

# Single-process versus multiple-strategy models of decision making: Evidence from an information intrusion paradigm



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## ABSTRACT

When decision makers are confronted with different problems and situations, do they use a uniform mechanism as assumed by single-process models (SPMs) or do they choose adaptively from a set of available decision strategies as multiple-strategy models (MSMs) imply? Both frameworks of decision making have gathered a lot of support, but only rarely have they been contrasted with each other. Employing an *information intrusion* paradigm for multi-attribute decisions from givens, SPM and MSM predictions on information search, decision outcomes, attention, and confidence judgments were derived and tested against each other in two experiments. The results consistently support the SPM view: Participants seemingly using a “take-the-best” (TTB) strategy do not ignore TTB-irrelevant information as MSMs would predict, but adapt the amount of information searched, choose alternative choice options, and show varying confidence judgments contingent on the quality of the “irrelevant” information. The uniformity of these findings underlines the adequacy of the novel *information intrusion* paradigm and comprehensively promotes the notion of a uniform decision making mechanism as assumed by single-process models.

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## 1. Introduction

Every day, humans are confronted with a multitude of choice problems and situations that differ, for example, in complexity, information accessibility, time constraints, and so on. Most researchers in the field of multi-attribute decision making agree that decision makers are able to adapt their behavior to these task features (Bröder & Schiffer, 2003a; Gigerenzer, Todd, & ABC Research Group, 1999; Payne & Bettman, 2001; Rieskamp & Hoffrage, 1999). There is, however, no consensus about how people adapt their behavior. Instead, two frameworks of multi-attribute decision making coexist that make fundamentally different assumptions about the process underlying this adaptivity.

Although several authors have advocated for the importance of distinguishing between these two frameworks (Glöckner & Betsch, 2011; Newell, 2005; Newell & Bröder, 2008) and a few attempts have

been made to do so (Bergert & Nosofsky, 2007; Glöckner, Betsch, & Schindler, 2010; Hausmann & Läge, 2008; Lee & Cummins, 2004; Newell, Collins, & Lee, 2007), there is no conclusive evidence, yet, to decide which framework fares better. The reason for this shortfall is an “empirical challenge,” as Newell (2005, p. 13) puts it. Both frameworks can often account for empirical findings equally well and are therefore virtually impossible to tease apart. As one potential solution to this problem, we introduce the *information intrusion* paradigm that builds on very basic assumptions of the two frameworks. Using this paradigm, we tested basic predictions of both approaches against each other.

In the remainder of the introduction, we describe the two frameworks of multi-attribute decision making in more detail and subsequently discuss some attempts that have been made to disentangle the two approaches. After introducing the theoretical foundations and the basic idea of the novel *information intrusion* paradigm, we present two empirical implementations of the paradigm. The first experiment contrasts the two frameworks of interest by means of information search, choice outcomes, and, additionally, memory performance, whereas the second study also considers confidence judgments.

### 1.1. Two frameworks of decision making

Multi-attribute decision making deals with preferential choice and probabilistic inferences. The difference between these two domains is

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that in the former decisions are made in relation to a subjective criterion (e.g., “Which dessert do you like better?”), whereas in the latter the decision criterion is an objective one (e.g., “Which dessert contains more calories?”). Formally, these domains are similar: The decision maker chooses between two or more options that are characterized by a categorical set of attributes (cues). The cue values display the, often binary (positive versus negative), evaluation of the options by the respective cue. The cues differ with regard to the strength of the correlation between their evaluation and the actual decision criterion (cue validity). As empirical similarities suggest similar cognitive processes in both domains (Bröder & Newell, 2008; Payne, Bettman, & Johnson, 1993; Todd, Gigerenzer, & ABC Research Group, 2012), we will consider models that were developed for preferential choice as well as models for probabilistic inferences in the subsequent discussion of frameworks for multi-attribute decision making.

### 1.1.1. Multiple-strategy models

One popular framework for multi-attribute decision making can be summarized by the notation of “multiple-strategy models” (MSMs, e.g., Beach & Mitchell, 1978; Gigerenzer et al., 1999; Payne et al., 1993; Scheibehenne, Rieskamp, & Wagenmakers, 2013). MSMs propose that decision makers have several distinct decision strategies or heuristics at their disposal (for example, the “adaptive toolbox,” Gigerenzer & Todd, 1999) and choose adaptively between them. The selected decision strategy determines the sequence of information search (search rule), the amount of information searched (stopping rule), and how information is integrated (decision rule).

One prominent decision strategy for multi-attribute decision making has received great attention: the “take-the-best” heuristic (TTB, Gigerenzer, Hoffrage, & Kleinbölting, 1991). It assumes a cue-wise information search along a cue validity hierarchy—from the cue with the highest validity to the cue with the lowest validity (TTB’s search rule). Information search terminates as soon as a cue discriminates between the considered options and favors only one of them (TTB’s stopping rule). The decision maker chooses the option favored by the discriminating cue (TTB’s decision rule). Thus, TTB offers a prominent example of a decision strategy that, if the stopping rule is satisfied before all cues have been investigated, uses only a subset of available and applicable information (so-called *frugality*, Gigerenzer & Goldstein, 1999).

The question, how the decision maker selects a decision strategy from the set of alternatives, has been posed by several researchers (e.g., Payne & Bettman, 2001; Payne et al., 1993). Whereas many authors seem to suggest a top-down mechanism (Beach & Mitchell, 1978; Marewski & Schooler, 2011; Payne et al., 1993), evidence accumulated that bottom-up learning also shapes strategy selection (Bröder, Glöckner, Betsch, Link, & Ettl, 2013; Bröder & Schiffer, 2006; Rieskamp, 2006; Rieskamp & Otto, 2006). In addition to this strategy selection problem, the MSMs need to deal with the question, how many strategies actually comprise the set of possible alternatives (cf., Marewski & Schooler, 2011; Scheibehenne et al., 2013).

### 1.1.2. Single-process models

The “single-process models” (SPMs, e.g., Busemeyer & Johnson, 2004; Busemeyer & Townsend, 1993; Glöckner & Betsch, 2008a; Hausmann & Läge, 2008; Lee & Cummins, 2004) comprise the second, coexisting framework for multi-attribute decision making. Here, it is assumed that instead of selecting one decision strategy from a set of different alternatives, the decision maker employs one single decision making mechanism (for example, the “adjustable spanner (or wrench),” Newell, 2005) that might be adjusted to the particular task at hand. Two prominent classes of the SPMs are connectionist models (e.g., Glöckner & Betsch, 2008a; Simon & Holyoak, 2002; Thagard & Millgram, 1995) and evidence accumulation models (e.g., Busemeyer & Johnson, 2004; Busemeyer & Townsend, 1993; Hausmann & Läge, 2008; Lee & Cummins, 2004; Newell, 2005).

Connectionist models assume that decisions are formed by parallel consideration of all available decision-relevant information in a neural network representing the decision problem (e.g., Glöckner & Betsch, 2008a; Simon & Holyoak, 2002; Thagard & Millgram, 1995). Activation spreads in the network until a stable state is reached and consistency is maximized. The option with the highest positive activation is chosen. The connectionist models focus on the process of information integration, given a set of information.

Evidence accumulation models, to name another class of SPMs, assume a sequential sampling process that terminates as soon as one option surpasses a certain threshold of preference or confidence (e.g., Busemeyer & Townsend, 1993; Hausmann & Läge, 2008; Lee & Cummins, 2004; Newell, 2005). Whenever this happens, a choice is made in favor of this option. Evidence accumulation models do not focus exclusively on information integration, but often also model the process of information search—either in a probabilistic (e.g., Busemeyer & Townsend, 1993) or a deterministic (e.g., Lee & Cummins, 2004) way.

Although the SPMs avoid the aforementioned strategy selection problem by assuming only one single mechanism that is applied to all multi-attribute decisions, one might argue that they merely replace this issue with a different problem (e.g., Marewski, 2010; Newell & Lee, 2011): How do decision makers adjust the proposed uniform mechanism? Some attempts have been made to answer this question for the SPMs in particular (e.g., Glöckner & Betsch, 2008a; Hausmann & Läge, 2008; Jekel, 2012; Newell & Lee, 2009) and some work on the strategy selection problem of the MSMs (e.g., concerning the central role of *learning*, Rieskamp & Otto, 2006) can probably be transferred to this problem. The theoretical advantage of the SPMs over the MSMs, however, lies in the fact that the MSMs often do not confine the set of decision strategies in a principled fashion. Hence, new behavioral phenomena may be captured by extending the toolbox with more sophisticated strategies (e.g., Glöckner & Betsch, 2011; Newell & Lee, 2011; Newell, 2005, but see Marewski, 2010). The downside of SPMs is, however, that they currently do not provide strict predictions for search or the selection of decision boundaries.

