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Debiasing Health-Related Judgments and Decision Making: A Systematic Review

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Abstract

Background. Being confronted with uncertainty in the context of health-related judgments and decision making can give rise to the occurrence of systematic biases. These biases may detrimentally affect lay persons and health experts alike. Debiasing aims at mitigating these negative effects by eliminating or reducing the biases. However, little is known about its effectiveness. This study seeks to systematically review the research on health-related debiasing to identify new opportunities and challenges for successful debiasing strategies. **Methods.** A systematic search resulted in 2748 abstracts eligible for screening. Sixty-eight articles reporting 87 relevant studies met the predefined inclusion criteria and were categorized and analyzed with regard to content and quality. All steps were undertaken independently by 2 reviewers, and inconsistencies were resolved through discussion. **Results.** The majority of debiasing interventions ($n = 60$) was at least partially successful. Optimistic biases ($n = 25$), framing effects ($n = 14$), and base rate neglects ($n = 10$) were the main targets of debiasing efforts. Cognitive strategies ($n = 36$) such as "consider-the-opposite" and technological interventions ($n = 33$) such as visual aids were mainly tested. Thirteen studies aimed at debiasing health care professionals' judgments, while 74 interventions addressed the general population. Studies' methodological quality ranged from 26.2% to 92.9%, with an average rating of 68.7%. **Discussion.** In the past, the usefulness of debiasing was often debated. Yet most of the interventions reviewed here are found to be effective, pointing to the utility of debiasing in the health context. In particular, technological strategies offer a novel opportunity to pursue large-scale debiasing outside the laboratory. The need to strengthen the transfer of debiasing interventions to real-life settings and a lack of conceptual rigor are identified as the main challenges requiring further research.

Keywords
biases, debiasing, decision making, judgment, systematic review

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When being confronted with uncertainty, people tend to apply heuristic principles.[1,2] These "cognitive shortcuts"[3] are useful tools for "fast and frugal" decision making as they "employ a minimum of time, knowledge, and computation to make adaptive choices in real environments."[4p 14] Despite their usual efficiency, heuristics have also been found to give rise to the occurrence of systematic biases, meaning that they can result in predictable errors in thinking.[1,5] These can lead to a deviation from the normatively expected judgment with potentially negative effects on the decision outcome.[1,6–8] A plethora of different biases has been identified in the literature,[9–12] including those relating to medical decision making.[13] Systematic biases can impair the judgment of the general population and health care professionals alike, with occasionally severe consequences for the people affected by the decision.[13]

When biases have unwanted effects on people's judgments and decisions (i.e., decision makers would prefer not be affected by the bias if they were aware of it),[14] debiasing becomes relevant.[6] It aims at inhibiting the detrimental effects by eliminating or mitigating the bias to

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improve the information processing and its subsequent outcome.[11,15]

The attempt to develop specific strategies to counter particular biases has led to a considerable fragmentation of the research field, leaving doubts about the worth and necessity of debiasing.[9,10,16–18] The criticism is mainly rooted in the absence of longitudinal effects,[11,16,19] a neglect of the existing evidence base,[16] and a lack of ecological validity since most debiasing research has been conducted in a controlled laboratory setting.[9,16,18] A further critique is the missing theoretical coherence[11] and the use of vague labels instead of precise definitions, with the latter aspect referring to debiasing and the heuristics and biases program alike.[16,20]

In an effort to overcome the fragmentation of the field, various classification schemes have been proposed that offer a framework for the categorization of debiasing strategies.[6,9,10,14,15,18] Larrick,[10] for instance, suggested a distinction between motivational, cognitive, and technological strategies. These categories are based on the different approaches one can adopt to approximate the normative ideal of reasoning.[10] The assumption underlying motivational strategies is that people are able to apply normative reasoning and that they will make use of it if they are motivated enough to do so.[10] Motivation can, for instance, be increased by holding people accountable for their decisions or offering incentives.[10] In contrast, cognitive and technological strategies rely on the presumption that "intuitive strategies are imperfect" and that people need to substitute them for strategies nearing normative standards.[10] While cognitive strategies reduce biases by prescribing feasible, often context-specific rules such as "consider-the-opposite" or educational trainings, technological strategies use "techniques external to the decision maker" to approach normative reasoning.[10] Technological strategies may be further differentiated into the use of computer-based applications such as decision support systems or a restructuring of the presented information, as is the case with decision aids that present risks and benefits of options in a balanced manner to facilitate decisions consistent with patients' values and preferences.[10,21]

Although the development of taxonomies enables the building of less comprehensive "midrange theories,"[22] which precede the formulation of universal theories and can be a first step to address the issue of theoretical incoherence,[18,22] a majority of health-related debiasing studies do not refer to them.[23–26] Moreover, it is still unclear what constitutes a successful debiasing strategy and whether the evidence points to a balance between the costs and benefits of debiasing efforts.[17] While there are several reviews on diagnostic errors and their cognitive remedies,[5,27–29] no such overview is available for the general health context and a broader spectrum of debasing interventions also including technological or motivational strategies.

At the same time, there appears to be a revival of the debiasing discussion[5,17,27,28] with a significant amount of primary research on health-related debiasing currently emerging.[24,30–33] If debiasing research wants to substantiate its claim to contribute to the improvement of health-related decision making,[16] conducting research in a "one-shot" manner[22] is, however, not enough. Instead, a more systematic approach that builds on previous research and addresses the prevailing criticism is needed. Accordingly, the purpose of the present systematic review is to address the field's fragmentation by systematically synthesizing, categorizing, and analyzing the existing debiasing research in the health domain. This will allow for conclusions about the actual effectiveness of health-related debiasing and lead to the identification of opportunities and challenges for the development of future debiasing interventions targeting both the general population and health care professionals.

