12 Heuristics and biases: Beyond Tversky and Kahneman's (1974) judgment under uncertainty

Klaus Fiedler and Momme von Sydow
(University of Heidelberg, Germany)

BACKGROUND TO THE CLASSIC STUDY

Heuristics and biases from a historical perspective

It is no exaggeration to say that today's psychology would not be what it is without Daniel Kahneman's and Amos Tversky's seminal work on heuristics and biases, as summarised in a *Science* article (Tversky & Kahneman, 1974) that was cited over 7,000 times – an unbelievable rate for a psychology article. A few years before this work spread like wildfire. The rationalist metaphor of a computer-like human memory and the man-as-scientist analogy conveyed in theories of consistency (Abelson, 1968) and attribution (Jones, Kanouse, Kelley, Nisbett, Valins, & Weiner, 1987) had brought about the so-called cognitive revolution (Dember, 1974). However, this naïvely optimistic view on the human mind turned rapidly into deflating pessimism when statistical tools began to dominate research and theorising came under the dominating influence of Kahneman and Tversky's research programme.

In accordance with Gigerenzer's (1991a) 'tools-as-theories' notion, new methodological tools determined the manner in which the cognitive psychology of the late 1960s and early 1970s now characterised *homo sapiens*. Statistical models now afforded normative benchmarks, to which human judgments and decisions were compared. In this comparison, any deviation between the mind and the normative models had to be interpreted as a failure of the human mind to apply logical and rational rules of thinking and reasoning.

Unlike the old research programme of psychophysics, within which deviations of subjective experience (e.g., loudness) from physical stimulus intensity (e.g., sound pressure) would be hardly interpreted as irrational or dysfunctional, the new programme of psycho-statistics was clearly more judgmental. Deviations of subjective from objective probabilities, or subjective value judgments from objective

quantities were from the beginning interpreted as reflective of the pitfalls of a fallible and lazy mind (Nisbett & Ross, 1980). Whereas the objective criterion in psychophysics was nothing but a mundane physical quantity, the criterion in the new psycho-statistics approach was treated like normative truth.

DETAILED DESCRIPTION OF THE CLASSIC STUDY

Starting from the premise that the subjective assessment of most real quantities has to rely on incomplete data of limited validity, Tversky and Kahneman (1974) postulated that the mind has to resort to so-called heuristics, or rules-of-thumbs, that afford useful proxies most of the time. 'These heuristics are highly economical and usually effective, but they lead to systematic and predictable errors' in certain task situations (Tversky & Kahneman, 1974, p. 1131). Just like the perceptual illusions in Gestalt psychology, such as colour or size constancy, whose adaptive function was always recognised, the cognitive illusions of the new research programme might have been treated functionally, as useful adaptive devices that allow for accurate inferences under appropriate conditions. However, although Kahneman and Tversky themselves did point out the functional value of heuristic inference tools, the empirical research they triggered was almost totally concerned with biases and shortcomings of the human mind (Gilovich, Griffin, & Kahneman, 2002; Nisbett & Ross, 1980; Ross, 1977) rather than with the adaptive value or maybe even the superiority of heuristics over the theorist's 'narrow' normative models (Gigerenzer, 1996, 2006; Gigerenzer & Todd, 1999).

Synopsis of most prominent heuristics

Let us first illustrate this state of affairs with reference to the three most prominent heuristics – representativeness, availability, and anchoring – all expounded in

Table 12.1 Overview and illustrations of most prominent heuristics

Heuristic	Field of application	Illustration/Example
Availability	Memory-based judgments of frequency or probability	Overestimation of risks that are easily available in memory
Representativeness	Judgments of likelihood of instances belonging to a category	Birth order son-daughter-son-daughter more representative of random outcome than son-son-son-son
Anchoring and adjustment	Quantitative estimates on a unidimensional scale	Cost calculations biased towards starting value

the classical paper by Tversky & Kahneman (1974) and summarised in Table 12.1. The scientific impact and the insights gained from the Kahneman–Tversky research programme will then be discussed in the remainder of this chapter.