## 1.2. How to distinguish between the two frameworks?

The coexistence of the two frameworks (SPMs and MSMs) is theoretically disappointing (Glöckner & Betsch, 2011), but consequential as both frameworks can often account for empirical data equally well. For example, a well-documented finding in multi-attribute decision problems refers to the influence of information costs on decision behavior: Increasing information costs leads to a more frequent use of fast and frugal heuristics like TTB instead of compensatory<sup>1</sup> strategies (MSM interpretation, Bröder, 2000, 2003; Newell & Shanks, 2003). This empirical finding can, however, also be interpreted from a SPM view—for example, as a lowering of the evidence threshold in an evidence accumulation model. Hence, both frameworks invoke different metaphors that explain and capture contingent decision behavior.

The crux is that the SPMs aim at unifying the different decision strategies incorporated in the MSMs (Glöckner & Betsch, 2008a; Hausmann & Läge, 2008; Lee & Cummins, 2004; Newell, 2005). Thus, it comes as no surprise that these SPMs can equally well account for decision behavior that can be described by the decision strategies. The quest to empirically distinguish between the two frameworks poses a challenging research task that some authors have doubted is solvable at all (Newell, 2005; Newell & Bröder, 2008). Nevertheless, in the next section some recent attempts to separate the two frameworks will be discussed.

<sup>1</sup> The term *compensatory* (or *noncompensatory* respectively) can describe a decision strategy as well as an environment. It refers to the degree of tradeoffs among cues. Noncompensatory decision strategies (like TTB) do not allow for a good value on one cue to make up for a bad value on a different one, whereas compensatory decision strategies allow for these tradeoffs (e.g., Payne et al., 1993). If the term is used for environments, it refers to the environment’s payoff structure—favoring either noncompensatory or compensatory cue integration (e.g., Bröder, 2003).

### 1.2.1. Recent attempts to disentangle the two frameworks

Lee and colleagues (Lee & Cummins, 2004; Newell & Lee, 2011; Newell et al., 2007) contrasted the evidence accumulation model proposed by Lee and Cummins (2004) with *pure* decision strategy models that assume that only one strategy (e.g., TTB) is employed by all participants in a particular multi-attribute decision problem. Across all cited studies, Lee and Cummins' (2004) model that unifies TTB and a compensatory, "rational" strategy yielded a better model fit for the observed choice outcomes than the *pure* decision strategy models. Although the SPM was penalized for its complexity in the model comparison (model fit criterion was the Minimum Description Length (MDL), e.g., Grünwald, 2000), this test does not invalidate the MSM view, because the assumption that all participants employ the same decision strategy is not an essential part of this framework (Rieskamp, 2006; Rieskamp & Otto, 2006) and has been shown to be empirically invalid (e.g., Bröder, 2000). Therefore, Newell and Lee (2011) included in their model fit analysis a naïve strategy selection model that assumes that each participant has an individual probability of selecting a particular decision strategy in each decision trial. Again, Lee and Cummins' SPM fared the best—achieving a better model fit (MDL) than the pure decision strategy models as well as the naïve strategy selection model.

Employing a Bayesian approach, Scheibehenne et al. (2013) showed that a model that assumes a toolbox containing a noncompensatory as well as a compensatory decision strategy can be superior to models that contain only one decision strategy. Although Scheibehenne et al. profess that their approach also in principle enables a comparison between SPMs and MSMs, such a model comparison is not reported in the publication. Nevertheless, Scheibehenne et al.'s explicit model specification of the adaptive toolbox approach (Gigerenzer & Todd, 1999) as well as their promising application of Bayesian inference techniques for the comparison of this approach to other models are valuable contributions to the quest of disentangling SPMs and MSMs.

Hausmann and Läge (2008) proposed an evidence accumulation model that unifies one-reason decision making (i.e., TTB) and more-reason (compensatory) decision making. In their study, Hausmann and Läge (2008, Experiment 1) estimated an evidence threshold for each participant based on the 51 trials of the first experimental phase. Based on this threshold (*Desired Level of Confidence*, Hausmann & Läge, 2008), twenty additional, individually tailored decision trials were created that allowed for specific information search predictions to contrast a one-reason decision strategy, a more-reason decision strategy, and the proposed SPM. The information search behavior on the individual level was better explained by Hausmann and Läge's model, using the estimated individual evidence thresholds, than by either a one-reason or a more-reason decision strategy. Hence, participants did not choose a strategy which they retained throughout the experiment, but they adjusted their behavior on a trial-by-trial basis, depending on the validity of the information encountered first.

Glöckner and colleagues investigated the connectionist Parallel Constraint Satisfaction (PCS) model proposed by Glöckner and Betsch (2008a). Some studies (e.g., Glöckner & Betsch, 2008b; Glöckner & Hodges, 2011; Horstmann, Ahlgrimm, & Glöckner, 2009) contrasted the SPM with different decision strategies, thus, treating the SPM as if it was one of several decision strategies in a MSM (cf. Söllner, Bröder, & Hilbig, 2013 for a more detailed discussion). From our point of view, this approach demonstrates that individual decision behavior can successfully be modeled by PCS, but offers no clear distinction between SPMs and MSMs. Glöckner et al. (2010) investigated a specific prediction made by connectionist models, but not by MSMs: In the course of consistency maximization in the proposed network, (subjective) cue validities are modified due to the assumed bidirectional connections between options and cues (*coherence shifts*, Glöckner et al., 2010). Across three experiments, Glöckner et al. (2010) found the predicted coherence shifts in subjective cue validities, highlighting an empirical result that cannot easily be accounted for by MSMs (but see Marewski, 2010, for a different view). Glöckner and Hilbig (2013) scrutinized whether

the repeatedly demonstrated finding (e.g., Bröder, 2003; Newell & Shanks, 2003) that high cue dispersion leads to more frequent use of the non-compensatory decision strategy TTB (MSM interpretation) can better be accounted for by an SPM like Glöckner and Betsch's PCS model. Including choices, decision times and confidence judgments in their analyses, Glöckner and Hilbig concluded that the expected "strategy shift" observable in choice outcomes, is better explained by assuming adjusted weights in the proposed network structures. Confidence judgments and decision times in the condition with high cue dispersion were better accounted for by PCS than by TTB. Finally, Glöckner and Betsch (2012) contrasted response time predictions derived from MSMs against PCS' predictions. In line with PCS, response time patterns were better explained by the coherence of the information set than by the number of computational steps as assumed by MSMs.

Summing up these recent attempts to separate the two frameworks, we first conclude that SPMs can often account very well for empirical data. These studies, however, also illustrate that the task to separate SPMs and MSMs is indeed challenging. When model fit is assessed the challenge lies in fully (and satisfactorily) specifying the competing models. Also, the general question arises, what models should enter the competition—single decision strategies, specific SPMs and MSMs (and how many of them), or even whole frameworks? And, to mention yet another caveat: What dependent variables should be considered? We believe that, although the described studies each contributed to our understanding of especially the SPMs, the question of which framework captures decision making in multi-attribute tasks best has not yet been answered satisfactorily.

### 1.2.2. The information intrusion paradigm

In the present article, we present a new attempt to empirically distinguish between the two frameworks to multi-attribute decision making. As such, we do not concentrate on specific models, but rather on the superordinate frameworks themselves. One approach for contrasting MSMs and SPMs is to flesh out their formal properties precisely and to compare them in terms of model fits for diagnostic data (e.g., Newell & Lee, 2011; Scheibehenne et al., 2013). Although this approach has many merits (e.g. the need for an explicit model specification), a potential drawback is that conclusions may be restricted to very specific instantiations of the model classes. Therefore, we do not engage in model fitting, but in testing basic assumptions shared by all models within one framework. Finally, we do not concentrate on either information search or choice outcomes alone, but consider both (and more) dependent variables for a broader empirical basis.

**1.2.2.1. The theoretical foundation.** Our approach rests on basic assumptions of the two frameworks. MSMs comprise decision strategies of different degrees of complexity (Beach & Mitchell, 1978; Gigerenzer et al., 1999; Payne et al., 1993). A key feature of the less complex strategies is that they concentrate on a specific part of the available information only, ignoring the remaining strategy-irrelevant part. One example for such a strategy is the aforementioned TTB heuristic. The cue-wise search follows a cue validity hierarchy and stops as soon as a cue discriminates between the considered options and favors only one of them (stopping rule). The favored option is chosen based on this one reason only—the less valid, so far not considered cues are ignored altogether and, therefore, do not influence the decision maker's behavior (e.g., Gigerenzer & Goldstein, 1999). Accordingly, Gigerenzer and Goldstein (1996, p. 653) described the TTB algorithm as "take the best, ignore the rest."

SPMs, in contrast, do not share this notion of valid, but potentially irrelevant information. Instead, they would predict that any applicable piece of information readily available to the decision maker is fed into the single decision making mechanism (Busemeyer & Townsend, 1993; Glöckner & Betsch, 2008a; Lee & Cummins, 2004; Newell, 2005) and therefore influences the decision maker's behavior. Importantly, SPMs can, of course, ignore information by giving a weight of zero to

it. This should be the case for invalid cue information that is unrelated to the decision criterion.

Hence, if people have learned or decided to employ a specific strategy as assumed in the MSM framework, their behavior should *ceteris paribus* not be influenced by information that is irrelevant to execute this strategy. If, however, valid information is automatically evaluated as is assumed in evidence accumulation or connectionist models, the decision maker's behavior should be influenced by this information.