Methods

Research Protocol and Systematic Search

A research protocol detailing the study's components was developed by the authors and reviewed by an external expert of judgment and decision-making research prior to conducting the systematic review. We performed a systematic literature search in 14 electronic databases: Academic Search Complete, CINAHL, Communication and Mass Media Complete, PsycARTICLES, PsycInfo, Psychology and Behavioral Sciences Collection, SocINDEX with Fulltext, Annual Reviews, CENTRAL (via Cochrane Library), Google Scholar, ISI Web of Knowledge, PubMed (including Medline), Science Direct, and Scopus. This search was complemented by a

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hand search of bibliographies of included studies. To achieve a comprehensive overview of the field, gray literature, such as dissertations and conference papers, were also included.

The search string comprised 3 elements of interest, namely, the 1) debiasing of 2) judgments and decision making in the 3) health context, and was adapted to the respective databases. PsycArticles was, for example, searched using the search string (debiasing OR "cognitive bias modification" OR "reduce cognitive bias" OR "reverse cognitive bias") AND ("risk communication" OR "risk perception" OR decision-making OR judgment OR judgement) AND (medicine OR medical OR health*). Studies were considered if published until 6 October 2016. No other time restrictions were applied.

Inclusion and Exclusion Criteria

To be included, studies had to investigate the effects of a debiasing intervention in the context of judgment and decision making. Studies that pursued an improvement of performance in a broader sense, and therefore only implicitly touching upon possible biases while focusing on different theoretical concepts, were not included. Further, studies had to be conducted in a medical context, thus reflecting "decisions made in a clinical setting by either patients or medical personnel"[13] or a general health context representing judgments and decisions made in the broader area of health promotion and disease prevention. Third, only primary studies with a (quasi-)experimental design were included. Studies from the field of clinical psychology that are associated with psychological dysfunctions were excluded from the review.[27]

Data Collection and Analysis

The systematic search was conducted by the first author. Duplicates were removed, and all titles and abstracts were screened for eligibility by 2 reviewers. If studies met the inclusion criteria or if a decision could not be made based on the abstract, full texts were obtained.

Relevant data were extracted from all eligible papers. To systematically categorize the debiasing strategies, we used an adapted version of Larrick's[10] taxonomy (see Supplementary Appendix 1). We deemed Larrick's categorization scheme[10] the most suitable for our purposes as it can be applied to any type of decision context. It further provides selective categories that directly refer to interventions aimed at improving people's judgments and decision making as opposed to taxonomies that mainly focus on the biases themselves and are therefore narrower in nature. Since we realized during the coding process that Larrick's categories do not capture debiasing strategies that aim to correct a biased risk perception by eliciting emotional states within the decision maker, we added a fourth category called "affective strategies" following inductive reasoning.

The studies' quality was assessed using the QATSDD tool[34] providing a checklist with 14 criteria for quantitative studies that can each be awarded a score from 0 to 3. The tool considers aspects such as the explicitness of the theoretical background, the data collection process, or a fit between hypotheses and applied statistical analyses.

Results

The systematic search resulted in 2748 papers to be screened, of which 68 articles comprising 87 relevant studies were included in the review (Figure 1; an additional search requested by *Medical Decision Making* included the term "diagnos*" and led to a screening of 1093 titles and abstracts and 6 additional full texts. As none of these studies met the inclusion criteria, the flow diagram of the initial search is presented.) The results show a continual increase in research output over time (this rise may partially be related to an overall increase of research output during the past decades; Figure 2). This includes 62 peer-reviewed journal articles, 5 dissertations, and 1 conference full paper.

Methodological Quality

Methodological quality of the 68 articles ranged from 26.2% to 92.9%, with an average rating of 68.7%. The quality appraisal identified an insufficient indication of sample size considerations ($n = 59$), a lack of statistical assessment of reliability and validity of measurement tools ($n = 48$), and missing evidence for pilot testing or user involvement in the study design ($n = 46$) as the most prominent methodological weaknesses.

Sample Population

The sample sizes ranged from 12 to 2012 participants ($\bar{x} = 289.4$, $s = 366.3$). Most studies (85.1%, $n = 74$) focused on debiasing within the general population, while only a minority of studies (14.9%, $n = 13$) investigated possibilities to overcome biases of health care professionals. Students made up most participants in both target groups: in 46 of the 74 studies addressing lay people (62.2%) and in 10 of the 13 studies targeting health care professionals ((ie, the targeted health care professionals

