, different experts (representing the cues) may provide information about investment options. The experts are not always able to identify the best option, but some experts are right more often (i.e., they represent a cue with a higher validity) than others.

It was suggested that such cue-information is used in different ways to reach a decision. In other words, the assumption is that people have access to a repertoire of different decision strategies and would select one that is adaptive given the specific task at hand (Gigerenzer, Todd, & the ABC Research Group, 1999; Payne et al., 1993). These strategies are either compensatory, and thus they trade off different pieces of information about a specific option, or they are non-compensatory, and thus a more valid cue cannot be compensated by a combination of less valid cues. Compensatory strategies are typically associated with option-wise processing. That is, they focus on one option after the next and integrate information across different cues. Non-compensatory strategies typically entail a cue-wise procedure. That is, they process information by focusing on one cue after the next and thus proceed across different options (e.g., Payne, Bettman, & Johnson, 1988; but see Bröder, 2000).

As an implementation of the non-compensatory strategies, the Take-the-Best heuristic (TTB; Gigerenzer & Goldstein, 1996) is often investigated. TTB acquires information in a cue-wise manner, starting with the most valid cue, but it stops as soon as a cue favors only one option and chooses the option supported by that cue. Among the compensatory strategies, the Weighted Additive (WADD; e.g., Payne et al., 1988) and the Equal Weight rules (EQW or Dawes' Rule according to Dawes, 1979) are the typical candidates. WADD and EQW integrate information in an option-wise manner. WADD weights each piece of information by a measure of the cues' validity and then computes the sum for each option; the option with the highest sum is chosen. EQW does the same but by weighting the cue information equally.

Information Presentation: Strategy-Compatibility and the Role of Processing Costs

Due to the above-introduced difference in the strategies' cue- versus option-wise nature, an information organization which groups information in an option-wise manner is compatible with compensatory strategies and an organization which groups information in a cue-wise manner is compatible with non-compensatory strategies. Previous research showed that these two ways of presenting information indeed foster the use of the respective search rules (Bettman & Kakkar, 1977; Jarvenpaa, 1989; Schkade & Kleinmuntz, 1994). Furthermore, in case of incompatibility of the information presentation and an instructed strategy, participants are either slower and sometimes less confident (Bettman & Zins, 1979) or they adapt information acquisition to the information presentation and only apply the decision rule according to the instructed strategy (Jarvenpaa, 1989).

However, these effects occurred in experiments that relied on rather strong manipulations. Bettman and Kakkar (1977), for instance, used different booklets to group information either according to options or cues. With this manipulation, if someone applied a cue-wise search rule with the option-wise grouped information, he would have to switch booklets after each piece of information he looked at. This would imply extra movements and extra time compared to looking through one booklet after the next; that is, compared to just using the information the way it is grouped. Hence, the incompatibility between presentation and strategy induced high opportunity costs. In Ettlin and Bröder (2015b), we used purely perceptual manipulations to induce the impression of cue- versus option-wise grouping. Specifically, we presented the information in matrices and used color to highlight either the rows (containing the information of one cue each) or the columns (containing the information of one option each). In a second perceptual manipulation, we spaced the cells slightly more closely to each other in the rows of the matrix than in the columns or vice-versa to induce the perception of rows and columns, respectively. With these manipulations, scanning a matrix row-wise is not more cumbersome if the columns rather than the rows are highlighted. Hence, the perceptual grouping did not induce opportunity costs. This type of manipulation did not yield any effect on decision behavior, neither on the decision process nor on the choices. In short, the booklet manipulation and the perceptual manipulations can be considered two extremes towards the opposite ends of a continuum: The former manipulation induces high processing costs for strategies deviating from the procedure suggested by the way the information is grouped; but not so the latter manipulations. Effects on decision behavior were hitherto only observed with the former type of manipulation (see also Bettman & Zins, 1979, and Jarvenpaa, 1989, for rather strong manipulations of information presentation), and differential processing costs for different strategies therefore seem a necessity for information presentation effects to occur.

Recently, we investigated subjective information organization; that is, we let people organize information themselves rather than providing it in differently grouped manner. The initial goal was to use subjective information organization as a means to get access to the participants' representation of the task (for details see Ettlin & Bröder, 2015a, and Ettlin, Bröder, & Henninger, 2015), and we expected that participants would organize information in a strategy-compatible manner—especially, when they experienced unbeneficial restrictions in information acquisition. But we discovered that participants only grouped information in a strategy-compatible manner with compensatory strategies (Ettlin & Bröder, 2015a).

This adherence to a strategy-compatible organization of only those participants who used strategies that are more complex and information-intensive brings the processing cost explanation back to the scene: In Ettlin and Bröder (2015a), we provided four separate circles on a single screen for participants to group information (like in Fig. 1, but they were empty). Due to wider distances and a more visible separation of the groups, the grouping of information in circles is a stronger manipulation than the perceptual manipulation based on differential spacing of cells in a matrix used in Ettlin and Bröder (2015b). But it is not as extreme as the one by Bettman and Kakkar (1977) who did not provide all information on a single screen but rather separated it into different booklets. Thus, with the circle manipulation, an incompatible organization might be sufficiently strong to induce higher processing costs if the grouping is not compatible with compensatory strategies. But for the more frugal non-compensatory strategies, which are assumed to be less cumbersome to execute per se (Beach & Mitchell, 1978; Gigerenzer et al., 1999), a strategy-incompatible grouping presented on a single screen may not suffice to increase processing costs.

The processing costs resulting from a strategy–organization incompatibility with the manipulation used in Ettlin and Bröder (2015a) have not yet been investigated. But the results by Bettman and Zins (1979) on presentation format preferences seem to contradict the processing cost explanation we suggested above: The ranking of decision times was in line with the strategy–format compatibility hypothesis. There were increased processing costs if the instructed strategy was incompatible with the information presentation. Nevertheless, participants did not select the compatible format, that is, brand- or attribute-wise grouping, and thus did not seem to have been aware of the processing costs or they simply neglected them. However, the vast majority of participants chose neither of the two formats but rather the format presenting all information in a brand by attribute-matrix, and indeed, they were fastest with the matrix format independent of the strategy they were instructed to use. In the third experiment, the matrix format was eliminated, but there was still no preference for the strategy-compatible format. However, there was also no effect of format on the decision time anymore (i.e., no differential processing costs due to the information presentation manipulation). In short, the overall pattern of results does not contradict the idea of processing costs as a determinant of information presentation effects on decision making.