**1.2.2.2. The task.** For the information intrusion paradigm we use a well-established task as starting point: forced choices in a closed information board (Payne, 1976; Payne et al., 1993). Here, decision makers uncover initially hidden cue value information by opening the respective cells in an option–cue–matrix (cf. Fig. 1). The decision maker searches for as many cue values as he or she wishes, terminates the information search at some point, and chooses one of the offered options. In the next trial, new options are offered and cue values have to be accessed. Information costs (Bröder, 2000, 2003; Newell & Shanks, 2003) are imposed in a way that has previously been shown to substantially increase the frequency of behavior in line with TTB's predictions (Bröder, 2003).

The novel contribution of the information intrusion paradigm is that not only the intentionally accessed cue values are uncovered, but additionally cue value information intrudes—particular cells in the matrix open without being clicked on. The participants are told that these cells open randomly, but in fact, they are chosen systematically. Our hypotheses refer to the influence of intruding information on decision makers' behavior.

The content of the intruding information can be described as follows: Taking the view of a genuine TTB-user (MSM), cue value information can either be *relevant* (i.e., it comes prior to the information search termination point defined by TTB's stopping rule) or *irrelevant* (i.e., it comes after that point) for a specific decision problem. For example, when the most valid cue discriminates between options and favors one of them, only cue value information for this one cue is relevant to employ the strategy. After this cue has been uncovered, information search is terminated and the choice is made. Importantly, cue value information on all less valid cues is irrelevant to the TTB-user and will therefore be ignored if someone uses a TTB strategy. A vital feature of this strategy-irrelevant information is that it is *not* irrelevant for the decision problem per se (as it is valid and applicable to the problem), but for the execution of the TTB algorithm it is not necessary. Thus, we refer to it as “irrelevant”, meaning that it is valid and applicable information that should therefore not receive a weight of zero within a SPM, but that is irrelevant from the perspective of a genuine TTB-user.

In our experiments reported below, we made sure that participants learned to use TTB as the optimal strategy in the task at hand. One can further classify the strategy-irrelevant information into two subgroups: Cue value information can either support the option favored by TTB (*compatible* information) or weaken it (*incompatible* information).

Fig. 1 shows an example for compatible (Fig. 1, left part) and incompatible (Fig. 1, right part) TTB-irrelevant information. As the most valid cue (“Broker 1”) discriminates and favors “Stock B,” only cue value information on this cue is TTB-relevant, whereas cue value information on the less valid cues (“Broker 2,” “Broker 3,” and “Broker 4”) is irrelevant to a TTB-user. Compatible TTB-irrelevant information supports the option favored by TTB and incompatible information weakens it. In the example depicted in Fig. 1, a positive evaluation of “Stock B” (i.e., the option favored by TTB) from “Broker 2” means compatible information, whereas a positive evaluation of an alternative option represents incompatible information.

## 2. Overview of the experiments

Both experiments reported here employed an identical task structure: Participants were repeatedly asked to choose one of three options that were described by four attributes (cues). The cue information was initially hidden, but participants could buy information (cue values) by clicking on it with the computer mouse. Once purchased, each piece of information remained visible on the screen until the participant finally chose one of the three options.

Participants were told that in each trial they were to invest 1000 *Penunzen* (a fictitious currency) in their favorite option, e.g., a drilling site in the oil drilling task of Experiment 1. The gain or loss made with this investment would be added to an account visible throughout the whole experiment. To ensure high motivation for optimal responding, four participants with the highest end balance would win a voucher worth 25 Euros. In order to aid their decision, the participants could buy information from four different sources (cues), e.g., test institutes in Experiment 1. For each purchase of cue value information participants had to pay 4% of their potential gain.

In each trial one or two pieces of this information showed up for free—they were not actively purchased by the participant and no information costs were attached to them. These information intrusions happened as soon as the first cue value information was intentionally acquired by the participant and remained visible until the participant made a choice for one of the three available options. If the participant happened to intentionally uncover the predefined cell for an information intrusion, no information costs were imposed for the acquisition. Note that amount and timing of the intrusions ensured that the need to search for information was not circumvented in our experiments. In fact, only in the rare event of two pieces of information intruding on the most valid cue *and* the participant clicking on the third cue value for this cue *and* this cue discriminating between the options, a TTB-user would not have to search for more information according to TTB's stopping rule. Therefore, in the vast majority of trials participants needed to employ some sort of search and stopping rule (e.g., the ones of the induced TTB heuristic) in order to make a (non-random) decision.

Which stock will have the best future performance?			
	Stock A	Stock B	Stock C
Broker 1	-	+	-
Broker 2	?	+	?
Broker 3	?	?	?
Broker 4	?	?	?
	Invest!	Invest!	Invest!

Which stock will have the best future performance?			
	Stock A	Stock B	Stock C
Broker 1	-	+	-
Broker 2	?	?	+
Broker 3	?	?	?
Broker 4	?	?	?
	Invest!	Invest!	Invest!

Fig. 1. Examples for compatible (left part) and incompatible (right part) TTB-irrelevant information.

Unbeknownst to the participants, the experiments consisted of two different phases: a learning phase and a test phase. In the initial learning phase participants should learn that TTB is the adaptive decision strategy for the environmental payoff structure. Previous research has demonstrated that by manipulating information costs, the use of the fast and frugal TTB heuristic can reliably be induced (Bröder, 2000, 2003; Bröder & Schiffer, 2006; Newell & Shanks, 2003).<sup>2</sup> The environmental structure of the experiments reported herein was taken from Bröder (2003, Experiment 2). In this experiment, the author classified a majority of 80% of his participants as TTB-users. As we aimed for a reliable TTB induction in our learning phase, we decided to employ the same weighing function for the cues:  $\text{Payoff} = 47 \times c_1 + 25 \times c_2 + 17 \times c_3 + 10 \times c_4 + \text{random}$ . The payoff is measured as the percentage increase (or decrease) of the invested 1000 Penunzen. Cues ( $c_1, c_2, c_3, c_4$ ) are coded “+1” for a positive cue value and “-1” for a negative cue value. The random component was drawn from a uniform distribution with a mean of zero and a range from -5 to 5. We also adopted the information cost manipulation, yielding a relative cost for each piece of information of 4% of the profit. The cue weights in this equation are not strictly noncompensatory, but they show a high dispersion, and although there are some trials in which TTB's payoff is slightly lower than that of a compensatory strategy, the saved information acquisition costs clearly favor TTB in the long run as well as in the vast majority of trials. Participants' decision strategies were classified according to the maximum likelihood outcome-based classification method by Bröder and Schiffer (2003b) on the basis of the 60 learning phase trials. In order to aid a successful strategy induction, 90% of the information intrusions were TTB-relevant and only 10% TTB-irrelevant in the learning phase. The within-subject manipulations relevant to our hypotheses were administered in the subsequent test phase. Thus, our analyses (apart from the aforementioned strategy classification) exclusively refer to the test phase. Importantly, in both phases the mean payoff for TTB was considerably better than for WADD (weighted-additive integration of all available information), the “equal weight rule” (EQW, Dawes, 1979, unweighted-additive integration of all available information), and random guessing—the competing decision strategies for the strategy classification method (Bröder, 2010; Bröder & Schiffer, 2003b). Importantly, the payoff function did not change from learning to test phase and TTB was the optimal decision strategy in both phases. Choice deviations from TTB due to “irrelevant” information as predicted by SPMs therefore could not be explained by adapting to a new environment. Rather, they would never be reinforced in this paradigm and can thus be considered maladaptive.

### 3. Experiment 1: Examining the influence of strategy-irrelevant information on information search, choice outcomes, and attention

In the first experiment, basic assumptions of SPMs and MSMs are contrasted. The logic of SPMs implies that if an accessible piece of information is applicable for a decision problem, it cannot be ignored but will be fed into the uniform mechanism proposed by the respective model. According to MSMs, in contrast, some pieces of information will be irrelevant for certain decision strategies and, therefore, they will be ignored by the decision maker who selected this strategy based on learning or explicit cost-benefit tradeoffs.

Following this reasoning, assumptions for two measures of decision behavior can be derived. First, with respect to search behavior TTB use implies search in order of validities terminating when a differentiating cue is found. Information search should not be affected by applicable information that lies behind the point defined by the stopping rule. As SPMs do not ignore applicable information, TTB-irrelevant information is not irrelevant here and search behavior may be affected by the content

of this information. In particular, evidence accumulation models predict information search contingent on the magnitude of accumulated evidence (that is influenced by the content of intruding information) in relation to the proposed evidence threshold (that is rather stable and established in the learning phase). As soon as the threshold is passed, information search terminates. Connectionist models such as PCS (Glöckner & Betsch, 2008b) capture the process of information integration, but do (so far) not specifically model the process of information search (but see Betsch & Glöckner, 2010 and Glöckner & Herbold, 2011, for general predictions of PCS concerning information search). Thus, they do not make predictions concerning the effect of additionally revealed information on information search.