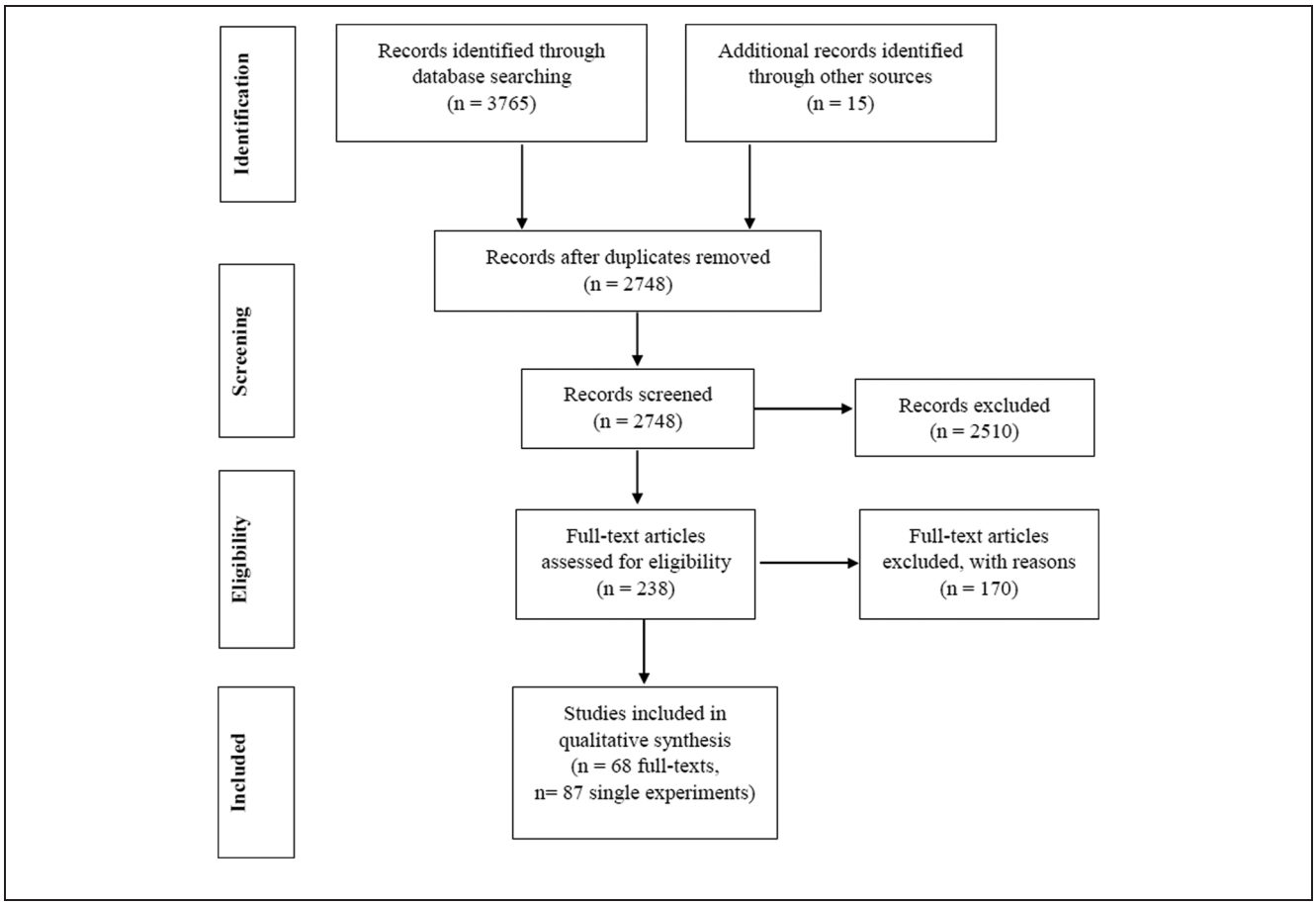

Figure 1 Flow diagram of the study selection process, adapted from Moher, Liberati, Tetzlaff, Altman, and The Prisma Group (2009).[63]

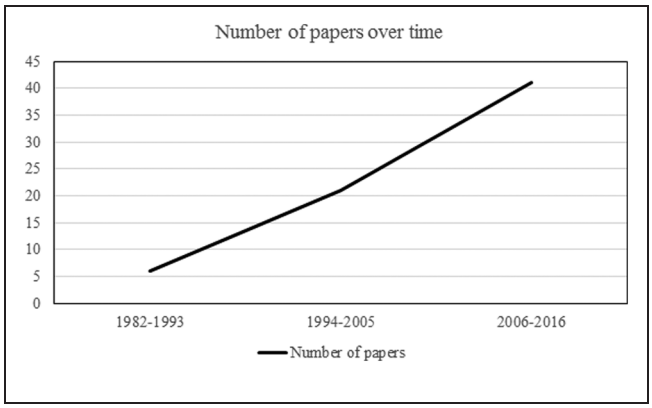

Figure 2 Number of papers (n = 68) examining debiasing in the health context from 1982–2016.

were still in training as opposed to independently practicing psychologists or physicians; 76.9%), they represented at least part of the sample. (The participants of 3 studies were coded as "young adults unspecified" as the authors did not provide any further background about their sample except from the age range.)[30,35]

Fifty-four (62.1%) experiments explicitly reported the random assignment of participants to experimental and control groups. Fourteen studies (16.1%) applied a quasi-experimental design (e.g., making comparisons between separate interventions and different participant populations). For 19 (21.8%) studies, it could not clearly be determined whether a random allocation of participants took place, as the respective reporting of information was incomplete.

Addressed Biases

The majority of studies (n = 75) aimed to eliminate or reduce one type of bias (see Table 1 for a definition of included biases). Eight studies sought to mitigate 2 different biases, 3 studies tackled 4 types of biases, and the

Table 1 Overview and Explanation of Mainly Addressed Biases

Biases according to Their Coding	Definition
Framing effect	"The psychological principles that govern the perception of decision problems and the evaluation of probabilities and outcomes produce predictable shifts of preference when the same problem is framed in different ways."[55p 453]
Optimistic bias	"According to popular belief, people tend to think they are invulnerable. They expect others to be victims of misfortune, not themselves. Such ideas imply not merely a hopeful outlook on life, but an error in judgment that can be labelled unrealistic optimism."[56p 806]
Base rate neglect (also denominator neglect and pseudo diagnostic reasoning)	". . . refers to people's tendency to pay too much attention to numerators in ratios (i.e., the number of times a target event has happened) and insufficient attention to denominators (i.e., the overall opportunities for it to happen)."[57p 391]
Hindsight bias	". . . reporting an outcome produces an unjustified increase in its perceived predictability, for it seems to have appeared more likely than it actually was."[58p 288]
Overconfidence	". . . an individual's overvaluation of her or his own skills, knowledge, or judgment."[59p 498]
Anchoring bias	". . . people make estimates by starting from an initial value that is adjusted to yield the final answer. The initial value, or starting point, may be suggested by the formulation of the problem, or it may be the result of a partial computation."[2p 14]
Availability bias	". . . situations in which people assess the frequency of a class or the probability of an event by the ease with which instances or occurrences can be brought to mind."[2p 11]
Confirmation bias (includes related biases such as positive hypothesis testing, search satisficing, premature closure)	". . . tendency to perceive more support for [one's prior] beliefs than actually exists in the evidence at hand."[60p 149]
Impact bias	". . . people overestimate the intensity and duration of their emotional reactions to future events—even when they know what the future event is likely to entail and they are not in a particularly 'hot' or 'cold' emotional state at the time of making their forecast."[61p 131]
Order effect	". . . refers to the phenomenon that the temporal order in which information is presented affects the final judgment of an event."[62p 569]

authors of 1 paper attempted to debias 5 different biases within 1 investigation. Most often, debiasing strategies were directed toward an elimination of people's optimistic bias ($n = 25$), followed by the attempt to debias framing effects ($n = 14$) or a base rate or denominator neglect ($n = 10$; see Supplementary Appendix 2 for further details).