Thus, it remains to be investigated whether the behavior observed for subjective information organization (Ettlin & Bröder, 2015a) also coheres to the processing cost explanation. With subjective information organization, there was a general preference for organizing information in an option-wise manner; that is, it was compatible only for strategies with an option-wise procedure but not for the cue-wise proceeding TTB heuristic. In order to be consistent with the adaptive decision maker hypothesis (Payne et al., 1993), the display layout used in Ettlin and Bröder (2015a) should not cause increased costs for users of the frugal TTB heuristic when information is organized in a strategy-incompatible, option-wise manner.

In the previous experiments, we (Ettlin & Bröder, 2015a) did not investigate costs on the process level, but we did indeed not observe costs for the ability to *apply* TTB: TTB users, who generally relied on a strategy-incompatible information organization, did not make more application errors than WADD/EQW users who relied on a strategy-compatible information organization. Furthermore, the TTB users who were forced to acquire information in a strategy-incompatible, option-wise manner did not commit more application errors than TTB users who were free to acquire information in any manner they liked.

For participants relying on the WADD and EQW strategies, which are more information-intensive and cumbersome than TTB, the situation was different. By organizing information in an option-wise manner, their organization behavior *was* strategy-compatible. They might have organized information that way in order to avoid increased processing costs due to a strategy-incompatible organization.

In order to investigate whether grouping information as clearly separated units on a single screen in a strategy-incompatible rather than a -compatible manner is costly for compensatory strategies but not so much for the non-compensatory TTB heuristic, we conducted two experiments. In comparison to classical investigations of information presentation effects in multi-attribute decisions, this display represents a less crude way of manipulating information presentation, and we thus used eye tracking to assess potentially subtle processing costs. We compared cue-wise and option-wise grouping, and analyzed the ability to apply the adopted strategy as well as the effort required in the decision process (quantified in terms of decision time and measures based on gaze data). Evidence in line with our expectations would supply further support for the role of processing costs in information presentation effects on multi-attribute decisions. Finally, in the General Discussion, we contemplate the results in light of the adaptive decision maker hypothesis (Payne et al., 1993) and the idea of cost–benefit tradeoffs in strategy selection (Beach & Mitchell, 1978; Johnson & Payne, 1985).

Experiment 1

In Experiment 1, we used eye tracking methodology to investigate potential processing costs resulting from the application of an adopted strategy with a display that contained strategy-incompatibly grouped information as compared to a situation with a strategy-compatible grouping. The manipulation was based on a modified version of the search and organization task (SOT; Ettlin et al., 2015) in which participants search for information and group it by themselves. Here, we pre-arranged the information using the same kind of template for grouping information as in the original SOT (see Fig. 1) and investigated participants' responses in terms of strategy selection, gaze behavior, and decision time. We arranged the information such that it was either compatible with TTB and incompatible with WADD and EQW (cue-wise organization) or such that the opposite was the case (option-wise organization). If a strategy-incompatible display incurs costs for processing, this should *either* manifest itself as a strategy switch *or* as increased processing costs as measured by the gaze behavior and decision times.

Methods

Task and conditions. The participants' task was to choose the best option for investment in each of 80 decision trials. In each trial, four market segments (Cargo, Hotel, Energy, and Pharmaceutical Industry) were presented as options and four brokers provided information about those options. Examples of what the task looked like are shown in Figure 1. The four options were presented on the top right and their order was randomized anew for each trial. The cues were presented on the top left with the leftmost broker being the one with the most valid predictions. The other three brokers were also ordered according to their validity and participants were informed about that in the task instructions. The information (i.e., the brokers' opinions about the four market segments) was arranged in the four circles, either cue-wise (i.e., compatible with TTB, incompatible with WADD/EQW) or option-wise (i.e., incompatible with TTB, compatible with WADD/EQW). That is, either all information stemming from one single cue was put in a single circle resulting in four circles holding the information from one cue each (Fig. 1, upper panel). Or the information about one single option was grouped in a single circle resulting in four circles containing the information about one option each (Fig. 1, lower panel).

The 80 items used in the current experiment allowed separating TTB from three versions of WADD differing in their compensatory character (but EQW would always choose the same as the most compensatory version of WADD and these two strategies could therefore not be further disentangled with the current item set). All these strategies performed equally well and achieved a maximum of 78% correct answers (63 out of 80), but all of them differed on some of the choices in order to allow an outcome-based strategy classification. Binary feedback was given to participants after each trial (i.e., one of the four options earned the participant one point, the others zero).

Design. There were two between-subject conditions, which differed in how the 16 pieces of cue-information were arranged in the four circles. The information was either grouped in a cue- or an option-wise manner.

Procedure. Participants were invited separately for the eye tracking experiment and one or two experimenters were present in the room during the sessions. Upon arrival, participants were randomly assigned to one of the two conditions, signed a consent form, and provided details on whether they wore glasses, contact lenses, or mascara (these factors could explain lower gaze data quality). Thereafter, participants were seated in front of the eye tracking device (SMI, RED500, 500 Hz sampling rate, binocular tracking) which was attached to a 1680 x 1050 pixel screen. One of the experimenters adjusted the distance to the screen and the height of the table such that tracking was possible for the entire area of the screen. A chin rest was used in order to keep the participants' position constant. Afterwards the experimenter explained the calibration procedure and calibrated the gaze recording. Next, participants worked through the task instructions before completing 80 decision trials.

Between the feedback following each decision and the next trial, a fixation-cross appeared for a maximum of five seconds. This fixation-cross was presented in the center of the screen and was in an invisible text field of 100 x 100 pixels that was gaze-contingent. Participants had to look at it continuously for a minimum of two seconds then the next trial would start. If they did not succeed in looking at it for two seconds without interruption within the five seconds for which the cross was maximally shown, rather than the next trial, a new calibration phase started. Only after a new calibration and validation procedure, the next decision trial would start. For each recalibration, the experimenter tried to achieve a deviation of no more than 0.5° on the x- and y-axes and only continued with higher deviations if the 0.5° threshold was not satisfied after several repetitions.