Second, we can derive contrasting assumptions for the choice outcomes. TTB's decision rule states that after information search is terminated the particular option will be chosen that is favored by the most valid discriminating cue. Again, this choice outcome is predefined by TTB's decision rule and will not be affected by TTB-irrelevant information. According to SPMs, TTB-irrelevant information can affect choice outcomes, because it will not be ignored. In particular, such information incompatible with TTB's predicted choice outcome might cause decision makers to choose an alternative option. For example, evidence accumulation models would predict that the incompatible information reduces the evidence accumulated in favor of the TTB-option. If it falls below the evidence threshold, information search proceeds and the choice outcome might deviate from the option predicted by TTB. Connectionist models, to give another example, would predict that the additional information becomes part of the neural network and thus influences the activation of the choice options. The TTB-option is only chosen when its activation (after the network has maximized its consistency) is higher than the activation of the alternative options.

In addition to information search and choice outcomes, we examined a third variable in Experiment 1: attention to cue information. Building on MSMs' basic assumption that only strategy-relevant information is considered, whereas strategy-irrelevant information is ignored, we included a potential measure for attention to cue value information in Experiment 1: memory performance for the respective cue value. If participants attend to cue values, their memory for this information should be superior to memory for information that was largely ignored.

#### 3.1. Method

##### 3.1.1. Design and procedure

We manipulated two factors within-subject: intrusion content (compatible TTB-irrelevant vs. incompatible TTB-irrelevant) and number of intrusions (1 vs. 2 fields of the information board). TTB-use was induced bottom-up by the information cost manipulation and additionally top-down as the instruction encouraged participants to employ the TTB heuristic which would be the best strategy for the task at hand. Participants' memory performance was tested in about 25% of the trials. For the 60 trials of the learning phase 90% of the intrusions were TTB-relevant (meaning that a TTB-user would have accessed this information anyway), whereas only 10% were TTB-irrelevant. The test phase consisted of 46 trials. In 40 trials the information intrusions were TTB-irrelevant. Half of them were compatible with the option favored by TTB and half of them were incompatible with it (cf. Fig. 1)—each with 50% one-field intrusions and 50% two-field intrusions. As attention to irrelevant as well as relevant information was of interest, additionally six trials with intruding relevant information were included in the test phase.

Participants were told to imagine being head of an oil drilling company (Rieskamp, 2006; Rieskamp & Otto, 2006). The company always looks for potential drilling sites and whenever three sites are available, the most promising one (containing most oil) has to be chosen. For each oil drilling, 1000 Penunzen of drilling costs are invested. As a decision aid, four different test institutes with varying levels of validity, which each perform a particular analysis (e.g., “seismic analysis”), can be commissioned to evaluate the available options (positive or negative

<sup>2</sup> Note that this labeling stems from the MSM view. This calibration phase can, however, of course also be described from the SPM view, e.g. in evidence accumulation models as learning to lower the evidence threshold.

**Table 1**  
Overview of hypotheses for Experiment 1.

Dependent variable	Hypothesis	Independent variable	MSM prediction	SPM prediction
Information search	1.a	Content of TTB-irrelevant intrusion	Purchased pieces of information: (incompatible) = (compatible)	Purchased pieces of information: (incompatible) > (compatible)
	1.b	Interaction: Number of intrusions * content	No interaction	Effect for Hypothesis 1.a: (2 fields) > (1 field)
Choice outcomes	2.a	Content of TTB-irrelevant intrusion	Proportion of choices in line with TTB: (incompatible) = (compatible)	Proportion of choices in line with TTB: (incompatible) < (compatible)
	2.b	Interaction: Number of intrusions * content	No interaction	Effect for Hypothesis 2.a: (2 fields) > (1 field)
Attention	3	TTB-relevance of intrusion	Memory performance: (relevant) >> (irrelevant)	Memory performance: (relevant) = (irrelevant)

Note: MSM = multiple-strategy model; SPM = single-process model; TTB = “take-the-best” heuristic.

evaluation of the drilling site). The concept of validity was explained and cue validities for the four test institutes were stated: 97%, 75%, 67%, and 60% respectively. Further, participants were told that each purchased piece of information would cost them 4% of their potential investment profit (percentage payoff as determined by the payoff function \* 1000 Penunzen), whereas no costs would occur for a loss. The gain (profit minus information costs) or loss would be added to a virtual account and the four best managers would earn a voucher worth 25 Euros. Participants learned that they would get one or two randomly chosen pieces of information for free in each trial. After each decision, feedback (graphical and percentage payoff) would be given on how well each of the three drilling sites would have turned out, and for the chosen drilling site monetary feedback (in Penunzen) on profit, costs, and gain (or loss) was displayed. Participants were additionally encouraged to use the TTB strategy. The instructor veridically said that this strategy would be the best for the task at hand. It introduced the strategy and explained to the participants that the low costs for this strategy would compensate for the fact that sometimes the optimal option would not be chosen.

Participants were also informed that in about 25% of the trials their memory performance would be assessed. In these trials, immediately after the performance feedback, participants were shown an empty information board with three<sup>3</sup> cells of the information board highlighted. For each of the highlighted pieces of information, participants were asked to indicate, whether it was a positive evaluation (+), a negative evaluation (−), or an unknown piece of information (?) in the previous choice problem. After the instructions participants could familiarize themselves with the task in a practice trial and subsequently start working on the experimental trials.

All our hypotheses build on the following basic assumptions of the competing frameworks: From the MSM perspective, applicable information can be regarded as either relevant or irrelevant for the chosen strategy (i.e., TTB). Irrelevant information will be ignored by the TTB-user. SPMs, on the other hand, maintain that no applicable information is irrelevant to a decision problem. Therefore, TTB-relevant and -irrelevant information will be fed into the uniform decision making mechanism. From these assumptions we can derive specific predictions concerning search behavior (Hypotheses 1.a and 1.b), choice outcomes

(Hypotheses 2.a and 2.b), and attention (Hypothesis 3) as they are depicted in Table 1.

### 3.1.2. Participants

Forty-eight participants (39 female, mean age 21.6) took part in the experiment, all but one being students from the University of Mannheim. They received course credit for their participation. The best four participants additionally received a voucher worth 25 Euros (approx. USD 35).

## 3.2. Results and discussion

### 3.2.1. Strategy classification

The decision strategy classification was based on the choice outcomes of the 60 trials of the learning phase that comprised three different item types: 18 trials of item type 1 (TTB predicts choosing one option, WADD and EQW predict choosing an alternative option), 20 trials of item type 2 (TTB and WADD predict choosing the same option, EQW predicts guessing between two options), and 22 trials of item type 3 (TTB, WADD, and EQW predict choosing the same option).<sup>4</sup> The upper part of Table 2 shows the result of the outcome-based strategy classification (Bröder, 2010; Bröder & Schiffer, 2003b). Strategy learning was successful as 47 participants were classified as TTB-users. Only one participant had to be excluded due to an estimated choice error rate for the best fitting strategy that exceeded .40 (Bröder & Schiffer, 2003b). Accordingly, 47 TTB-users were included in the analyses reported below.

### 3.2.2. Information search

The information search behavior can be characterized by the number of purchased pieces of information. As a dependent variable, we calculated the difference between the number of actual information purchases and the number predicted by TTB. Hence, this relative number of purchases is 0 if the stopping rule conforms to TTB and larger than 0 if the purchases exceed TTB's prediction. Fig. 2 shows the mean relative number of purchased pieces of information separated by the within-subject factors.

For Hypothesis 1.a we find a significant effect of the factor content of information ( $F(1, 46) = 47.17, p < .001, \text{partial } \eta^2 = .51$ ) in line with the SPM prediction: When incompatible information intrudes, participants engage in a more extensive information search than when the content of the intrusion is compatible with the option preferred by TTB. As the interaction term suggests, this effect is more pronounced when two pieces of information intrude than when only one field gives the compatible or incompatible information ( $F(1, 46) = 24.79, p < .001, \text{partial } \eta^2 = .35$ ), which is in line with the SPM prediction for Hypothesis 1.b. Additionally, we find a main effect of the factor number of intrusions ( $F(1, 46) = 17.70, p < .001, \text{partial } \eta^2 = .28$ ): Participants engage in a more extensive information search when two

<sup>3</sup> We decided to assess memory performance for three pieces of information instead of one for several reasons: (1) Participants should not become aware of the fact that we were mainly interested in their memory for intruding information. Asking for non-intrusions therefore seemed advisable. (2) As there were only three answering options available (+, −, ?), all three should be included in the correct response pattern. That would not have been the case if we asked for intruding pieces of information only. (3) The number of trials with subsequent memory performance assessment should not exceed 25% of the total number of trials as participants should concentrate on their choice task. We worried that more frequent memory performance assessments might lead to the unsatisfactory result that participants try to memorize each cue information in order to be successful in the upcoming memory test.

<sup>4</sup> Due to a data collection error five trials (0.083% of all trials) could not be analyzed and were therefore excluded from the analyses.