(In)consistent Use of Terminology

Although all included studies tested strategies to overcome negative effects of biases, this was not always explicitly stated. Forty of 68 papers (58.8%) used the term "debiasing," while the remaining 28 articles used expressions such as "overcome common decision errors"[36] or "eliminate unrealistic optimism."[37] Similarly, only one-quarter of studies ($n = 17$) provided a clear definition of debiasing. The remaining papers explained the term in context, for example, by describing the expected effects of the intervention or interpreting the results in the light of improved judgment and decision making.

Taxonomy of Debiasing Strategies

Cognitive and technological debiasing strategies were most often tested, with a notable increase of applications over the past 10 years (see Figure 3). Cognitive strategies, which primarily aim at improving people's critical thinking skills,[17] were used in 36 of 87 studies (41.1%). These strategies often comprised training to raise awareness of and acquire techniques for avoiding cognitive biases.[32,33,38–41] Thirty-three studies (37.9%) applied a technological debiasing strategy[10] (e.g., by providing graphical in addition to statistical information to eliminate framing effects or base rate neglects).[42–44] Two studies (2.3%) employed a motivational debiasing strategy by holding people accountable for their decisions.[45]

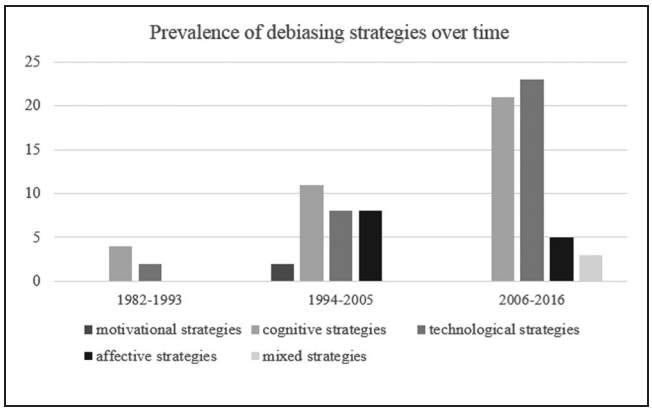

Figure 3 Prevalence of debiasing strategies over time.

Thirteen studies (14.9%) applied an affective strategy aiming at overcoming biases (e.g., by using in-group v. out-group framing or inducing feelings).[36,46–48] Finally, 3 studies applied a mixed intervention, twice consisting of a cognitive and a technological strategy and 1 time of a combination between an affective and a technological strategy (see Supplementary Appendix 2 for a list of all reviewed strategies).

Effectiveness of Debiasing Interventions

Across the 87 interventions, 69.0% ($n = 60$) of debiasing interventions were completely or partially successful. More specifically, 37 studies (42.5%) found support for all their debiasing-related hypotheses, and 23 studies (26.4%) did so for at least 1 of their assumptions. The authors of 25 studies (28.7%) concluded that their debiasing attempt was ineffective. In 1 study,[40] the debiasing strategy's effectiveness was irrelevant since the assumed biases did not occur. With regard to debiasing strategies' effectiveness across different categories, one notices that 87.9% ($n = 29$) of technological interventions were partially or completely successful. In turn, cognitive strategies were in 50.0% ($n = 18$) of cases effective.

Considering the main types of addressed biases, a slight advantage for overcoming the framing effect and denominator neglect emerges. In 90% of the cases ($n = 9$), it was at least partially possible to debias the denominator neglect. Similarly, 85.7% ($n = 12$) of anti–framing-effects strategies led to a positive outcome. The optimistic bias appears to be more robust: 64.0% ($n = 16$) of interventions achieved a debiasing effect, whereas 36.0% ($n = 9$) did not.

Further, if a sample consisted (partially) of students, debiasing was successful in 71.4% ($n = 40$) of cases. Nonstudent samples could be debiased in 64.3% of analyzed cases ($n = 18$).

Discussion

Conclusions

Overall, this systematic review finds that debiasing interventions in the health context appear to work better than their reputation might adumbrate: more than two-thirds of the reviewed interventions were at least partially effective. Optimistic biases, framing effects, and biases related to base rate neglects were the main targets of debiasing efforts. This mirrors the results of a recent systematic review on cognitive biases in medical decision making, in which framing effects, relative risk bias, and the availability bias were most often identified.[13] (In the review,[13] relative risk bias was defined "as stronger inclination to [choose treatment] when presented with the relative . . . risk than when presented with the same [information] described in terms of the absolute . . . risk," according to Forrow and colleagues.[49] It is therefore regarded as similar to base rate neglect.)

With regard to the categorization of debiasing techniques, one notes an imbalance in favor of cognitive (41.4%) and technological (37.9%) strategies. While the high prevalence of cognitive strategies could be explained by the origin of the heuristics and biases program during the great rationality debate with a strong focus on cognitive factors, the emergence of technological interventions is a novelty.[10] Their increase over time from 2 interventions between 1982 and 1993 to 23 studies during the past 10 years might point to the adoption of a broader perspective on what constitutes rationality and debiasing.[10] Thus, there is a shift from the sole focus on cognitive aspects to the consideration of the decision environment and integrated tools to approach rationality.[10] Yet the rise of technological strategies leads to a need for further differentiating between debiasing techniques within this category. This may include the establishment of subgroups capturing different technological approaches. Such subcategories could, for example, distinguish between strategies comprising the restructuring of information to facilitate information processing, as done by decision or visual aids, on the one hand, and strategies using technology to design entire information environments promoting unbiased reasoning on the other hand.