The participants completed the decision task and worked through unrelated math tasks. Finally, participants indicated whether they wished to get a debriefing email and were paid in performance-contingent manner. If needed, they could get course credits.

Figure 1. Screenshot of a decision trial; the Cue-wise (upper panel) and the Option-wise (lower panel) Conditions. Original in German, faces not disguised.

Participants. Sixty-four participants are in the final sample (32 in each condition). Nineteen participants aborted the experiment (and were replaced) because they had to recalibrate after almost every trial (see details in "Procedure"). Forty-five (70%) of the participants were female, and their mean age was 21 years (*SD* = 4). Most of them were students of the University of Mannheim.

Measures. For strategy classification, we used the outcome-based procedure by Bröder and Schiffer (2003). With this method, each participant is classified as user of the strategy for which the choice vector of a person is maximally likely. The process measures stemmed from decision times and gaze data. To compute the different process measures based on gaze data, we mainly relied on fixations.[1] The four circles containing the information (Fig. 1) were designated as areas of interest (AOIs).

Hypotheses. ***Strategy hypothesis.*** The strategies of interest perform equally well, so the payoff structure does not lead to strategy predictions (on adaptivity to payoff environments, see, for instance, Bröder & Schiffer, 2006, and Rieskamp & Otto, 2006). Rather we hypothesize that participants will adopt a strategy that is compatible with the presented organization of information.

Search hypothesis. If participants use a strategy that is *in*compatible with the organization of information, we expect that they will look back to previously inspected circles more often, that they will need longer to reach a decision, and that they will make more fixations on the AOIs than participants who use a strategy that is compatible with the information organization. We expect that especially compensatory strategies will be affected by increased processing costs due to a strategy-incompatible information organization.

[1] We used the default high-speed event detection algorithm of BeGaze 3.4.52 (Saccade detection parameters: min. duration = 22 ms, peak velocity threshold = 40°/s, peak velocity: 20% to 80% of saccade length, min. fixation duration = 50 ms).

Results

Data quality checks. We computed the mean validation values of all calibrations per participant. None of the means were above 1.0° which we designated as the threshold for excluding participants. In addition, we checked whether there were events (fixations and saccades) for at least 60% of the trial duration in the majority of the trials (cf. Scholz, von Helversen, & Rieskamp, 2015). Only two participants in one trial each did not reach this criterion and therefore, also with this second data quality check, no participants were excluded.

Outcome-based strategy classification: Test of the strategy hypothesis. [2] The strategy classification is presented in Table 1. Whether the information was presented in a cue-wise or an option-wise manner did not influence participants' choice behavior. The majority of participants in both conditions were classified as users of a compensatory WADD strategy.

[2] We report one-tailed tests for the analyses of our hypotheses, but not for the post-hoc or exploratory analyses.

Table 1

Outcome-based strategy classification for Experiment 1

	Strategy Classification[a]		χ^2-Test
	TTB (%) [b]	WADD (%) [b]	
Cue-wise Condition	4 (12.9%)	27 (87.1%)	$\chi^2(1) = 2.06$, $p = .151$,
Option-wise Condition	1 (3.1%)	31 (96.9%)	Cramér's $V = .181$ [c]

Note. [a] If the deviation from the best fitting strategy (application error) was higher than 30% in total or the error due to the choice of the strategy incompatible option (in contrast to an error due to the choice of a dominated option) was higher than 20%, the participant was labeled *unclassified*. This did not happen in Experiment 1, but one participant in the Cue-wise Condition had equal likelihoods for TTB and a version of the WADD strategy and could therefore not be classified. The mean error for the application of the classified strategies was 7%.

[b] Percentages are users of a particular strategy within a particular condition.

[c] 50% of cells had a minimum expected frequency below 5: Fisher's Exact Test: $p = .196$, odds ratio = 4.49.

Gaze data: Test of the search hypothesis. We analyzed the process measures only for those participants who had been classified as users of a WADD strategy. Because there were only five TTB users in total, a separate analysis was not meaningful. The decision process of WADD users can be compared between the Cue-wise and the Option-wise Conditions in order to detect possible costs of a strategy-incompatible organization of information (cue-wise) compared to a strategy-compatible one (option-wise).

Gaze data: Revisits. Revisits are the number of times a person looked back to a previously looked at AOI (mean per trial). Specifically, as soon as a participant placed a fixation on one of the AOIs (i.e., circles), that AOI was considered as "inspected". Whenever the participant looked back again at that same AOI and at least one other AOI was fixated in between, a Revisit was counted. The results on Revisits are presented in Table 2 [3]. As hypothesized, if the information was organized in a cue-wise manner, participants who applied a strategy that required option-wise integration of information looked back to previously inspected groups of information more often than if the information was presented in an option-wise manner.

Gaze data: Fixations. Fixations were determined as described in Footnote 1 (mean per trial). As shown in Table 2, even though a strategy-incompatible organization of information led to more looking back to previously inspected groups of information, this did not result in more fixations overall.

Gaze data: Decision time. We also inspected the median duration of each trial per participant, henceforth, MDN Time. In accordance with the results for Fixations, MDN Time did not differ between the two conditions. Also the median time per trial participants looked at one of the AOIs (MDN AOI Time) did not differ between the Cue-wise and the Option-wise Conditions (Table 2).

[3] Here, as well as for all further analyses, we provide non-parametric tests if the assumptions regarding the distribution of the data were violated; otherwise we provide the parametric tests.