**Table 2**  
Strategy classification for Experiments 1 and 2.

Experiment, condition	TTB			WADD			EQW		Unclassified	
	Number	Percent	Mean $\epsilon^a$	Number	Percent	Mean $\epsilon^a$	Number	Percent	Number	Percent
1, top-down	47	98%	.07	0	0%	–	0	0%	1	2%
2, top-down	28	93%	.08	2	7%	.23	0	0%	0	0%
2, bottom-up	26	87%	.12	4	13%	.22	0	0%	0	0%

Note: TTB = “take-the-best” heuristic; WADD = “weighted-additive rule”; EQW = “equal weight rule”.

<sup>a</sup>  $\epsilon$  is the error probability for choosing the nonpredicted option (see Bröder, 2010).

pieces of information intrude than when only one piece of information shows up for free.

### 3.2.3. Choice outcomes

As TTB only predicts a different choice outcome than WADD and EQW for one item type, choice outcomes were only analyzed for the 16 trials of this diagnostic item type in the test phase. Fig. 3 shows the mean proportion of choices in line with TTB separated by the within-subject factors.

Again, the result for Hypothesis 2.a is more in line with the SPM than the MSM view. The factor content of information significantly influences participants' choices ( $F(1, 46) = 68.19, p < .001, \text{partial } \eta^2 = .60$ ): Participants refrain from choosing the option preferred by TTB more frequently when incompatible information is given than when compatible information intrudes. Testing Hypothesis 2.b, we find further support for the SPM view: As the interaction term suggests, the aforementioned effect is more pronounced when two pieces of information intrude than when an intrusion consists of only one piece of information ( $F(1, 46) = 46.71, p < .001, \text{partial } \eta^2 = .50$ ). In addition to the predicted effects, we again find a main effect of the factor number of intrusions ( $F(1, 46) = 21.56, p < .001, \text{partial } \eta^2 = .32$ ): Participants decide against the option favored by TTB more frequently when two pieces of information intrude than when only one field opens for free.

### 3.2.4. Attention

In order to assess attention to cue information, we tested participants' memory for eight irrelevant (four incompatible and four compatible with TTB's choice outcome prediction) intrusions in the test phase. Additionally, in each of the six trials with relevant information intrusions, we assessed memory performance for intruding information. Although in some of the trials the intruding information consisted of two pieces of information rather than only one (within-subject manipulation “number of intrusions”), memory performance was always assessed for one piece of information only.

Memory performance for irrelevant information intrusions ( $M = .58, SD = .23$ ) significantly exceeds the chance level<sup>5</sup> of .50 ( $t(46) = 2.24, p = .03$ ). Testing the directional MSM prediction for Hypothesis 3 that memory performance is better for relevant intrusions than for irrelevant ones with a paired  $t$ -test, we find a small, but significant effect in the assumed direction. The mean number of correct responses is higher for relevant ( $M = .66, SD = .27$ ) than for irrelevant pieces of information:  $t(46) = 1.83, \text{one-tailed } p = .04, d_z = 0.27$ .

### 3.2.5. Discussion

The reported analyses largely support SPMs' basic assumption that applicable information is not ignored when making multi-attribute decisions. Specifically, participants successfully trained to employ the TTB heuristic do not adhere to TTB's stopping rule when incompatible irrelevant information intrudes. Furthermore, these “TTB-users” refrain from choosing the option favored by TTB more frequently when incompatible

information is given than when compatible information intrudes. Both effects are more pronounced when two pieces of information convey the incompatible irrelevant information. Note that deviations from TTB are maladaptive since TTB was the decision strategy with the highest payoff—both in the learning phase as well as in the test phase. Hence, the effects can *not* be explained by a re-learning of contingencies in the test phase since deviations from TTB were not reinforced.

These so far unanimous findings in line with SPMs' predictions are challenged by the observation in line with MSMs' prediction that strategy-relevant information receives more attention than strategy-irrelevant one. However, it is possible that this difference merely mirrors the assumption largely shared by SPMs and MSMs that more valid information receives more attention. Due to TTB's search rule that entails information search in descending order of cue validity, it comes as a confound in our paradigm that relevant information is associated with cues of higher validity than irrelevant information. When only the ten trials (four irrelevant and all six relevant information intrusions trials) are included that test intruding information of the same validity (i.e., for the second most valid cue), the difference in the mean number of correct responses between relevant ( $M = .66, SD = .27$ ) and irrelevant ( $M = .61, SD = .25$ ) pieces of information is not observed:  $t(46) = 1.01, \text{one-tailed } p = .16$ . Thus, when controlling for cue validity, relevant information does not receive more attention than irrelevant information—a finding that does not support the MSM view, but is in line with SPMs' prediction. However, strong conclusions from the memory measure are not warranted because of the inevitable confound with validity that we did not think of before the experiment. We also cannot rule out the possibility that the memory assessment might have caused participants to pay more attention to the information intrusions than they would have done without this instruction. Thus, one could argue that the memory assessment might have biased the participants against the ignorance of information as predicted by TTB. Therefore, in Experiment 2 we did not assess memory performance, but asked for confidence judgments for which competing hypotheses can be derived from MSMs and SPMs.

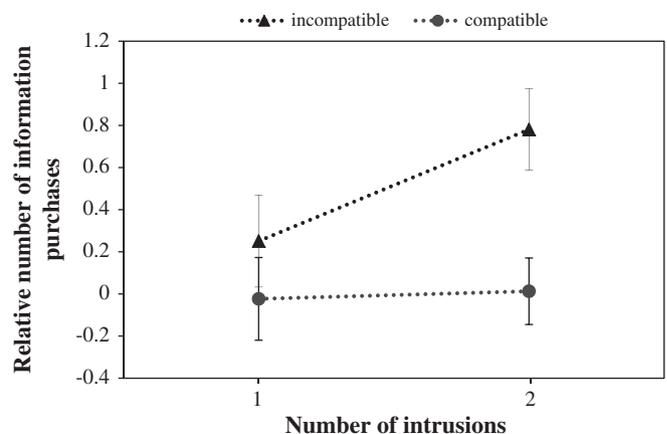


Fig. 2. Mean relative number of purchased pieces of information in Experiment 1 (error bars represent standard errors).

<sup>5</sup> Note that we administered a conservative test here by, instead of adopting the obvious chance level of .33 given the three answering options, choosing a chance level of .50 that assumes that decision makers are aware that the tested cell had been uncovered.

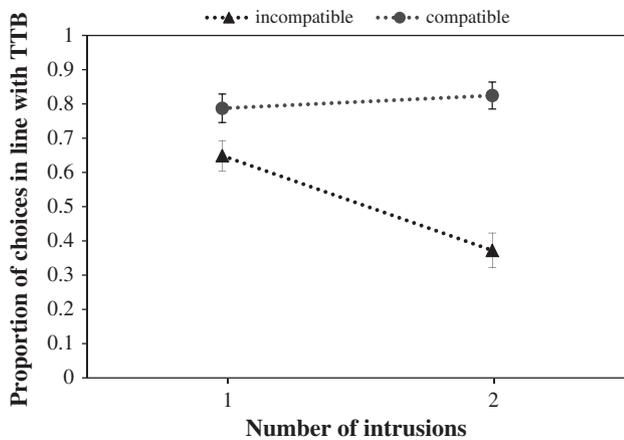


Fig. 3. Mean proportion of choices in line with TTB for the diagnostic item type in Experiment 1 (error bars represent standard errors). Note: TTB = “take-the-best” heuristic.

#### 4. Experiment 2: Examining the influence of strategy-irrelevant information on information search, choice outcomes, and confidence judgments

The results of Experiment 1 are compatible with a uniform decision making mechanism as assumed by single-process models (SPMs). Participants classified as users of the TTB strategy did not ignore TTB-irrelevant information intrusions, but adapted their information search as well as their choice behavior to the content and the amount of the “irrelevant” information. Importantly, there was no recognizable change from the learning to the test phase—the task was identical.

As the results of the previous experiment constitute a novel finding, Experiment 2 aims to replicate the results within another task domain. Therefore, in Experiment 2 participants were repeatedly asked to choose among three stocks the one that will probably have the best future performance (Bröder, 2000, 2003; Newell & Shanks, 2003).

To further broaden the empirical basis for contrasting the two frameworks of decision making in Experiment 2, we asked the participants for confidence ratings on their choices. If decision makers choose the option predicted by TTB, SPMs would assume that confidence judgments should be lower when (TTB-irrelevant) incompatible information is presented than when compatible information intrudes. On the other hand, a decision maker employing the TTB heuristic will base a confidence judgment exclusively on TTB-relevant information. The confidence judgment should mirror the validity of the best discriminating cue (Gigerenzer et al., 1991) and not depend on the content of TTB-irrelevant information.

Finally, in Experiment 2 two different strategy induction procedures are employed in an explorative manner. Use of the TTB heuristic is either induced bottom-up only or in combination with a top-down instruction as in Experiment 1. This manipulation was introduced to test (1) whether the bottom-up induction alone would suffice to reliably induce TTB-use and (2) whether the induction method influences, how persistently TTB-users stick to their decision strategy, in particular to TTB's stopping and decision rule.