Although the effectiveness across types of strategies needs to be interpreted with caution, technological interventions appear to be promising with a success rate of 87.9%. Cognitive strategies, in turn, yielded mixed effects as they worked in half of the studies. This finding

supports the prevailing skepticism toward the feasibility and usefulness of cognitive interventions in relation to their transferability and resource needs.[6,10,17] One reason for the limited success of cognitive strategies might relate to the different kinds of biases that exist (i.e., those that stem from a "failure to know or apply an explicit rule of inference" and those that result from unconscious or irrepressible mental processes, also called "mental contamination").[14] While the first category could be overcome with teaching cognitive strategies—given people's awareness and motivation to correct the bias[14]—the latter might be more effectively addressed by the provision of external tools that facilitate comprehensive information processing. Nevertheless, it will be a future challenge to integrate technological interventions into people's daily lives. On a policy level, this challenge relates not only to the development of decision tools and easy-to-process information presentation formats but also to their implementation, dissemination, and the provision of large-scale access. On an individual level, the main challenge will be to demonstrate to potential users the benefits of these tools and how they can be adopted.[10]

Limitations

This study is not without limitations. First, even though we conducted a systematic and comprehensive search, some articles may be missing in this systematic review. This is especially conceivable for papers that do not use the applied terminology related to debiasing and systematic biases or study performance improvement in a broader sense.[50,51] Second, the findings of this systematic review might be limited because of publication bias. That is, we cannot judge how many articles have not been published or written because the applied debiasing strategy was not effective. Third, in the field of diagnostic reasoning, there exist several excellent reviews that are concerned with cognitive or dual-process interventions to reduce diagnostic errors.[5,27–29] These studies review cognitive interventions to improve diagnostic reasoning and include a broader range of underlying reasons for diagnostic failures. In turn, we focus on how to remedy biased judgments and decisions but expand this investigation beyond cognitive interventions and also capture lay people's decision making and a variety of thematic contexts. Last, it was not possible to conduct a meta-analysis because of the different ways in which debiasing was conceptualized, operationalized, and measured.[52]

Implications for Future Research

Several implications for future debiasing research can be drawn from this systematic review. Considering the new possibilities to implement technological debiasing strategies as well as their high effectiveness, their further investigation seems auspicious. Technological strategies also afford the opportunity to address several of the points of criticism related to debiasing research. First, as the provision of "tools external to the decision maker"[10] is most useful in real-life settings, technological interventions call for a testing outside the laboratory context. The use of technological interventions further allows for debiasing on a large scale as the change of the information environment requires as much effort for one user as for a thousand, a feature that distinguishes technological from cognitive strategies, in which a bigger sample population requires more resources. Here, it is crucial to note that the term *technological strategies* might be misleading as they do not necessarily comprise a complex intervention based on technology but also refer to simple changes with respect to the format in which information is displayed.[10,42–44] Future research could address this issue conceptually by proposing an updated definition of technological debiasing that is more differentiated and takes the empirical advance of strategies within this category into account.

Moreover, it is worth considering that the majority of studies draw their conclusions from studies involving student samples. While this review does not find any differences between student and nonstudent samples related to effectiveness, these differences might emerge with an increasing number of heterogeneous samples. To gain more valid insights into the long-term relevance and adequacy of debiasing interventions, studies with more representative samples are needed.

Also, debiasing research still faces some major challenges when it comes to theoretical rigor. The lack of internal coherence across the different studies needs to be addressed by future research. The terminology that is used when talking about the various types of biases and debiasing strategies varies considerably.[18] This applies to the seemingly arbitrary labeling of biases (e.g., *optimistic bias, optimism bias*, and *comparative optimism* all refer to the same phenomenon) as well as to the inconsistent use of the term *debiasing*. The question referring to what constitutes the core of debiasing research and how debiasing can be distinguished from similar concepts such as nudging[53] or boosting[54] goes hand in hand with this issue but relates to a desire for external discrimination. Especially the stronger environmental focus of technological debiasing strategies may result in confusing these approaches, with researchers rightly asking about unique features of each approach.

In conclusion, debiasing interventions have the potential to enhance health-related judgments and decisions of

health care professionals and the general population and thus merit further investigation. Especially technological strategies offer a promising opportunity to pursue large-scale debiasing outside the laboratory through creating a fit between human thinking processes and the respective information environment. Future debiasing research will face 2 main challenges: First, the transfer of debiasing interventions to real-life settings in which people routinely and willingly use debiasing tools is required.[10] Second, researchers need to address the issue of theoretical rigor by distinctly defining the singularities and underlying assumptions of their approach taken to differentiate it from related concepts.

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Supplementary Material

Supplementary material for this article is available on the *Medical Decision Making* Web site at http://journals.sagepub.com/home/mdm.