Table 2

Process measures for Experiment 1; only compensatory strategies

	Cue-wise Condition [a] *M* (*SD*) *Mdn*	Option-wise Condition [b] *M* (*SD*) *Mdn*	t-Test / U-Test
Revisits	7.3 (4.3) 5.4	3.9 (1.6) 4.0	$U = 246$, $z = -2.69$, $p = .004$ (one-tailed), $r = 0.35$
Fixations	29.8 (8.0) 30.2	27.3 (9.0) 25.8	$t(55.99) = 1.12$, $p = .135$ (one-tailed), Cohen's $d = 0.29$
MDN Time	9153 ms (2403) 8377 ms	8325 ms (3087) 7250 ms	$U = 313$, $z = -1.65$, $p = .050$ (one-tailed), $r = 0.22$
MDN AOI Time	5874 ms (1843) 5305 ms	5369 ms (2158) 4828 ms	$U = 332$, $z = -1.35$, $p = .089$ (one-tailed), $r = 0.18$

Note. [a] $n = 27$

[b] $n = 31$

Even though we investigated gaze data, with which we should have been able to detect subtle processing costs, there was barely any impact of a strategy-incompatible information organization. This result seemed surprising, and thus to establish better understanding, we investigated the potential costs for compensatory strategies with a more fine-grained classification. With the number of cues and the item types we used, it is possible to distinguish three versions of WADD, as already mentioned above in “Task and conditions”. These versions differ in how much counter evidence from less valid cues is necessary in order to compensate a more valid cue. A slightly compensatory version, $WADD_{low}$, may have the weights $44*c_1 + 37*c_2 + 6*c_3 + 4*c_4$ in the current item set. Hence, the most valid cue can only be overruled if all three less valid cues speak against it. A medium compensatory version, $WADD_{medium}$, could have the weights $37*c_1 + 35*c_2 + 32*c_3 + 4*c_4$ in the current item set, so that the combination of the second and third (or second and fourth) cues can compensate the most valid cue. Finally, a strictly compensatory version, $WADD_{high}$, could have the weights $37*c_1 + 35*c_2 + 32*c_3 + 30*c_4$ in the current item set, allowing for any combination of two cues to compensate the most valid cue. The amount of information necessary for applying a version of WADD depends on the compensatory nature of that WADD strategy. Generally, the more compensatory the nature of the WADD, the more information it needs. If we consider only those participants who were classified as users of the strictly compensatory WADD strategy ($WADD_{high}$), we observe the expected costs of a strategy-incompatible organization of information: The $WADD_{high}$ users not only had a higher number of Revisits in the Cue-wise ($n = 8$, $M = 9.3$ [$SD = 4.7$], $Mdn = 10.4$) than in the Option-wise Condition ($n = 6$, $M = 2.5$ [$SD = 0.9$], $Mdn = 2.9$; $U = 3$, $z = –2.71$, $p = .005$, $r = 0.72$). They also made more fixations in the Cue-wise Condition ($M = 32.5$ [$SD = 7.8$], $Mdn = 31.3$) than in the Option-wise Condition ($M = 20.1$ [$SD = 4.6$], $Mdn = 20.4$; $t(11.51) = 3.70$, $p = .003$, Cohen's $d = 1.99$). $WADD_{high}$ users were also slower (MDN Time) in the Cue-wise ($M = 9764$ ms [$SD = 2143$], $Mdn = 9964$ ms) than in the Option-wise Condition ($M = 5990$ ms [$SD = 1168$], $Mdn = 6470$ ms; $U = 0$, $z = –3.10$, $p = .002$, $r = 0.83$), and they spent more time looking at AOIs (MDN AOI Time) when they were in the Cue-wise ($M = 6364$ ms [$SD = 1579$], $Mdn = 6339$ ms) rather than in the Option-wise Condition ($M = 3862$ ms [$SD = 943$], $Mdn = 4336$ ms; $U = 2$, $z = –2.84$, $p = .005$, $r = 0.76$). Analyzing $WADD_{low}$ and $WADD_{medium}$ in combination yielded no significant differences between the conditions ($n_{Cue\text{-}wise} = 19$, $n_{Option\text{-}wise} = 25$). Focusing only on $WADD_{medium}$ users only led to a significant difference for Revisits (more Revisits in the Cue-wise Condition, $p < .05$; $n_{Cue\text{-}wise} = 9$, $n_{Option\text{-}wise} = 15$).

Costs on the outcome level. We focused on the decision process and did not make any specific predications for the outcome level apart from the strategy hypothesis. But for a more complete picture, we analyzed the ability to apply the compensatory strategies and the performance (i.e., money earned in the experiment), but did not detect any influence of information organization.

Strategy application error. The error committed in the application of the classified strategy was low and very similar in both conditions (Cue-wise $\text{Condition}_{\text{WADD}}$: $n = 27$, $M = 8\%$ [$SD = 4$]; Option-wise $\text{Condition}_{\text{WADD}}$: $n = 31$, $M = 8\%$ [$SD = 3$]; $t = -0.06$, $df = 51.98$, $p = .949$, Cohen's $d = 0.02$). This was also the case if only $\text{WADD}_{\text{high}}$ users were considered (Cue-wise $\text{Condition}_{\text{WADD-high}}$: $n = 8$, $M = 4\%$ [$SD = 3$]; Option-wise $\text{Condition}_{\text{WADD-high}}$: $n = 6$, $M = 5\%$ [$SD = 5$]; $t = -0.49$, $df = 7.18$, $p = .640$, Cohen's $d = 0.29$).

Performance. Nearly everyone reached the maximum that could be reached by consistently applying one of the above-mentioned strategies (Cue-wise $\text{Condition}_{\text{WADD}}$: $n = 27$, $M = 6.07$ € [$SD = 0.24$], $Mdn = 6.20$ €; Option-wise $\text{Condition}_{\text{WADD}}$: $n = 31$, $M = 6.15$ € [$SD = 0.25$], $Mdn = 6.20$ €; $U = 496$, $z = 1.22$, $p = .221$, $r = 0.16$). Again the result was the same if only $\text{WADD}_{\text{high}}$ users were considered (Cue-wise $\text{Condition}_{\text{WADD-high}}$: $n = 8$, $M = 6.19$ € [$SD = 0.19$], $Mdn = 6.25$ €; Option-wise $\text{Condition}_{\text{WADD-high}}$: $n = 6$, $M = 6.02$ € [$SD = 0.37$], $Mdn = 6.15$ €; $U = 15.5$, $z = -1.12$, $p = .261$, $r = 0.30$). In short, there were no costs on the outcome level.

Discussion

To summarize, the grouping manipulation did not influence strategy selection. Due to the small minority applying TTB, we only analyzed those, who used a compensatory strategy: A strategy-incompatible, cue-wise organization of information was not generally costly for the application of compensatory strategies. That is, participants did not need longer to decide and they did not have to make more fixations than those who saw the information in a strategy-compatible, option-wise manner. Also the outcome level (money earned and error in strategy application) was not affected. The only difference was that participants who got the information organized in a strategy-incompatible, cue-wise manner looked back to previously inspected information more often.