Representativeness (Kahneman & Tversky, 1972) was introduced as a heuristic for judging the probability that a stimulus sample belongs to a category. For instance, a stimulus sample or description, *D*, may describe a person named Linda as '31 years old, single, outspoken, and very bright, with a major in philosophy; has concerns about discrimination and social justice; and was involved in anti-nuclear demonstrations while a university student'. This person is judged to be more likely to belong to category '*A & B*' (Women who are active in the feminist movement and bank tellers) than to category '*B*' (Women who are bank tellers). But this often-replicated finding violates the conjunction rule, which says that the conjunction of two events (active feminist and bank teller) cannot be more probable than any of the two events alone (bank teller): $P(A \& B) \leq P(B)$. Yet, according to the representativeness heuristic, the description of Linda (*D*) is more representative of, or more similar to, the conjunction (*A* & *B*) than of the conjunct (*B*). This exemplifies a phenomenon that is commonly known as the conjunction fallacy (Tversky & Kahneman, 1983).

The representativeness heuristic, like some other theories of the conjunction fallacy (e.g., Fisk, 1996; Hertwig & Chase, 1998), involves the prediction of the so-called base-rate neglect. In medical judgments, for instance, having a pain in one's chest (representative of a heart attack) may suggest that one is probably having a heart attack, although – due to many other causes – the base rate of this symptom is relatively high and the probability of a heart attack may actually be lower than supposed.

Another feature of representativeness, besides base-rate neglect, is insensitivity to sample size. Thus, when asked to judge the number of days in a year on which more than 60% of all babies born are boys, most people erroneously believe that the rate of such abnormal days is approximately the same in a large (45 babies born each day) and in a small hospital (15 babies each day). However, while ≤60% is equally representative of the expected 50% in any hospital, outliers (>60%) occur at a higher rate in small than in large samples. Human judges are often insensitive to this law of the large number (Bernoulli, 1713).

The availability heuristic, too, serves to estimate absolute or relative probabilities or frequencies of events. Unlike representativeness, however, availability is a heuristic driven by a meta-cognitive cue. Judgments of the occurrence rate of a class of events *E* are supposed to reflect the ease with which examples of *E* can be retrieved from memory. To the extent that ease of retrieval is a valid cue for predicting frequency of occurrence – because, conversely, what is frequently encountered can also be easily retrieved – the availability heuristic should provide accurate estimates most of the time. However, whenever memory strength is biased towards other causal factors than original occurrence rate, judgments by availability can be misleading. In a frequently cited classical study, for instance, the frequency of words in the English dictionary with a 'k' as initial letter was erroneously judged to be

higher than the frequency of words with a 'k' in the third position (Tversky & Kahneman, 1973). Apparently, the first letter is easier to use as retrieval prompt than the third letter of a word.

Third, the anchoring-and-adjustment heuristic (Tversky & Kahneman, 1974) applies to all kinds of estimations on a specified quantitative dimension. As a starting point for such cognitive estimation processes, judges often use an initial anchor, which is then adjusted in the light of further information stemming from memory or from external sources. This adjustment process is typically insufficient so that final judgments tend to be biased towards the initial anchor. That is, depending on whether the process starts with a low or high anchor, the final judgments tend to be under- or overestimations, respectively. In the planning fallacy (Buehler, Griffin, & Peetz, 2010), for instance, the time required for a project is underestimated when the calculation starts from a low anchor (or zero time). An alternative calculation that starts from a high anchor of maximal time required for comparable projects would arrive at much higher estimates. Most impressive experimental demonstrations refer to the impact of completely irrelevant numerical anchors without any diagnostic value for the quantity to be judged. For instance, judgments of the number of African countries in the United Nations were influenced by starting values established randomly by a roulette wheel.

IMPACT OF THE CLASSIC STUDY

Heuristics and biases in cognitive, social, and applied psychology

As already mentioned, the impact of this research on the development of cognitive, social, and applied psychology was immense. Nowadays, textbooks and curricula in behavioural science are unimaginable without sizeable parts devoted to heuristics and biases. Modern research on judgment and decision making, cognitive psychology, and in social cognitive psychology still relies heavily on Kahneman and Tversky's work, referring to representativeness when explaining stereotypes and causal attributions, to availability when explaining the overestimation of salient risks (Combs & Slovic, 1979) and egocentric overestimations of one's own contributions (Ross & Sicoly, 1979), and to anchoring when explaining biased cost estimations (Buehler et al., 2010) or courtroom decisions (Englich & Mussweiler, 2001). The notion of heuristics has become common sense shared by students of many other disciplines, medical scientists, journalists, practitioners, and even politicians. And last not least, heuristically biased assessments of probability and utility had a strong impact on prospect theory (Kahneman & Tversky, 1979) – the most prominent decision theory in economics and for which Daniel Kahneman, after Amos Tversky's death, received the 2002 Nobel Prize in economics. Prospect theory predicts risk-aversive behaviour when decisions are framed in terms of possible gains but risk-seeking when decisions are framed in terms of losses (cf. Chapter 13 on Prospect Theory).