References

1. Tversky A and Kahneman D. Judgment under uncertainty: heuristics and biases. *Science*. 1974;185(4157):1124–31. Available from: URL: http://www.jstor.org/stable/1738360
2. Tversky A and Kahneman D. Judgment under uncertainty: heuristics and biases. In: Kahneman D, Slovic P and Tversky A, eds. Judgment under Uncertainty: Heuristics and Biases. New York: Cambridge University Press; 1982. p 3–20.
3. Wilke A and Mata R. Cognitive bias. In: Ramachandran VS, ed. *The Encyclopedia of Human Behavior*. Volume 1.2nd ed. London: Academic Press; 2012. p 531–5.
4. Gigerenzer G and Todd PM, ABC Research Group. Simple Heuristics That Make Us Smart. New York: Oxford University Press; 1999.
5. Croskerry P, Singhal G and Mamede S. Cognitive debiasing 1: origins of bias and theory of debiasing. *BMJ Qual Saf*. 2013;22(Suppl 2):ii58–64.
6. Kenyon T and Beaulac G. Critical thinking education and debiasing. *Informal Log*. 2014;34(4).
7. Keren G and Teigen KH. Yet another look at the heuristics and biases approach. In: Koehler DJ and Harvey N, eds. *Blackwell Handbook of Judgment and Decision Making*. Malden, MA: Blackwell; 2004. p 89–109.
8. Todd PM and Gigerenzer G. Précis of simple heuristics that make us smart. *Behav Brain Sci*. 2000;23:727–80.
9. Arkes HR. Costs and benefits of judgment errors: implications for debiasing. *Psychol Bull*. 1991;110(3):486–98.
10. Larrick P. Debiasing. In: Koehler D and Harvey N, eds. The Blackwell Handbook of Judgment and Decision Making. Malden, MA: Blackwell; 2004. p 316–37.
11. Lilienfeld SO, Ammirati R and Landfield K. Giving debiasing away: can psychological research on correcting cognitive errors promote human welfare? *Perspect Psychol Sci*. 2009;4(4):390–8.
12. Montibeller G and von Winterfeldt D. Cognitive and motivational biases in decision and risk analysis. *Risk Anal*. 2015;35(7):1230–51.
13. Blumenthal-Barby JS and Krieger H. Cognitive biases and heuristics in medical decision making: a critical review using a systematic search strategy. *Med Decis Mak*. 2015;35(4):539–57.
14. Wilson TD and Brekke N. Mental contamination and mental correction: unwanted influences on judgments and evaluations. *Psychol Bull*. 1994;116(1):117–42.
15. Fischhoff B.Debiasing. In: Kahneman D, Slovic P and Tversky A, eds. Judgments under Uncertainty: Heuristics and Biases. 24th ed. New York: Cambridge University Press; 1982. p 422–44.
16. Aczel B, Bago B, Szollosi A, Foldes A and Lukacs B. Is it time for studying real-life debiasing? Evaluation of the effectiveness of an analogical intervention technique. *Front Psychol*. 2015;6:1120.
17. Correia V. Contextual debiasing and critical thinking: reasons for optimism. *Topoi*. 2016:1–9.
18. Kaufmann L, Carter CR and Buhrmann C. Debiasing the supplier selection decision: a taxonomy and conceptualization. *Int J Phys Distrib Logist Manag*. 2010;40(10):792–821.
19. Willingham DT. Critical thinking: why is it so hard to teach? *Arts Educ Policy Rev*. 2008;109(4):21–9.
20. Gigerenzer G and Gaissmaier W. Heuristic decision making. *Annu Rev Psychol*. 2011;62:451–82. Available from: URL: www.annualreviews.org
21. Elwyn G, O'Connor A, Stacey D, et al. Developing a quality criteria framework for patient decision aids: online international Delphi consensus process. *BMJ*. 2006;333(7565):417.
22. Bunn MD. Taxonomy of buying decision approaches. *Source J Mark*. 1993;57(1):38–56. Available from: URL: http://www.jstor.org/stable/1252056
23. Almashat S, Ayotte B, Edelstein B and Margrett J. Framing effect debiasing in medical decision making. *Patient Educ Couns*. 2008;71(1):102–7.
24. Feyzi-Behnagh R, Azevedo R, Legowski E, Reitmeyer K, Tsytlin E and Crowley RS. Metacognitive scaffolds improve self-judgments of accuracy in a medical intelligent tutoring system. *Instr Sci*. 2014;42:159–81.
25. Greening L, Chandler CC, Stoppelbein L and Robison LJ. Risk perception: using conditional versus general base rates for risk communication. *J Appl Soc Psychol*. 2005;35(10):2094–122.

26. Rose JP. Debiasing comparative optimism and increasing worry for health outcomes. *J Health Psychol*. 2011;17(8): 1121–31.
27. Croskerry P, Singhal G and Mamede S. Cognitive debiasing 2: impediments to and strategies for change. *BMJ Qual Saf*. 2013;22:ii65–72.
28. Lambe KA, O'Reilly G, Kelly BD and Curristan S. Dual-process cognitive interventions to enhance diagnostic reasoning: a systematic review. *BMJ Qual Saf*. 2016;25:808–20.
29. Graber ML, Kissam S, Payne VL, et al. Cognitive interventions to reduce diagnostic error: a narrative review. *BMJ Qual Saf*. 2012;21:535–57.
30. Kayhan VO. Seeking health information on the web: positive hypothesis testing. *Int J Med Inform*. 2013;82(4):268–75.
31. Abhyankar P, Summers BA, Velikova G and Bekker HL. Framing options as choice or opportunity: does the frame influence decisions? *Med Decis Mak*. 2014;34:567–82.
32. Sherbino J, Kulasegaram K, Howey E and Norman G. Ineffectiveness of cognitive forcing strategies to reduce biases in diagnostic reasoning: a controlled trial. *Can J Emerg Med*. 2014;16(1):34–40.
33. Smith BW and Slack MB. The effect of cognitive debiasing training among family medicine residents. *Diagnosis*. 2015;2(2):117–21.
34. Sirriyeh R, Lawton R, Gardner P and Armitage G. Reviewing studies with diverse designs: the development and evaluation of a new tool. *J Eval Clin Pract*. 2012;18(4): 746–52.
35. Ayers B and Myers LB. Do media messages change people's risk perceptions for binge drinking? *Alcohol Alcohol*. 2012;47(1):52–6.
36. Bansback N, Li LC, Lynd L and Bryan S. Development and preliminary user testing of the DCIDA (Dynamic computer interactive decision application) for "nudging" patients towards high quality decisions. *BMC Med Inform Decis Mak*. 2014;14(62).
37. Klein WM. Maintaining self-serving social comparisons: attenuating the perceived significance of risk-increasing behaviors. *J Soc Clin Psychol*. 1996;15(1):120–42.
38. Reilly JB, Ogdie AR, Von Feldt JM and Myers JS. Teaching about how doctors think: a longitudinal curriculum in cognitive bias and diagnostic error for residents. *BMJ Qual Saf*. 2013;22:1044–50.
39. Weinstein ND and Klein WM. Resistance of personal risk perceptions to debiasing interventions. *Heal Psychol*. 1995;14(2):132–40.
40. Friedlander ML and Phillips SD. Preventing anchoring errors in clinical judgment. *J Consult Clin Psychol*. 1984;52(3):366–71.
41. Sherbino J, Dore KL, Siu E and Norman GR. The effectiveness of cognitive forcing strategies to decrease diagnostic error: an exploratory study. *Teach Learn Med*. 2011;23(1):78–84.
42. Garcia-Retamero R, Galesic M and Gigerenzer G. Do icon arrays help reduce denominator neglect? *Med Decis Mak*. 2010;30:672–84.
43. Garcia-Retamero R and Galesic M. Communicating treatment risk reduction to people with low numeracy skills: a cross-cultural comparison. *Am J Public Health*. 2009;99(12):2196–202.
44. Garcia-Retamero R and Galesic M. How to reduce the effect of framing on messages about health. *J Gen Intern Med*. 2010;25(12):1323–9.
45. Friedrich J, Barnes P, Chapin K, Dawson I, Garst V and Kerr D. Psychophysical numbing: when lives are valued less as the lives at risk increase. *J Consum Psychol*. 1999;3(3):277–99.
46. Lench HC and Levine LJ. Effects of fear on risk and control judgements and memory: implications for health promotion messages. *Cogn Emot*. 2005;19(7):1049–69.
47. Myers LB. Changing smokers' risk perceptions—for better of for worse? *J Health Psychol*. 2014;19(3):325–32.
48. Reed MB and Aspinwall LG. Self-affirmation reduces biased processing of health-risk information. *Motiv Emot*. 1998;22(2):99–132.
49. Forrow L, Taylor WC and Arnold RM. Absolutely relative: how research results are summarized can affect treatment decisions. *Am J Med*. 1992;92(2):121–4.
50. Kostopoulou O, Porat T, Corrigan D, Mahmoud S and Delaney BC. Diagnostic accuracy of GPs when using an early-intervention decision support system: a high-fidelity simulation. *Br J Gen Pract*. 2017;67(656):e201–8.
51. Kostopoulou O, Rosen A, Round T, Wright E, Douiri A and Delaney B. Early diagnostic suggestions improve accuracy of GPs: a randomised controlled trial using computer-simulated patients. *Br J Gen Pract*. 2015;65(630):e49–54.
52. Lipsey MW and Wilson DB. Practical Meta-Analysis. 49th ed. Thousand Oaks, CA: SAGE; 2001.
53. Thaler RH and Sunstein CR.Nudge. Improving Decisions About Health, Wealth, and Happiness. *Statewide Agricultural Land Use Baseline* 2015. New Haven, CT: Yale University Press; 2008.
54. Grüne-Yanoff T and Hertwig R. Nudge versus boost: how coherent are policy and theory? *Minds Mach*. 2016;26(1–2): 149–83.
55. Tversky A and Kahneman D. The framing of decisions and the psychology of choice. *Sci New Ser*. 1981;211(4481): 453–8.
56. Weinstein ND. Unrealistic optimism about future life events. *J Pers Soc Psychol*. 1980;39(5):806–20.
57. Okan Y, Garcia-Retamero R, Cokely ET and Maldonado A. Individual differences in graph literacy: overcoming denominator neglect in risk comprehension. *J Behav Decis Mak*. 2012;25(4):390–401.
58. Fischhoff B. Hindsight not equal to foresight: the effect of outcome knowledge on judgment under uncertainty. *J Exp Psychol Hum Percept Perform*. 1975;1(3):288–99.
59. Sternberg RJ and Sternberg K. Cognitive Psychology. 6th ed. Belmont, CA: Wadsworth, Cengage Learning; 2012.
60. Ross L and Anderson CA. Shortcomings in the attribution process: on the origins and maintenance of erroneous social assessments. In: Kahneman D, Slovic P and Tversky A,