The picture changed when we only looked at those participants who integrated all available information in a strictly compensatory manner. For users of such a strictly compensatory WADD strategy (including EQW), a strategy-incompatible, cue-wise information organization was costly in terms of processing parameters. These participants not only looked back to already inspected areas more often, but they also needed longer to decide and made more fixations. The outcome level was still not affected, though.

The only influence that was observable for the whole range of WADD strategies was the increased amount of looking back to previously inspected information when the organization was cue-wise—even though this did only entail costs in terms of time and amount of fixations when a strictly compensatory version of WADD (or EQW) was used. So while an option-wise organization allows people relying on WADD (or EQW) to look at one group after the next and to integrate the grouped information, decision makers who see the information grouped according to cues need to either look back and forth or need to keep the information they need to integrate in working memory. Contrary to the finding by Ballard, Hayhoe, and Pelz (1995), we did not observe that people relied more on working memory when a just-in-time strategy based on direct use of the fixated information was more costly due to larger distances. This diverging result might have occurred due to the more complex nature of our task compared to the one used by Ballard and colleagues. In their experiments, configurations of blocks had to be copied. If the model and the workspace were moved further apart, participants relied more on memorized information, which resulted in less returning to the model. Keeping block configurations in mind is probably less complex than trying to remember up to 16 pieces of information and to integrate them.

However, in the current experiment, participants could actually have shifted to another strategy instead of accepting increased processing costs, especially since the payoff environment was benign to a whole range of different strategies. The results on processing costs imply that a shift to TTB or a partially compensatory version of WADD would have sufficed to eliminate the extra processing costs resulting in the Cue-wise Condition. But strictly compensatory strategies ($WADD_{high}$/EQW) were not applied less often in the Cue-wise than in the Option-wise Condition. This is not in line with what one would expect from an adaptive decision maker (cf. Payne et al., 1993). But concluding that strategy selection is insensitive to this kind of costs would be premature given the low share of participants relying on such a strictly compensatory strategy.

In the introduction, we referred to compensatory strategies as information-intensive. There are no stopping rules for information search for any version of WADD. Nevertheless, sometimes “intelligent” versions of those strategies are investigated with which information search is stopped when it becomes clear, after acquiring the first few pieces of information, that the current option cannot beat a previously considered one (see e.g., Bröder & Gaissmaier, 2007; Rieskamp & Dieckmann, 2012). Generally, the less compensatory the nature of the WADD, the sooner the search can be aborted. Thus, partially compensatory versions of WADD do not require all available information, and therefore, it seems plausible that they are less susceptible to a strategy-incompatible information organization than strictly compensatory strategies.

To conclude, with the type of grouping manipulation we applied, we observed processing costs due to a strategy-incompatible organization for very information-intensive strategies that integrate information in a strictly compensatory manner (i.e., strictly compensatory version of WADD including EQW). We did not observe costs for the whole range of compensatory strategies. Therefore, even if we could not test whether the second part of the hypothesis based on the idea of the adaptive decision maker holds, that is, whether TTB users do not suffer any costs from a strategy-incompatible information organization, we can conclude that this seems rather unlikely. TTB is mostly more frugal than the less compensatory versions of WADD, and the latter strategies did not suffer an increase in processing costs due to a strategy-incompatible information organization as compared to a strategy-compatible one with the current manipulation (with the exception of an increase in how often they looked back to previously inspected information). However, there were only 14 participants in the sample who engaged in an elaborative, strictly compensatory strategy, and we focused on that subgroup because of post-hoc contemplations. The second experiment was conducted (1) to replicate the patterns observed in Experiment 1 and (2) to substantiate our post-hoc conclusions.

Experiment 2

In this second experiment, we used a payoff environment that clearly favored a strictly compensatory version of WADD ($WADD_{high}$; fully compensatory use of the four cues). We thereby wanted to more strongly promote fully compensatory decisions than in Experiment 1 because the goal of Experiment 2 was to replicate the findings on increased processing costs for the application of $WADD_{high}$ (and EQW) with a cue-wise compared to an option-wise information organization.

Methods

Task and conditions. The task and conditions in this second experiment were basically identical to those in Experiment 1. The main difference was that the payoff environment was not benign to all the strategies of interest anymore but was strictly compensatory. Feedback about the choice options' performance was continuous. If all available information was integrated in a fully compensatory manner, one could always identify the option with the highest outcome.[4]

Design. Experiment 2 included the exact same two between-subject conditions as Experiment 1. The conditions differed in whether the 16 pieces of information in the four circles were grouped according to cues or according to options.

Procedure. The procedure did only deviate in a few details from the one in Experiment 1: Participants worked through 50 instead of 80 decision trials, they got continuous rather than binary feedback, and they did not complete the math tasks in the end of the session. We used the same gaze-contingent fixation cross and recalibration procedure as in the previous experiment.

Participants. Sixty participants are in the final sample (30 in each condition). Nine participants aborted the experiment (and were replaced) because they had to recalibrate after almost every trial (see details in "Procedure" of Experiment 1). Thirty-four (57%) participants were female, their mean age was 22 years (*SD* = 6), and the majority of participants were students from the University of Mannheim.

Measures. We used the same measures as the ones we described and analyzed in Experiment 1.

Hypotheses. We hypothesize that, in the Option-wise Condition, the majority of participants will adopt a strictly compensatory version of the WADD strategy ($WADD_{high}$). We have two different predictions, however, for the Cue-wise Condition, in which $WADD_{high}$

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[4] The payoff structure was $37*c_1 + 35*c_2 + 32*c_3 + 30*c_4$ where the c's need to be replaced by either +1 or –1 depending on the cue value which can be either positive or negative, respectively. In each decision trial, the criterion value for each of the four options was determined by this equation. However, we added a random integer between –2 and +2 to each outcome (or just between –1 and +1, depending on the possibility of rank order switches of the options), in order to lower the chances that people just learned criterion values by heart instead of using a rule.

is also the adaptive strategy (according to the payoff structure) but in which the organization of information is incompatible with the application of $WADD_{high}$. On the one hand, participants may rely on the outcome feedback they get after each decision and thus adopt the adaptive $WADD_{high}$ strategy, which should lead to longer decision times, more fixations, and more looking back to previously inspected groups of information than in the Option-wise Condition. On the other hand, participants may focus on effort, that is, on saving processing costs, and thus adopt a strategy that is easier to apply with a cue-wise information organization such as TTB or, more likely, a less compensatory version of WADD thereby saving time and effort invested in gathering information from the screen.