#### 4.1. Method

##### 4.1.1. Design and procedure

The design of Experiment 2 closely resembled the one of Experiment 1. Instead of testing the memory performance, participants were asked to judge their confidence. The additional factor strategy induction (bottom-up vs. bottom-up plus top-down) was manipulated between participants, whereas the factors intrusion content (compatible TTB-irrelevant vs. incompatible TTB-irrelevant) and number of intrusions (1 vs. 2 fields of the information board) were within-subject manipulations as in Experiment 1. Participants were randomly assigned to the

two strategy induction conditions (with forced equal size of 30 participants per condition). In the bottom-up condition TTB use was induced by the reinforcement structure of the environment only, whereas in the second condition participants were additionally asked to employ the TTB heuristic (cf. Experiment 1). As we did not assess memory performance, we excluded the six test trials with relevant information intrusions of Experiment 1. Thus, Experiment 2 comprised 100 experimental trials—Experiment 1's 60 learning phase trials plus Experiment 1's 40 test trials with irrelevant information intrusions.

The procedure of Experiment 2 also closely resembled the one of Experiment 1. Participants were told that they would play a stock market game. In each trial they were to invest 1000 *Penunzen* into one of the three available stocks. For each of the stocks they could buy information (positive or negative evaluation of the respective stock) from four different brokers whose judgments had varying levels of validity. The remaining procedure was equivalent to Experiment 1's procedure, except that (1) participants in the bottom-up condition were not instructed to use the TTB heuristic and (2) memory performance was not assessed. Instead, in 25% of the trials the participants were asked for a confidence judgment for the just chosen option prior to the feedback. Confidence judgments were assessed on a scale ranging from “very unconfident” (0) to “very confident” (100).

Again, our hypotheses are derived from the basic assumptions of SPMs and MSMs concerning the ignorance of strategy-irrelevant information (cf. Experiment 1). For Experiment 2, we test the hypotheses for information search (Hypotheses 1.a and 1.b) and choice outcomes (Hypotheses 2.a and 2.b) displayed in Table 1. For the third dependent variable (i.e., confidence judgments) we are also interested in the main effect of the content of TTB-irrelevant intrusions (Hypothesis 3.a) and the interaction between content and number of intrusions (Hypothesis 3.b). MSMs predict that the content of the irrelevant information will not influence participants' confidence judgments. SPMs, on the other hand, predict that when encountering incompatible information participants should be less confident in choosing the outcome favored by TTB than when compatible information is given. This effect should be more pronounced when two pieces of incompatible or compatible information intrude than when only one field gives the information. Additionally, we explore whether the strategy induction method influences participants' search and choice behavior.

##### 4.1.2. Participants

Sixty participants (50 students of the University of Mannheim plus 10 advanced level high school graduates, 33 female, mean age 21.0) took part in Experiment 2. They received course credit or monetary compensation (5 Euros) for their participation. The best four participants (with the highest end account balance in *Penunzen*) received a voucher worth 25 Euros.

#### 4.2. Results and discussion

##### 4.2.1. Strategy classification

Strategies were again classified with the outcome-based classification method (Bröder, 2010; Bröder & Schiffer, 2003b) on the basis of the 60 learning phase trials. As can be seen in the lower part of Table 2, the strategy induction procedure was successful: 90% of all participants were classified as users of the intended TTB strategy and therefore included in the subsequent analyses. There was no significant difference between conditions ( $\chi^2(1, N = 60) = 0.74, p = .39$ ). Thus, the success of the bottom-up strategy induction was not worse than when strategy-use was induced bottom-up and top-down.

##### 4.2.2. Information search

As for Experiment 1, we first analyzed the relative number of information purchases (absolute number minus the number predicted by TTB's stopping rule). Fig. 4 shows the mean relative number of

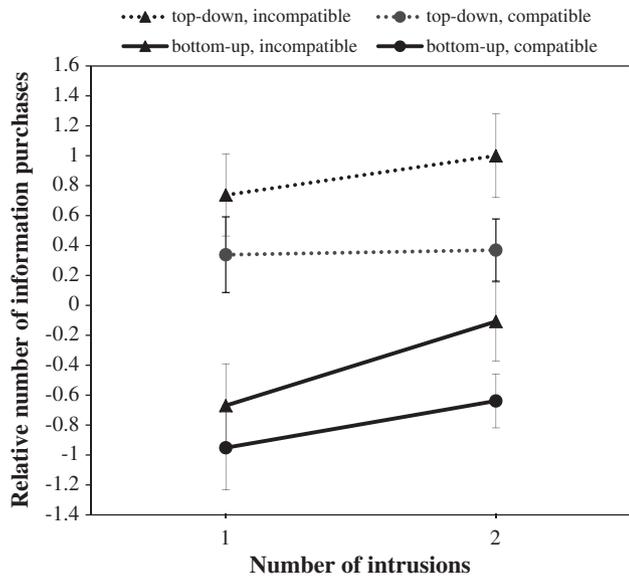


Fig. 4. Mean relative number of purchased pieces of information in Experiment 2 (error bars represent standard errors).

purchased pieces of information separated by conditions and by the within-subject factors content of information and number of intrusions.

Testing Hypothesis 1.a, we find support for the SPM prediction that the factor content of information systematically influences information search behavior: Participants classified as TTB-users purchase more pieces of information when the content of TTB-irrelevant intrusions was incompatible rather than compatible ( $F(1, 53) = 54.60, p < .001$ , partial  $\eta^2 = .51$ ). The results for Hypothesis 1.b are also more in line with the SPM prediction as we find a significant interaction of the within-subject factors ( $F(1, 53) = 4.25, p = .04$ , partial  $\eta^2 = .07$ ): The aforementioned effect is stronger when two pieces of information intrude than when only one field gives the information. In addition to these predicted effects, we find a significant main effect of the factor number of intrusions ( $F(1, 53) = 20.05, p < .001$ , partial  $\eta^2 = .27$ ): When two pieces of information intrude participants purchase more information than when only one field gives the compatible or incompatible TTB-irrelevant information.

Employing a *t*-test for independent samples, we find that the method of strategy-induction also significantly influences information search behavior: When TTB-use had been induced bottom-up TTB-users purchase less pieces of information than when TTB-use had additionally been suggested in the instructions ( $t(52) = 3.48, p = .001, d = 0.95$ ).

#### 4.2.3. Choice outcomes

Choice outcomes were considered for the 16 test trials of the diagnostic item type, because only for this item type the choice outcome predictions of TTB and the other decision strategies (i.e., WADD and EQW) differ from each other. The mean proportion of choices in line with TTB separated by the conditions and the within-subject factors is displayed in Fig. 5.

For Hypothesis 2.a the factor content of information shows a significant main effect in the direction predicted by the SPM view ( $F(1, 53) = 97.79, p < .001$ , partial  $\eta^2 = .65$ ): When the “irrelevant” information is incompatible to the TTB-option participants choose this option less often than when the intruding information is compatible with it. In line with the SPM prediction for Hypothesis 2.b, this effect is more pronounced when two pieces of information intrude than when only one field opens ( $F(1, 53) = 27.16, p < .001$ , partial  $\eta^2 = .34$ ). Thus, for choice outcomes, the results are again more in line with the SPM than the MSM view. Again, we find a significant main effect of the factor number of intrusions ( $F(1, 53) = 30.23, p < .001$ , partial  $\eta^2 = .36$ ): When two pieces of information intrude

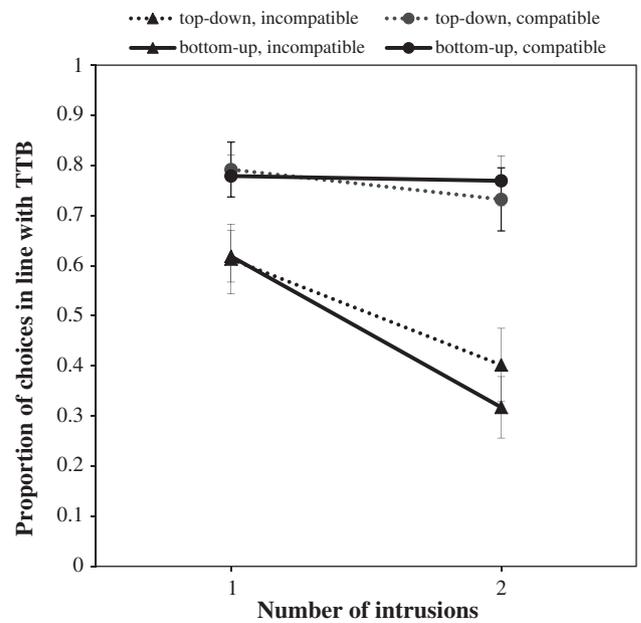


Fig. 5. Mean proportion of choices in line with TTB for the diagnostic item type in Experiment 2 (error bars represent standard errors). Note: TTB = “take-the-best” heuristic.

participants choose the option favored by TTB less frequently than when only one field gives the intruding information.