eds. *Judgment under Uncertainty Heuristics and Biases*. New York: Cambridge University Press; 1982. p 129–52.
61. Wilson TD and Gilbert DT. Affective forecasting knowing what to want. *Curr Dir Psychol*. 2005;14(3):131–4.
62. Wang H, Zhang J and Johnson TR. Human belief revision and the order effect. In: Gleitman LR and Joshi AK, eds. *Proceedings of the Twenty-Second Annual Conference of the Cognitive Science Society*. Philadelphia: *Insititute for Research in Cognitive Science, University of Pennsylvania*; 2000. p 547–58.
63. Moher D, Liberati A, Tetzlaff J and Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Ann Intern Med*. 2009;151(4):264–9.
64. Zikmund-Fisher BJ, Ubel PA, Smith DM, et al. Communicating side effect risks in a tamoxifen prophylaxis decision aid: the debiasing influence of pictographs. *Patient Educ Couns*. 2008;73(2):209–14.
65. Harris P, Middleton W and Joiner R. The typical student as an in-group member: eliminating optimistic bias by reducing social distance. *Eur J Soc Psychol*. 2000;30: 235–53.
66. Shaffer VA, Focella ES, Scherer LD and Zikmund-Fisher BJ. Debiasing affective forecasting errors with targeted, but not representative, experience narratives. *Patient Educ Couns*. 2016;99(10):1611–9.
67. Amsterlaw J, Zikmund-Fisher BJ, Fagerlin A and Ubel PA. Can avoidance of complications lead to biased healthcare decisions? *Judgm Decis Mak*. 2006;1(1):64–75.
68. Arkes HR, Guilmette TJ, Faust D and Hart K. Eliminating the hindsight bias. *J Appl Psychol*. 1988;73(2):305–7.
69. Chew KS, Durning SJ and Merriënboer JJ. Teaching metacognition in clinical decision-making using a novel mnemonic checklist: an exploratory study. *Singapore Med J*. 2016;57(12):694–700.
70. Chua FJ and Job RFS. Event-specific versus unitary causal accounts of optimism bias. *J Behav Med*. 1999;22(5): 457–91.
71. Groeger JA and Chapman PR. Errors and bias in assessments of danger and frequency of traffic situations. *Ergonomics*. 1990;3311(10):1349–63.
72. Jenkins MM. Cognitive Debiasing and the Assessment of Pediatric Bipolar Disorder (PhD dissertation). *University of North Carolina, Chapel Hill*, 2012.
73. Kim S, Goldstein D, Hasher L and Zacks RT. Framing effects in younger and older adults. *J Gerontol Psychol Sci*. 2005;60B(4):P215–8.
74. Lench HC, Bench SW and Davis EL. Distraction from emotional information reduces biased judgements. *Cogn Emot*. 2016;30(4):638–53.
75. Li M and Chapman GB. "100% of anything looks good": the appeal of one hundred percent. *Psychon Bull Rev*. 2009;16(1):156–62.
76. Marchiori D, Papies EK and Klein O. The portion size effect on food intake. an anchoring and adjustment process? *Appetite*. 2014;81:108–15.
77. Parmley MC. The Effects of the Confirmation Bias on Diagnostic Decision Making (PhD dissertation). *Drexel University, Philadelphia*, 2006.
78. Payne VL. Effect of a Metacognitive Intervention on Cognitive Heuristic Use during Diagnostic Reasoning (PhD dissertation). *University of Pittsburgh, PA*, 2011.
79. Robb KA, Campbell J, Evans P, Miles A and Wardle J. Impact of risk information on perceived colorectal cancer risk: a randomized trial. *J Health Psychol*. 2008;13(6): 744–53.
80. Savani K and King D. Perceiving outcomes as determined by external forces: the role of event construal in attenuating the outcome bias. *Organ Behav Hum Decis Process*. 2015;130:136–46.
81. Scherer L, de Vries M, Zikmund-Fisher BJ, Witteman HO and Fagerlin A. Trust in deliberation: the consequences of deliberative decision strategies for medical decisions. *Health Psychol*. 2015;34(11):1090–9.
82. Sieck WR and Yates JF. Overconfidence effects in category learning: a comparison of connectionist and exemplar memory models. *J Exp Psychol Learn Mem Cogn*. 2001;27(4):1003–21.
83. Sparks P, Harris PR and Raats M. Imagining and explaining hypothetical scenarios: mediational effects on the subjective likelihood of health-related outcomes. *J Appl Soc Psychol*. 2003;33(4):869–87.
84. Stock ML, Gibbons FX, Beekman JB and Gerrard M. It only takes once: the absent-exempt heuristic and reactions to comparison-based sexual risk information. *J Pers Soc Psychol*. 2015;109(1):35.
85. Sutton S. Influencing optimism in smokers by giving information about the average smoker. *Risk Decis Policy*. 2002;7:165–74.
86. Takemura K. Influence of elaboration on the framing of decision. *J Psychol*. 1994;128(1):33–9.
87. Van Geene K, de Groot E, Erkelens C and Zwart D. Raising awareness of cognitive biases during diagnostic reasoning. *Perspect Med Educ*. 2016;5(3):182–5.
88. Weinstein ND and Lachendro E. Egocentrism as a source of unrealistic optimism. *Personal Soc Psychol Bull*. 1982;8(2):195–200.
89. Bernstein LM, Chapman GB and Elstein AS. Framing effects in choices between multioutcome life-expectancy lotteries. *Med Decis Mak*. 1999;19:324–38.
90. Brown SL and Imber A. The effect of reducing opportunities for downward comparison on comparative optimism. *J Appl Soc Psychol*. 2003;33(5):1058–68.
91. Chandler CC, Robison LJ, Greening L and Stoppelbein L. It can't happen to me or can it? Conditional base rates affect subjective probability judgments. *J Exp Psychol Appl*. 1999;5(4):361–78.
92. Fagerlin A, Wang C and Ubel PA. Reducing the influence of anecdotal reasoning on people's health care decisions: is a picture worth a thousand statistics? *Medical Dec Mak*. 2005;25(4):398–405.