Results

Data quality checks. We computed the mean validation values of all calibrations per participant. One participant exceeded the 1.0° threshold we had set (x-value deviation = 2.03; y-value deviation < 1°) and was therefore excluded from all analyses based on process data. In addition, we again checked whether there were events (fixations and saccades) for at least 60% of the trial duration in the majority of the trials. This was the case for all participants in all trials and therefore, we excluded no more participants.

Outcome-based strategy classification: Test of the strategy hypothesis. The strategy classification is presented in Table 3. As in the previous experiment, the choice behavior was not influenced by the way information was organized. The majority of participants in both conditions were classified as users of one of the compensatory strategies. But we had changed the payoff structure to be strictly compensatory, and as expected, we observed a larger share of $WADD_{high}$ users than in the previous experiment.

Furthermore, the share of $WADD_{high}$ users was high in both conditions, not just in the Option-wise Condition with the $WADD_{high}$-compatible information organization. The share of partially compensatory and strictly compensatory strategies in the Cue-wise and the Option-wise Conditions did not differ (Cue-wise Condition: $WADD_{low}/WADD_{medium} = 7$ [5], $WADD_{high}/EQW = 18$; Option-wise Condition: $WADD_{low}/WADD_{medium} = 12$ [5], $WADD_{high}/EQW = 12$; $\chi^2(1) = 2.50$, $p = .114$, Cramér's $V = .226$).

Table 3

Outcome-based strategy classification for Experiment 2

	Strategy Classification[a]						Total compensatory strategies
	TTB	$WADD_{low}$	$WADD_{medium}$	$WADD_{high}$	EQW[b]	WADD unequivocal classification[c]	
CC	1	4	2	15	3	4	28
OC	1	1	10	11	1	5	28

Note. CC = Cue-wise Condition, OC = Option-wise Condition.

[a] If the deviation from the best fitting strategy (application error) was higher than 30% in total or the error due to the choice of the strategy incompatible option (in contrast to an error due to the choice of a dominated option) was higher than 20%, the participant was labeled *unclassified*. This was the case for two participants in Experiment 2, one in each condition. The mean error for the application of the classified strategy was 9%.

[b] EQW users were distinguishable from $WADD_{high}$ users in the current item set, but we combined them for further analyses because of the low number of EQW users.

[c] Likelihoods for at least 2 WADD strategies were identical; $WADD_{low}$ or $WADD_{medium}$: $n = 2$; $WADD_{medium}$ or $WADD_{high}$: $n = 6$; $WADD_{low}$, $WADD_{medium}$ or $WADD_{high}$: $n = 1$.

Gaze data: Test of the search hypothesis. We analyzed the same process measures as in Experiment 1 but we only present the analyses for $WADD_{high}$ and EQW users; that is, for those strategies that were influenced by the manipulation of information organization in the previous experiment. The results are presented in Table 4. In addition, Figure 2 presents

[5] Includes category "$WADD_{low}$ or $WADD_{medium}$" (see Note c, Table 3).

the descriptive results for all unequivocally classifiable participants who were classified as users of one of the compensatory strategies.

Gaze data: Revisits. As hypothesized, the $WADD_{high}$/EQW users looked back to previously inspected groups of information more often in the Cue-wise than in the Option-wise Condition; that is, they looked back more often if the organization was strategy-incompatible.

Gaze data: Fixations. The $WADD_{high}$/EQW users in the Cue-wise Condition also made more fixations than those in the Option-wise Condition.

Gaze data: Decision time. In addition, the $WADD_{high}$/EQW users took longer to decide in the Cue-wise than in the Option-wise Condition (MDN Time). And also the median time $WADD_{high}$/EQW users looked at one of the AOIs per trial was longer in the Cue-wise than in the Option-wise Condition (MDN AOI Time).

Figure 2 shows that, descriptively, the costs of a strategy-incompatible information organization tend to be higher for more compensatory strategies on all investigated process measures.

Table 4

Process measures for Experiment 2; only $WADD_{high}$ and EQW users

	Cue-wise Condition [a] *M* (*SD*) *Mdn*	Option-wise Condition [b] *M* (*SD*) *Mdn*	U-Test
Revisits	10.3 (7.6) 8.7	3.7 (1.2) 3.3	U =30.5, z = –3.17, p = .001 (one-tailed), r = 0.59
Fixations	39. 9 (17.0) 41.7	27.9 (8.7) 24.8	U = 61, z = –1.82, p = .035 (one-tailed), r = 0.34
MDN Time	11399 ms (4512) 11324 ms	8294 ms (2965) 7900 ms	U =50, z = –2.30, p = .011 (one-tailed), r = 0.43
MDN AOI Time	7567 ms (3561) 7363 ms	5123 ms (2073) 4573 ms	U = 55, z = –2.08, p = .019 (one-tailed), r = 0.39

Note. The participant with >1.0° deviation on the x-axis is excluded from all analyses in this table. The participant was a $WADD_{high}$ user in the Cue-wise Condition.