CRITIQUE OF THE CLASSIC STUDY

Nevertheless, despite the overwhelming acceptance and applause for Kahneman and Tversky's heuristic approach to understanding cognitive illusions, the industrious research it elicited was also met with scepticism and serious critique. Several theorists were concerned with the inherently negative lessons gained from research designs that guarantee deviations from normative models that will inevitably be attributed to insufficiencies of the human mind. Krueger and Funder (2004) pointed out that allegedly irrational judgments and decisions can often be re-interpreted in terms of reasonable assumptions about the task and the problem setting. Others (e.g., Lopes & Oden, 1991) have argued that content-blind normative models are often inappropriate and unjustified as benchmarks of rationality.

However, nobody has pronounced the critique as forcefully as Gigerenzer (1991b, 1996). His dissatisfaction is summarised in the following quotation:

> The heuristics in the heuristics-and-biases program are too vague to count as explanations. They are labels with the virtue of Rorschach inkblots: A researcher can read into them what he or she wishes. The reluctance to specify precise and falsifiable process models, to clarify the antecedent conditions that elicit various heuristics, and to work out the relationship between heuristics have been repeatedly pointed out. (Gigerenzer, 1996, pp. 593–594)

Gigerenzer disqualified one-word-labels like 'representativeness' as theory surrogates that fail to place any testable constraints on the cognitive decision process. A similar point was made by Wolford (1991).

To understand this critical appraisal and why it is presumably justified, let us consider some of the most prominent heuristic explanations. For instance, in an often-cited article on biases in risk assessment (Combs & Slovic, 1979), the overestimation of some causes of death (e.g., murder, lightning) and the underestimation of others (suicide, coronary disease) is confidently attributed to the availability heuristic. Because murder and lightning are readily reported in the media, whereas suicide and coronary disease are rarely reported, it is argued that the former are easier to recall than the latter. However, ease of recall is neither measured nor manipulated directly. Moreover, the very explanation in terms of media coverage suggests an external cause, biased media report, which has to be distinguished from the internal cause of biased memory judgment that is the focus of an availability-heuristic account. Granting fully unbiased and comparable recall of all causes of death, the unequal media coverage provides an alternative sampling account that is essentially different from availability.

In another prominent application, the availability heuristic has been used to explain the so-called egocentric bias (Ross & Sicoly, 1979), that is, the belief that oneself has contributed more than partners or other people to joint activities (e.g., in partnerships or work groups). This phenomenon has been ascribed to enhanced memory of one's own deeds relative to other people's deeds. However, this interpretation is exclusively based on correlational evidence; ease of recalling one's own

and other's activities was not manipulated experimentally. The correlation may be simply due to self-consistency; frequency judgments may be attuned to match the recall output, or recall efforts may be adjusted to justify frequency judgments.

The lack of cogent evidence for the underlying cognitive process also characterises the empirical research on the anchoring heuristic. Hardly any research has ever attempted to demonstrate a gradual process of insufficient adjustment of an initial anchor value. Thus, when participants whose last four digits in their social security number was higher also accepted higher selling prices (Chapman & Johnson, 1999), this may simply reflect the impact of numerical priming on the elicitation of a response on a numerical judgment scale (Oppenheimer, LeBoeuf, & Brewer, 2008). It need not be the result of an updating or adjustment process that remains incomplete, due to premature truncation. Epley and Gilovich's (2006, 2010) conclusion that anchoring effects may originate in a variety of different cognitive process is tantamount to giving up the specific process suggested in the heuristic's original account. To be sure, countless experiments testify to the ability of preceding stimuli to affect subsequent judgments. While such ordinary priming effects may be renamed as different types of anchoring effect, they hardly support the mechanism suggested originally by Tversky and Kahneman (1974) and adopted uncritically by behavioural scientists.