93. Gharibian GG. Counselor Confirmation Bias: Can the Internet Serve as a Debiasing Tool? (PhD dissertation). University of Memphis, GA, 2014.
94. Klayman J and Brown K. Debias the environment instead of the judge: an alternative approach to reducing error in diagnostic (and other) judgment. *Cognition*. 1993;49(1):97–122.
95. Lau AYS and Coiera EW. Can cognitive biases during consumer health information searches be reduced to improve decision making? *J Am Med Inform Assoc*. 2009;16(1):54–65.
96. Lipkus IM and Klein WMP. Effects of communicating social comparison information on risk perceptions for colorectal cancer. *J Health Commun*. 2006;11:391–407.
97. Ludolph R, Allam A and Schulz PJ. Manipulating Google's knowledge graph box to counter biased information processing during an online search on vaccination: application of a technological debiasing strategy. *J Med Internet Res*. 2016;18(6):e137.
98. Rebitschek FG, Bocklisch F, Scholz A, Krems JF and Jahn G. Biased processing of ambiguous symptoms favors the initially leading hypothesis in sequential diagnostic reasoning. *Exp Psychol*. 2015;62:287–305.
99. Roy MC and Lerch FJ. Overcoming ineffective mental representations in base-rate problems. *Inf Syst Res*. 1996;7(2):233–47.
100. Ubel PA, Smith DM, Zikmund-Fisher BJ, et al. Testing whether decision aids introduce cognitive biases: results of a randomized trial. *Patient Educ Couns*. 2010;80(2): 158–63.
101. Weinstein ND. Reducing unrealistic optimism about illness susceptibility. *Health Psychol*. 1983;2(1):11–20.
102. Zikmund-Fisher BJ, Fagerlin A, Roberts TR, Derry HA and Ubel PA. Alternate methods of framing information about medication side effects: incremental risk versus total risk of occurrence. *J Health Commun*. 2008;13:107–24.
103. Dillard AJ, Fagerlin A, Dal Cin S, Zikmund-Fisher BJ and Ubel PA. Narratives that address affective forecasting errors reduce perceived barriers to colorectal cancer screening. *Soc Sci Med*. 2010;71(1):45–52.
104. Ofir C and Mazursky D. Does a surprising outcome reinforce or reverse the hindsight bias? *Organ Behav Hum Decis Process*. 1997;69(1):51–7.
105. Thompson SC, Kyle D, Swan J, Thomas C and Vrungos S. Increasing condom use by undermining perceived invulnerability to HIV. *AIDS Educ Prev*. 2002;14(6):505.
106. Yanovitzky I. Debiasing pluralistic ignorance. *Presented at the Annual Convention of the National Communication Association*, Chicago, IL; 2005.
107. Angott AM, Comerford DA and Ubel PA. Imagining life with an ostomy: does a video intervention improve quality-of-life predictions for a medical condition that may elicit disgust? *Patient Educ Couns*. 2013;91(1):113–9.
108. Garcia-Retamero R and Cokely ET. Simple but powerful health messages for increasing condom use in young adults. *J Sex Res*. 2015;52(1):30–42.