[a] n = 17

[b] n = 12

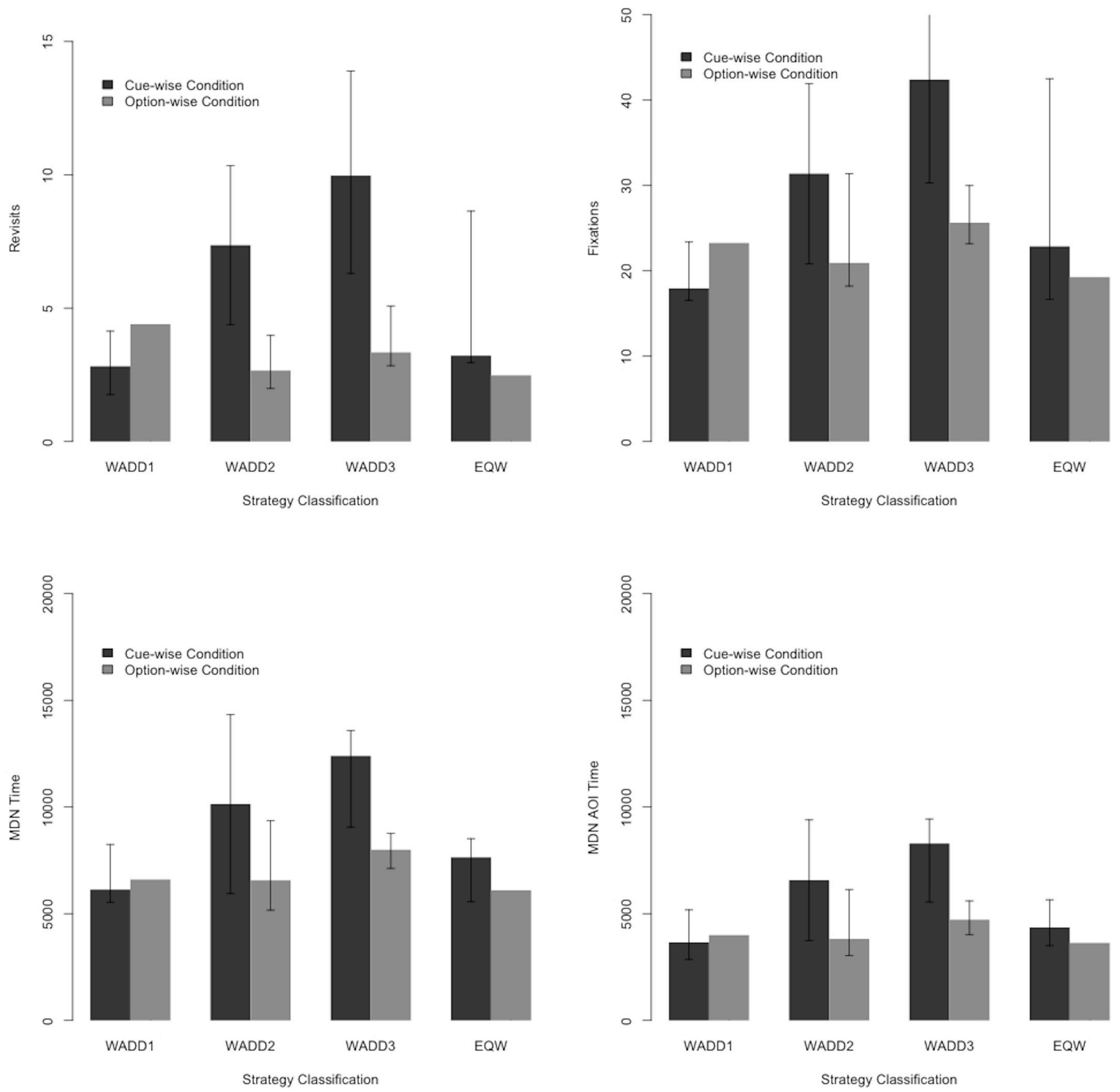

Figure 2. Median Revisits (top left), Median Fixations (top right), Median MDN Time (bottom left), and Median MDN AOI Time (bottom right) for conditions and strategies (without TTB users as well as without participants who could not be classified unequivocally as users of one of the compensatory strategies). Number of participants in each group from left to right: 4, 1, 2, 10, 14, 11, 3, 1. Error bars represent bootstrapped 95% CI (percentiles; 10’000 samples).

Costs on the outcome level. We again tested for influences on the outcome level. As before, there was no impact of the organization, neither on the ability to apply $WADD_{high}$/EQW, nor on the amount of money earned.

Strategy application error. The application error for $WADD_{high}$/EQW was low and did not differ between the conditions (Cue-wise $Condition_{WADD\text{-}high/EQW}$: $n = 17$, $M = 8\%$ [$SD = 5$]; Option-wise $Condition_{WADD\text{-}high/EQW}$: $n = 12$, $M = 8\%$ [$SD = 5$]; $t = –0.24$, $df = 23.19$, $p = .814$, Cohen's $d = 0.09$).

Performance. The amount of money earned was the same for $WADD_{high}$/EQW users in both conditions (Cue-wise $Condition_{WADD\text{-}high/EQW}$: $n = 17$, $M = 4.06$ € [$SD = 0.32$], $Mdn = 4.07$ €; Option-wise $Condition_{WADD\text{-}high/EQW}$: $n = 12$, $M = 4.15$ € [$SD = 0.18$], $Mdn = 4.18$ €; $U = 114$, $z = 0.53$, $p = .595$, $r = 0.10$).

Discussion

In a nutshell, the results of Experiment 2 replicated the findings of the post-hoc analysis in Experiment 1. For a strictly compensatory version of WADD or EQW, a strategy-incompatible organization of information was costly in terms of processing efficiency: $WADD_{high}$/EQW users looked back to previously inspected groups of information more often, made more fixations, needed longer to take a decision, and needed more time to look at the information when the information organization was strategy-incompatible (cue-wise) rather than when it was strategy-compatible (option-wise).

General Discussion

In this article, we investigated processing costs of an information presentation manipulation with cue- versus option-wise grouped information. Our manipulation was stronger than purely perceptual manipulations (cf. Ettlin & Bröder, 2015b) but less invasive than the strong manipulations typically used in research on information presentation effects (e.g., Bettman & Kakkar, 1977; Jarvenpaa, 1989). Therefore, on the continuum of processing costs induced by incompatible information organizations, our manipulation should be in an intermediate range. In two eye tracking experiments, we could show that there were processing costs and, as expected, they were not very high. The decision process was affected, but only when very information-intensive, strictly compensatory strategies were used; partially compensatory versions of WADD were not affected. With the current grouping manipulation, a strategy-incompatible, cue-wise organization of information in combination with a strictly compensatory use of information ($WADD_{high}$ and EQW) led to more effortful gaze behavior and longer decision times than when the organization was option-wise and therefore compatible with $WADD_{high}$ and EQW.