In one experiment designed to test the continuous adjustment assumption, Fiedler, Schmid, Kurzenhaeuser, and Schroeter (2000) drew on the notion of anchoring in lie detection (Zuckerman, Koestner, Colella, & Alton, 1984). When a series of communications is judged on two tasks supposed to induce cooperation (do you understand the message?) and suspicion (could it be a lie?), the communications appear less truthful when the suspicious task that precedes the cooperative task sets a negative anchor. Using a mouse-tracking technique to assess online changes in the subjective believability of a video-taped communication presented on the computer, Fiedler et al. (2000) did not find evidence for an insufficiently adjusted initial bias to either trust or distrust the communicator. Rather, the mouse coordinates started in a middling position and then became more polarised as the communication unfolded, thus reflecting a longitudinal process opposite to the insufficient depolarisation process suggested in the anchoring heuristic.

Last but not least, the failure to establish anchoring as a unique cognitive mechanism is apparent in the co-existence of two completely different theoretical accounts, numerical priming and selective accessibility. Whereas the numerical-priming account predicts that even fully irrelevant numerical primes can influence judgments, the selective-accessibility account (Strack & Mussweiler, 1997) is restricted to the impact of anchors that are relevant to activating knowledge that is relevant to the contents of the judgment task. Note that both accounts not only refer to completely independent process stages – the early stage of knowledge activation and the late stage of transforming a judgment onto a numerical scale. Both processes also diverge from the original account of an insufficient adjustment process. This equivocal state of affairs seems to corroborate Gigerenzer's (1996) fundamental critique that there is little evidence for these heuristics as distinct cognitive processes that might afford precise algorithmic explanations of distinct judgment biases.

Heuristics in the post-Kahneman–Tversky era

The adaptive toolbox. What were the reactions to these complaints, and the new development, in what might be called the post-Kahneman–Tversky era? To be sure, Gigerenzer and his co-workers came up with their own theoretical conception, for which they coined the metaphor of a 'heuristic toolbox'. Each tool in this toolbox is described as a fast and frugal heuristic that requires little information to make people (or animals) smart if applied in the appropriate moment and environment. For instance, the Take-the-Best heuristic (Gigerenzer & Goldstein, 1996), which only uses the one ecologically most valid cue to make a prediction or choice, is only applicable in task settings in which one cue is clearly the most valid. In contrast, tallying (i.e., giving the same weight to many different cues) is appropriate when there are many similarly valid cues.

Related to the Take-the-Best is the recognition heuristic (RH) (Goldstein & Gigerenzer, 2002; see also Pachur, Todd, Gigerenzer, Schooler, & Goldstein, 2011), which is ideally suited to illustrate how the adaptive toolbox functions. RH has a clearly defined domain and decision rule. When exposed to a pair of options in a choice task (e.g., Which one of two towns is larger? Which of two shares should be purchased?), the RH first assesses the value of the two options on the recognition cue (i.e., whether it is recognised as experienced before or not). If the recognition cue discriminates between the two options (i.e., if one is recognised but one is not), RH will choose the familiar option. Since heuristics are applied as adaptive or domain-specific tools, the recognition heuristic should only apply if recognition is highly correlated with the criterion value (as in the city example). In this case, however, no further information should be considered (non-compensatory one-reason decision making) (cf. Pohl, 2011). If the recognition cue does not discriminate, however, another heuristic must be applied (e.g., the fluency heuristic that is sensitive to the frequency of prior exposure), or a decision must be based on random guessing (cf. Hilbig, Erdfelder, & Pohl, 2010). As the ecological validity of the recognition cue is amazingly high (Goldstein & Gigerenzer, 2002) – recognised shares are typically more successful than unrecognised ones – this primitive decision rule leads to a high rate of correct decisions in many task settings. Moreover, the RH can explain why less can be more, that is, why laypeople who only rely on a feeling of familiarity due to recognition can sometimes outperform more knowledgeable judges, who try to utilise more cues at the same time and who thereby capitalise on chance (i.e., give unwarranted weight to invalid cues).

Note that unlike the classical heuristics of the original Kahneman–Tversky programme, the heuristics from the adaptive toolbox are based on clearly spelled-out algorithms. Many constitute lexicographic strategies that rely on a single cue rather than trade-offs between multiple, mutually compensatory cues. Note also that the heuristics of the adaptive toolbox are supposed to render people smart in terms of Simon's (1982) criterion of bounded rationality, rather than being illusory and indicative of cognitive illusions and shortcomings.