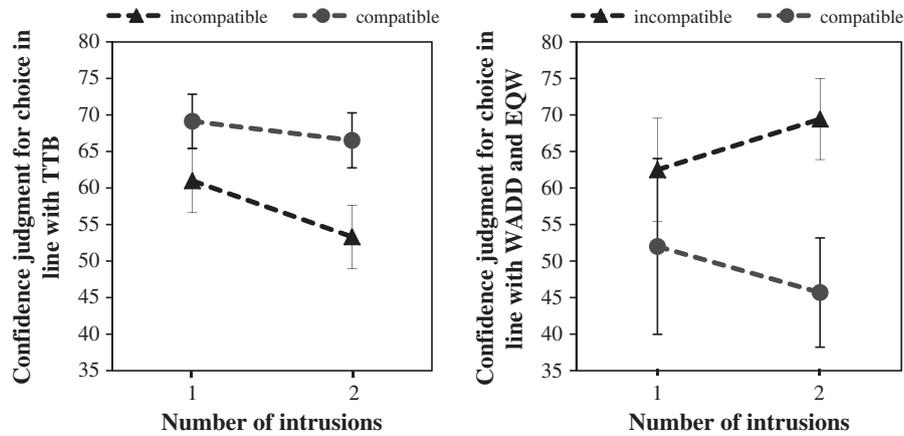
The method of strategy-induction shows no significant effect on choice outcomes ( $t(49.39) = 0.17, p = .86$ ). Thus, the choice behavior of participants who were additionally encouraged to employ the TTB heuristic did not differ from the behavior of participants who learned the decision strategy bottom-up only.

#### 4.2.4. Confidence judgments

The analyses for this variable were conducted on the basis of the same test trials that have been analyzed for choice outcomes. Only for these test items TTB predicted a different choice outcome than the compensatory decision strategies WADD and EQW.

Hypotheses 3.a and 3.b refer to confidence judgments for choices in line with TTB. Thus, in order to test these hypotheses we analyzed choices of the TTB-option for the diagnostic item type. As there were only 22 TTB-users (13 in the top-down and nine in the bottom-up condition) whose choices were in line with TTB at least once for all combinations of the two within-subjects factors, our analyses for confidence judgments rely on a reduced sample size.

Testing Hypothesis 3.a we find a significant main effect of the factor content of information as predicted by the SPM view: When information intrudes that is incompatible with the option favored by TTB, participants are less confident when choosing this option than when the “irrelevant” information is compatible with the option ( $F(1, 21) = 14.04, p = .001$ , partial  $\eta^2 = .40$ ). Eight participants classified as TTB-users (four in the top-down and four in the bottom-up condition) chose the option favored by WADD and EQW at least once for all combinations of the two within-subject factors. Therefore, we were able to additionally analyze the confidence judgments for choices in line with these compensatory decision strategies for the diagnostic item type. Again, the factor content of information has a significant main effect ( $F(1, 7) = 7.49, p = .03$ , partial  $\eta^2 = .52$ ), but in the opposite direction than for choices in line with TTB: If participants classified as TTB-users choose the compensatory option *not* favored by TTB, they are more confident when the intruding information was incompatible with the TTB-option than when the intruding information was compatible with the TTB-option. Fig. 6 shows the mean confidence judgments for choices in line with TTB (left part) and choices in line with WADD and EQW (right part) for the diagnostic



**Fig. 6.** Mean confidence judgments for choices in line with TTB (left part) and choices in line with WADD and EQW (right part) for the diagnostic item type in Experiment 2 (error bars represent standard errors). Note: TTB = “take-the-best” heuristic; WADD = “weighted-additive rule”; EQW = “equal weight rule”.

item type, separated by the within-subject factors and pooled across conditions.

Though a trend is observable in Fig. 6, the interaction predicted by the SPMs for Hypothesis 3.b is neither significant for choices in line with TTB ( $F(1, 21) = 2.10, p = .16$ ) nor for choices in line with compensatory decision strategies ( $F(1, 7) = 4.07, p = .08$ ). The small  $N$  for these analyses ( $N = 22$  for choices of the TTB-option and  $N = 8$  for choices of the option favored by WADD and EQW) reduced the power of the tests considerably and gives a plausible explanation for the insignificance.

Nevertheless, in addition to the predicted effects we find a significant main effect for the TTB-option choices of the factor number of intrusions ( $F(1, 21) = 9.79, p = .01$ , partial  $\eta^2 = .32$ ): When two pieces of information intrude participants are less confident in their choice in line with TTB than when only one piece of information intrudes. For the choices in line with the compensatory decision strategies there is no significant effect of the factor number of intrusions ( $F(1, 7) = 0.01, p = .95$ ).

#### 4.2.5. Discussion

Experiment 2 replicated Experiment 1's unanimous results concerning information search and choice outcomes: “TTB-users” did not generally adhere to TTB's stopping rule, but adapted their information search to the content of the intruding “irrelevant” information. Also, they refrained from choosing the TTB-option when the “irrelevant” information was incompatible with this option more frequently than when it was compatible. Both effects were more pronounced when two fields conveyed the intruding information. Taken together, these findings exactly replicate Experiment 1's results and thus concordantly support SPMs' predictions rather than the MSM view. Importantly, as we did not assess memory performance in Experiment 2, it can be ruled out that the observed violation of TTB's ignorance prediction is due to participants' desire to do well in the memory test.

As a complement to these variables, we investigated confidence judgments in Experiment 2. Again, the results were more in line with the predictions of SPMs than MSMs: “TTB-users” choosing the TTB-option were less confident with their choice when incompatible information intruded than when the “irrelevant” information was compatible with their choice. Interestingly, we observed the opposite pattern for “TTB-users” choosing an alternative option (favored by the compensatory decision strategies) over the one favored by TTB: When the “irrelevant” information was incompatible with the TTB-option they were more confident with their deviance than when the information was compatible with the TTB-option. Thus, the findings for the third dependent variable – confidence judgments – comprehensively corroborate the aforementioned results.

To account for the confidence results, one might argue that choices and confidence judgments are generated separately and based on different strategies and pieces of information. Although choices might be generated using a TTB strategy, the process of generating confidence judgments could include further available information and might be conducted only after the decision has been made (e.g., Pleskac & Busemeyer, 2010). We cannot rule out that the latter process might be influenced by information intrusions independent of the choice strategy, which could account for the confidence results as well. Thus, although the confidence judgment results are well in line with our predictions derived from SPMs and corroborate our findings for information search and choice outcomes, they can only be considered as weaker empirical arguments since their interpretation depends on the previously made assumption (e.g., Gigerenzer et al., 1991; Glöckner, 2009; Jekel, Nicklisch, & Glöckner, 2010) that people base choices and confidence judgments on the same strategies and pieces of information.

All results of Experiment 2 are in line with SPMs' basic assumption that applicable information cannot be ignored, but will be integrated in the decision making mechanism. Although the TTB heuristic outperforms (in terms of monetary payoff) other decision strategies in our environment, decision makers do not generally adhere to its stopping and decision rule, but adapt information search, choices, and confidence judgments to the content of TTB-irrelevant information. Importantly, this adaption cannot be attributed to learning processes in the test phase since deviations from TTB choices were not reinforced.

In Experiment 2, we also explored the role of how strategy-use is induced. Specifically, we compared one condition with top-down as well as bottom-up TTB-induction (as in Experiment 1) with one condition that relied on a bottom-up induction of the respective strategy only. Although both induction methods worked equally well concerning the outcome-based strategy classification (Bröder, 2010; Bröder & Schiffer, 2003b) of the learning phase, in the test phase we observed a discrepancy in information search behavior: Participants, classified as TTB-users, that acquired a decision strategy without top-down instruction purchased less pieces of information than those who were advised to employ the TTB heuristic. In fact, these participants regularly acquired less information than predicted by TTB. There was, however, no difference in choice outcomes between the two conditions. Thus, the bottom-up “TTB-users” evidently employed “heuristics” that are even more frugal than TTB, but lead to a high percentage of choices in line with TTB. Possibly, the instruction to purchase single cue values (Newell & Shanks, 2003; instead of cues as a whole, cf. Newell, Weston, & Shanks, 2003) leads participants to apply especially frugal “heuristics”. This tendency is annihilated when a top-down instruction is added. However, it might be the case that this frugality effect was caused (or enhanced) by the task domain of Experiment 2: The stock market task might have worked as a prime for self-sufficiency (Vohs, Mead, & Goode,

2006, 2008), which could lead to the employment of heuristics that require especially few information from advisors. Importantly, our conclusions concerning the distinction between SPMs and MSMs are not invalidated by the observation that (some) participants employed an even more frugal decision strategy than the TTB heuristic. As long as this alternative decision strategy entails precise search, stopping, and decision rules and ignores strategy-irrelevant information, it can serve as an adequate substitute for the TTB heuristic for the purpose of our investigation.

## 5. General discussion

In multi-attribute decision making two frameworks coexist that make profoundly different assumptions about how people adapt to different environments. Empirical findings can often be explained very well by both frameworks. Previous attempts to distinguish between the two approaches have not yet satisfactorily shown which one of the frameworks is superior to the other.