These results are in accordance with the results on subjective information organization investigated with the same display as we used in the current experiments (Ettlin & Bröder, 2015a). The main difference in the subjective information organization experiments was the necessity for participants to organize the (initially hidden) information themselves (into the four circles on the display) rather than receiving it in a prearranged manner (Fig. 1). In those experiments, we observed a general preference for option-wise information organization independent of the adopted strategy (Ettlin & Bröder, 2015a). That is, only compensatory decision makers organized information in a strategy-compatible manner. Thus, according to the adaptive decision maker hypothesis (Payne et al., 1993), a strategy-incompatible information organization will not imply higher costs for TTB users, otherwise they would have engaged in organizing information in a strategy-compatible manner. In Ettlin and Bröder (2015a), we showed that there were no costs on the outcome level for TTB users. In the current experiments, we focused on effort expenditure during the decision process with a strategy-compatible versus -incompatible organization. We could not investigate the effects on the TTB heuristic, however, because only a small minority of participants endorsed the heuristic in the currently investigated decision task. Nevertheless, it seems rather unlikely that users of the frugal TTB heuristic suffer processing costs due to a strategy-incompatible organization with the current grouping manipulation given that we only observed increased processing costs due to a strategy-incompatible organization for strictly compensatory strategies but not for more frugal, partially compensatory strategies.

It was more costly to apply $WADD_{high}$ and EQW in the Cue-wise than in the Option-wise Condition. Therefore, according to the adaptive decision maker hypothesis (Payne et al., 1993) and according to the idea of cost–benefit approaches (Beach & Mitchell, 1978; Johnson & Payne, 1985), these strategies should have been less common in the Cue-wise than in the Option-wise Condition. However, this equation ignores the benefits: The payoff environment in Experiment 2 clearly favored $WADD_{high}$ and therefore participants may have concluded that the processing costs induced in the Cue-wise Condition were compensated for. EQW was not as successful as $WADD_{high}$ because it had to guess in some cases. Nevertheless, we cannot conclude that the strategy was used maladaptively because it was not used by enough participants to compare the frequency of its use in situations with a strategy-compatible versus -incompatible information organization. In Experiment 1, however, the payoff environment was not biased toward $WADD_{high}$ and therefore its use in the Cue-wise Condition cannot be justified with the above cost–benefit tradeoff. Nevertheless, it was used about equally often with a cue- as with an option-wise organization of information (eight and six in the Cue- and Option-wise Condition, respectively). This pattern does not cohere to an adaptive use of the strategy; but evidence based on 14 participants is hardly enough to draw firm conclusions. At best we can conclude that it remains to be investigated whether people are aware of subtle processing costs like more cumbersome gaze patterns and whether they consider them in strategy selection. In the current experiments, we could not show favorable evidence, but there was a clear lack of statistical power to resolve that question.

In Ettlin and Bröder (2015b), we extensively discussed the importance of processing costs for information presentation effects in multi-attribute decisions. Previous research

(Bettman & Kakkar, 1977; Bettman & Zins, 1979; Jarvenpaa, 1989) showing an impact of information presentation on the decision process applied manipulations inducing high processing costs for strategies deviating from the one suggested by the information organization. In the current experiments, we did not observe an impact for all strategies but only for very information-intensive strategies integrating information in a strictly compensatory manner. We used a weaker information presentation manipulation than most previous studies, however. Bettman and Kakkar (1977), for instance, organized information according to options or cues by using different booklets to group information instead of merely different circles on a single screen as we did. Therefore, the application of a search strategy that was incompatible with the grouping would have been much more costly, for instance, in terms of decision time than with our display manipulation. With the booklet manipulation, a cue-wise strategy would have to switch booklets after each piece of information if applied in the Option-wise Condition. In short, the current experiments provide further evidence in favor of the idea of a processing cost continuum: The manipulation we used was on an intermediate level and it induced only subtle costs and only for certain strategies, namely for those which are more cumbersome per se as they engage in more extensive information integration.

Moreover, the research showing that the decision process but not the outcome is affected by a strategy-incompatible information organization (e.g., Bettman & Zins, 1979; Jarvenpaa, 1989) is in accordance with our results. Russo (1977), however, observed that in consumer decisions with hard to process formats, people ended up making worse decisions. But Russo not only manipulated the format (i.e., prices spread out on shelf tags vs. ordered in a single list) but also the actual attribute information (i.e., product price vs. unit price). The former manipulation, the way information was organized, had a weaker impact on the outcome than the latter manipulation and did not reliably occur for all investigated products.

Hence, in line with our results and with Schkade and Kleinmuntz's (1994) investigations of display effects, information organization affects the decision process rather than the outcome.

A possible limitation of our experiments is the implementation of the information grouping. When the organization of information was strategy-incompatible, it was still very organized. The grouping just went against the dimension that would have been compatible with the strategy, but the individual pieces of information within each circle were always organized the same way in all four circles. That is, the information on the top left in each circle, for instance, was always from the same cue when the organization was option-wise (see Fig. 1). That is, we never systematically compared a strategy-compatible information organization to a strategy-incompatible information organization that was completely disorganized on the strategy-relevant dimension. That is, the absence of *any* kind of organization (i.e., complete randomness in organization) might be costly for all types of strategies (cf. Schkade & Kleinmuntz's, 1994, manipulation of organization).

Finally, in the subjective organization experiments (Ettlin & Bröder, 2015a), we observed a general preference for organizing information in an option-wise manner. Thus participants using TTB seemed to pursue other purposes with information organization rather than to support a coherent task representation as we had initially assumed. Possibly, they grouped the information in an option-wise manner to represent the units of choice (i.e., the options) holistically in order to verify their decision before indicating their choice (see Russo & Leclerc's, 1994, verification stage in multi-attribute decisions). This speculation is subject to future research—but it might also play a role in the compensatory strategy users' preference for grouping information in an option-wise manner.

Conclusion

Strategy-incompatible information organization is only costly if a lot of information needs to be integrated. The application of more frugal strategies, like only partially compensatory versions of WADD, is not more costly if the information organization is strategy-incompatible. In light of previous research on information presentation effects, it has to be added that this conclusion only holds for display manipulations that are moderately invasive in how they form groups of information. However, future research needs to investigate whether or when people are aware of subtle processing costs like the ones induced by the current manipulation and if so, whether, in accordance with the adaptive decision maker hypothesis (Payne et al., 1993), they consider those subtle costs in strategy selection.

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