However, despite the more transparent algorithms used for simulation studies of this new heuristic research programme (Gigerenzer & Todd, 1999), cogent

experimental evidence that human participants' cognitive processes generally follow these specific algorithms remains scarce (Hilbig, 2010; Pohl, 2011). On the one hand, little is known about how the subjective discrimination between recognised and unrecognised options is accomplished. Maybe the seemingly unique recognition cue is itself inferred from a more complex repertoire of other (vicarious) cues. In a similar vein, it is unclear how humans and animals can diagnose the validity of different cues and how they select the cues to be utilised for an inference problem in the first place.

On the other hand, a few experimental tests of specific heuristics suggest that they may not describe the cognitive reality. For example, the so-called priority heuristic assumes that choices between pairs of lotteries involve a three-stage process: (1) choosing the option with the higher minimal outcome if the minimal outcomes are different enough; (2) choosing the option with the higher winning probability if probabilities are different enough; or else (3) choosing the option with the higher maximal outcome. The implications of this algorithm that probabilities only matter when minimal values do not strongly differ and that maximal values only matter if probabilities are similar were recently found to be disconfirmed (Fiedler, 2010).

Dual-process approaches

While the adaptive toolbox approach arose from a fundamental critique of the old heuristics-and-biases programme, the abundance of dual-process approaches starting in the 1980s can be understood as attempts to reconcile the notion of fallible heuristics with the possibility of accurate and rational information processing (Chaiken & Trope, 1999). Despite the notable differences between the almost 30 dual-process theories proposed, for example, by Petty and Cacioppo (1986), Sloman (1996), Evans (2003) or, more recently, by Stanovich & West (2002), Strack and Deutsch (2004), and Kahneman and Frederick (2005), they all converge in assuming two fundamentally different modes of information processing. Only one of these processing modes is supposed to be prone to heuristic shortcuts and intuitive strategies, whereas the other mode is supposed to use systematic and exhaustive strategies deemed to produce normative results under many conditions. Because the moderator conditions that can evoke one or the other mode are manifold, these dual-process theories offer an account for virtually all judgments that disconfirm some heuristic. For example, if judges do not fall prey to the conjunction fallacy, do not ignore base rates and sample sizes, or if they are not misled by an anchor, one only has to assume that the secondary system has been invoked, which enables unbiased thinking.

Given that thousands of empirical studies and hundreds of scientific careers are grounded on dual-process approaches, it would be justified to praise them as extremely fertile and successful (cf. Smith & DeCoster, 2000). However, they have also been the target of harsh critique (Keren & Schul, 2009; Kruglanski & Thompson, 1999; Osman, 2004), raising the question whether they have delayed

rather than supported progress in research on judgment and decision making. What renders dual-process theories unrealistic and scientifically weak is that the two systems are presumed to differ in too many attributes at the same time. One system is supposed to involve automatic associative processes, relying on heuristics and intuition, little capacity constraints and low effort expenditure, no conscious awareness, and no meta-cognitive control. The other system, in contrast, is allegedly based on reflective propositional operations, adhering to rule-based and exhaustive processing demanding high cognitive capacity and effort expenditure, conscious awareness, and meta-cognitive monitoring and control. The assumption that all these attributes are perfectly or highly correlated is far from being confirmed empirically. On the contrary, there is ample evidence to show that even effortful, persistent, and highly conscious and controlled attempts to solve logical problems can produce strong biases (Fiedler, 2008; Le Mens & Denrell, 2011) of the same type as the classical heuristics (e.g., conjunction fallacies, sample-size neglect, or anchoring effects). Conversely, even intuitive, low-effort inferences from single cues and incomplete samples can lead to accurate and logically coherent mental structures (Dijksterhuis & Nordgren, 2006). Whereas some prominent biases are associated with low cognitive ability, others are not (cf. Stanovich & West, 2008).

CONCLUSIONS

Appraisal of 40 years of research on heuristics and biases

So what can we conclude from this sketch of the heuristics and biases programme and its impact on subsequent behavioural research across four decades? We believe that a fair and appropriate answer has to be split into two radically different conclusions. One conclusion is, frankly speaking, disillusioning whereas the other one is enthusiastic.