We approached this question by introducing the novel information intrusion paradigm that builds on basic assumptions of the competing frameworks: Whereas MSMs propose that applicable information will be ignored when irrelevant for the chosen decision strategy, SPMs hold that any applicable information is relevant and will therefore influence a decision maker's behavior. In two experiments, information search and choice behavior followed SPMs' predictions—the strategy-irrelevant information intrusions were not ignored as their content influenced the decision makers' behavior in the direction predicted by the SPMs. In line with the SPM perspective, both effects were more pronounced when more information intruded. Experiment 1 additionally assessed memory performance, whereas Experiment 2 investigated confidence judgments instead. The findings for the latter are in line with SPMs' predictions as the content of the strategy-irrelevant information intrusions also influences confidence judgments in the predicted direction.

The uniformity of these findings speaks for the adequacy of the novel information intrusion paradigm to distinguish between the two frameworks of decision making. We believe that by concentrating on the basic assumptions of the two frameworks and thus contrasting the frameworks themselves rather than specific models that represent them, the current work appreciably contributes to the quest to distinguish between the two coexisting frameworks. Furthermore, the paradigm allows the assessment of a broad empirical basis that comprises search and choice behavior as well as confidence judgments. Thus, our conclusions rest on a considerable amount of diverse, but concordant findings.

A potential criticism from a MSM view could be that there was an environmental change from learning to test phase since, on average, the nature of the intruding information changed. This change might have led participants to question the initially learned decision strategy TTB and therefore caused the observed shift in the participants' behavior in the test phase. We believe this objection to be implausible for two reasons: (1) The payoff function did not change throughout the experiment, the performance feedback was identical, TTB was the strategy with the highest payoff in both learning and test phase (this is also true when compatible and incompatible test trials are considered separately) and the additional tasks (memory assessment in Experiment 1 and confidence judgment in Experiment 2) were also administered in both phases. Thus, we took all measures to design learning and test phase as similar to each other as possible. (2) During the learning phase TTB-irrelevant information intruded in 10% of all trials. Therefore, participants employing the TTB heuristic should have realized already in the learning phase that the intruding information can be either helpful or useless. Since there was no recognizable change in the task structure and appearance, no change in payoffs, and a consequent further reinforcement of using TTB, a strategy selection approach would certainly have to pull up ad hoc assumptions to explain the consistent behavioral effects observed here.

A related criticism of our conclusion might argue that we circumvented strategy selection in the first place by focusing on TTB. However, the MSM view assumes that a strategy is selected contingent on task and environmental demands, and our predictions concern processing after people have allegedly selected the TTB strategy. In fact, not all participants were classified as using TTB, so they apparently selected other strategies. However, the “top–down” conditions may still be criticized to cause a rather unnatural selection situation by providing an instruction how to use TTB. This criticism does not touch the “bottom–up” condition, however, in which only the environmental payoff led most people to select TTB in an adaptive manner (Bröder, 2003; Rieskamp & Otto, 2006). The pattern of results is identical if only this condition is analyzed (see Appendix). Hence, the conclusions also hold for a situation typically characterized by MSMs to involve strategy selection.

To summarize, our results are in line with the SPMs' assumption that any applicable information will be fed into an assumed single decision making mechanism. From the view of evidence accumulation models (e.g., Lee & Cummins, 2004), our results can be interpreted as follows: In the learning phase the evidence threshold is lowered until any discriminating cue reliably causes the overstepping of the threshold. Thus, information search and choice behavior are in line with TTB's predictions (e.g., Hausmann & Läge, 2008). In the test phase, TTB-incompatible information intrusions automatically will be fed into the mechanism and can therefore cause an undershooting of the threshold. As information search is only terminated when the threshold is reached, in these cases decision makers need to search for additional information before making a decision. Furthermore, in these cases they will not blindly follow TTB's decision rule, but integrate the searched (and intruded) information in their decision. Confidence judgments mirror the stopping point of the evidence accumulation in relation to the threshold: With additional compatible information, the decision maker is very confident with choosing the option favored by TTB, because the threshold is considerably overstepped. Incompatible information reduces evidence for and thus confidence in a choice in line with TTB's prediction.

Also another prominent class of SPMs, the connectionist models (e.g. PCS, Glöckner & Betsch, 2008a), can account for our findings although it has to be augmented with auxiliary assumptions to account for search behavior. For example, the PCS model (as well as other connectionist models, cf., Simon & Holyoak, 2002; Thagard & Millgram, 1995) precisely describes the process of information integration, but gives only a general idea of how the process of deliberate information search might interact with it. However, in line with Betsch (2005, p. 51), one can assume that “suboptimal outcomes of prior decisions” lead to a deliberate mode of decision making that entails a thorough consideration of what information is searched for and fed into the neural network. Thus, in the learning phase, decision makers can learn to calibrate their information search to the environment. Glöckner and Betsch (2008a, p. 222) further propose that “deliberate constructions” help to form and adjust the network. As this process is not fully specified, we can only assume that incompatible information intrusions might lead to such a low level of consistency (achieved after the automatic maximization process) that deliberate information search is initiated (Betsch & Glöckner, 2010; Glöckner & Betsch, 2008a). With regard to choice outcomes and confidence judgments, the predictions of the PCS model are precise and in line with our findings: When feeding incompatible information into the network, the activation of the TTB-option decreases and the alternatives' activation increases. Thus, the difference in activation is reduced, leading to lower confidence judgments when choosing the TTB-option (e.g., Glöckner, 2009; Jekel et al., 2010). If the activation of an alternative option exceeds the activation of the TTB-option, this alternative will be chosen and confidence judgments will mirror the absolute difference in activation between the TTB-option and the chosen alternative.

One might argue that our findings are also in line with MSMs. Of course, one can make the assumption that whenever information is for

free and applicable, it is not ignored. Instead, whenever this “irrelevant” information is incompatible with the option favored by the (bottom-up learned and sometimes additionally top-down induced) TTB heuristic, this successful decision strategy is abandoned in favor of a compensatory one. This interpretation would speak against findings that show routine effects in decision strategy use (c.f., Bröder & Schiffer, 2006; Rieskamp, 2006) and violate the standard assumption underlying most strategy classification methods (e.g., Bröder & Schiffer, 2003b; Glöckner, 2009; Payne et al., 1993) that the same strategy is employed throughout one experiment when the environment remains stable. Moreover, if one assumed a screening mechanism that checks for every trial whether an application of a strategy is worthwhile, and the application of this decision rule is changed contingent on this screening, the term “strategy” as an ordered set of processes to solve a task would hardly retain its meaning. Nevertheless, we cannot rule out this post hoc MSM interpretation on the basis of our results. But we can reflect on the parsimony of this interpretation.

A possible limitation of the approach used here is the focus on serial heuristics in the toolbox that are rather nested within an SPM view. For example, we have not considered similarity-based mechanisms as proposed, for instance, in exemplar models of decision making (e.g. Juslin, Olsson, & Olsson, 2003).<sup>6</sup> These models, however, currently do not specify search mechanisms, but they rely on similarity matches between whole cue patterns. Hence, the search data presented here are *prima facie* not compatible with assuming a similarity-based mechanism. In addition, empirical evidence seems to suggest that exemplar-based mechanisms in judgment are only used in restricted sets of situations (see Karlsson, Juslin, & Olsson, 2008, for an overview). It is an open question for future research whether the similarity mechanisms demonstrated in these situations can also be subsumed under an evidence accumulation perspective, for example by assuming that the internal decision criterion is switched to similarity when objective information is hard to encode (Platzer & Bröder, 2013). Furthermore, it might be possible to capture similarity mechanisms also in parallel constraint satisfaction approaches, which have been successfully applied as models for similarity based analogical reasoning (Holyoak & Thagard, 1989).

Both frameworks to multi-attribute decision making are metaphors that try to describe human behavior, and as Ebbinghaus (1885) elegantly put it, the only thing we know for sure about our metaphors is that they are ultimately wrong. Sometimes, competing metaphors are so flexible that they are able to account for any empirical finding (see the discussion on mental rotation, Shepard & Metzler, 1971; Pylyshyn, 1979, on persuasion, Kruglanski & Thompson, 1999; Manstead & van der Pligt, 1999, or, in decision making research, on the indistinguishability of exemplar memory and rule abstraction, Barsalou, 1990) and it becomes therefore impossible to empirically distinguish between them. Here, one should ask for the more elegant metaphor that can account for the variety of empirical findings with only a minimum of amendments. Thus, the parsimony of a metaphor must be taken into account. Even our highly consistent empirical findings, that are completely in line with the predictions a priori derived from SPMs' basic assumptions, can be explained by the MSM interpretation that participants adapt their decision strategy from each trial to the next. The more elegant explanation for the results presented here is given, however, by assuming a single uniform mechanism for decision making. Given, that contingent decision making can be “explained” equally well by assuming either a shift in decision strategies or an adjustment of decision thresholds (or a connectionist network), the parsimony consideration rather favors the SPM view.

To end with an amicable notion for researchers preferring the MSM metaphor and methodology, however, it must be acknowledged that their findings and interpretations are by no means invalidated by this conclusion. In fact, most of our own work would be questioned if we took such an extreme position! Rather, we suggest to scrutinize strategy

shift interpretations of former work for the possibility to reinterpret them as, for example, threshold shifts. We expect this to be possible in most instances.

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