Theory development. On the one hand, what is disillusioning and disappointing is how little precision, refinement, and progress was obtained at the theoretical level. Very few cleverly designed experiments were conducted that might have provided cogent evidence for the causal dependence of specific judgment biases – like base-rate neglect, conjunction fallacies, or anchoring effects – on the mechanisms depicted in the classical heuristics. The 'judgment of Solomon' that the same biases can originate in many processes (Epley & Gilovich, 2010) amounts to giving up the explanatory value of the original heuristics. A few serious attempts to test heuristics precisely, according to the standards of modern cognitive science, ruthlessly uncover this frustrating state of affairs.

Considering representativeness, Kahneman and Frederick (2002, 2005) have specified a two-step process of a prototype heuristic, in which a category (e.g., 'bank teller') is represented by a prototypical exemplar, and a second process in which 'a (non-extensional) property of the prototype is then used as a heuristic attribute to evaluate an extensional target attribute'. This does go beyond a 'one-word' heuristic.

Still, Nilsson, Olsson, and Juslin's (2005) attempt to investigate the cognitive substrate of the representativeness heuristic had to start from complete uncertainty about what similarity function is used in the representativeness heuristic, whether categories are indeed represented as prototypes or as lists of exemplars, or what metric is used to compare several categories' representativeness. Empirical and theoretical research at the level of sober cognitive research turns out to be hardly available. As long as no comprehensive theory can predict what bias reflects what process under what condition, the theoretical status of a heuristic is little more than a plausible verbal label for a set of seemingly related findings. Maybe the most conspicuous sign of theoretical vacuum is the lack of debates relating the heuristics-and-biases idea to a growing list of demonstrations of biases emerging from non-heuristic processes (Fiedler, 2008; Le Mens & Denrell, 2011).

At the level of applied psychology, too, the lack of clearly spelt-out theories and the failure to specify heuristics as algorithms have prevented systematic attempts to evaluate the costs and benefits of heuristics relative to other strategies supposed to be non-heuristic – whatever this negation might refer to. As a consequence, researchers and practitioners are free to point out either the fallibility and danger or the intuitive wisdom and low opportunity costs of heuristics in such domains as medical diagnosis, investment, consumer choices, risk control, personnel selection, law, and politics. Whereas clearly explicated decision tools, such as signal-detection analysis (Swets, Dawes, & Monahan, 2000) or lexicographic algorithms (Martignon, Katsikopoulos, & Woike, 2008), have been shown to support accurate judgments and decisions in health, law, and other areas of risk assessment, the classical heuristics have been hardly implemented practically.

Inspiration and fertilisation. On the other hand, however, in spite of the stagnation of strict and precise theorising, the fertility and the fascinating impact that Kahneman and Tversky's work had on contemporary research can be hardly overstated. It may be typical of the growth of science that the impact of a theoretical idea can be detached from the ultimate validity of the original idea itself. Like Wittgenstein's metaphor of a ladder that is no longer needed when one has climbed up a wall, the enormous, almost immeasurable fertilisation and inspiration that grew out of Kahneman and Tversky's work is detached from any empirical test of representativeness, availability, and anchoring. Whoever witnessed the verve and excitement that spread like wild fire among scientists exposed to these authors' disarming demonstrations will probably agree that the impact was gigantic. Psychologists recognised a new research potential that would afford motivation and orientation for many young scientists and a challenging new programme of rationality research. This programme entails a significant task for behavioural scientists to educate the public, journalists, politicians, and professionals in a genuinely behavioural domain: (ir)rational judgment and decision making.

Indeed, the message that not only lay people but also professionals and highly educated experts fall prey to cognitive biases and illusions has become an integral part of intellectual culture and common sense. It is included in curricula for graduate students, undergraduates and even high school students, magazines, popular books, radio and TV programmes, and countless internet sites. The

number of references to 'heuristics' found in the PsychInfo data bank amounts to almost 10,000. The readiness with which the notion was adopted in multiple areas of research is evident from the number of references obtained for 'heuristic' AND 'health' (1,452), 'clinical' (1,081), 'medical' (607), 'risk' (595), 'consumer' (391), 'economic' (444), 'organizational' (632), and 'law' (289), to list but a few prominent areas.

Nevertheless, this success story reflects a dialectical rather than a confirmatory process. Pertinent research has flourished not because the original thesis received strong support, but because the provocative demonstration of biases and shortcomings instigated a flood of loosely related studies leading to various anti-theses and sub-theses. Gigerenzer and colleagues' (Gigerenzer & Todd, 1999) adaptive toolbox was antithetical, but was nevertheless motivated by the work of Kahneman and Tversky. The state of the art in current research on cognitive illusions is often detached from, or even inconsistent with, the original heuristic accounts, which have nevertheless inspired the whole research programme.

For instance, research on the conjunction fallacy has led to different potential causes like misunderstanding of logical terms (Hertwig, Benz, & Krauss, 2008) and representation format effects (Hertwig & Chase, 1998). Moreover, it has been argued that standard probability judgments may actually be replaced by averaged probabilities (Jenny, Rieskamp, & Nilsson, 2014), inverse probability judgments (Fisk & Slattery, 2005), pattern probability judgments (von Sydow, 2011), or support judgments (Tentori, Crupi, & Russo, 2013). Presumably the conjunction fallacy is caused by more than one process. In any case, great progress in modern research (e.g., Tentori et al., 2013) no longer relies on representativeness, but is nevertheless influenced by the old heuristic idea.

Likewise, research on anchoring effects is detached from the old anchoring heuristic but has led to many new insights about biased planning calculation (Buehler et al., 2010), legal judgments (Englich & Mussweiler, 2001), prices obtained in auctions (Ritov, 1996), nuclear war risks (Plous, 1989), or social comparisons (Mussweiler, 2003).

In a similar vein, new developments in research on meta-cognition, dealing with fluency and ease of retrieval (Unkelbach & Greifeneder, 2013; Winkielman, Schwarz, & Belli, 1998) as determinants of liking and attitudes, grew out of the availability heuristic, which appears to be obsolete as a testable cognitive process assumption.

Apart from the impact of specific heuristics, the resulting research programme as a whole contributed to several exciting new developments, such as the collaboration between psychologists and economists in rationality research, the new role of behavioural scientists as consultants for politicians and administrative decision makers, and new lines of health education (Gigerenzer, Gaissmaier, Kurz-Milcke, Schwartz & Woloshin, 2007; Swets et al., 2000). Resistance to the pessimistic image of a heuristic mind has led to novel theorising about the appropriateness of normative models (Krueger & Funder, 2004). And last but not least, the dissatisfaction with the restricted focus on heuristic processes within the individual's mind has led to a new cognitive-ecological framework, within which biases can be

shown to arise in the absence of biased cognitive processes, merely as a side-effect of information sampling in a complex world (Denrell & Le Mens, 2007; Fiedler & Juslin, 2006).

CONCLUDING REMARK

Provided the present perspective on heuristics-and-biases research is not fully inappropriate, the main conclusion is that the huge impact of Kahneman and Tversky's work is not due to the accrual of confirmatory evidence, but, ironically, to its imperfectness and the persistent failure to clearly define and thus perhaps to falsify and discard the original heuristics. Considered from a distance, this may not be too unusual a state of affairs in the history of scientific discovery (Kuhn, 1962). Still, the accumulated empirical evidence on biases in judgments and decisions is impressive, and many incidental side-effects of this research industry are of practical and theoretical value.

Notwithstanding all empirical results, though, the apparent deficits at the theoretical level must not be overlooked but must be tackled as a challenge for future research. The most difficult and ambitious goal for future behavioural science is not so much to enhance empirical output but to develop theoretical frameworks that allow for critical tests of existing data as well as for the theory-driven refinement of raw hypotheses to be tested in cleverly designed studies. However, this situation – characterised by theory lagging behind empirical evidence – may not be peculiar to heuristics and biases but rather typical of current behavioural science.

Author note: Work on the present paper was supported by a Koselleck grant by the Deutsche Forschungsgemeinschaft to Klaus Fiedler (Fi 294/23-1) and by a DFG grant to Momme von Sydow (Sy 111/2-1, within the priority programme New Frameworks of Rationality, SPP 1516). Valuable comments on this chapter by Mandy Hütter are gratefully acknowledged. Correspondence may be sent via electronic mail to kf@psychologie.uni-heidelberg.de

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