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Decision threshold models in medical decision making: a scoping literature review

Andrew Scarffe[1,2,3*], Alison Coates[1], Kevin Brand[1] and Wojtek Michalowski[1]

Abstract

Background Decision thresholds play important role in medical decision-making. Individual decision-making differences may be attributable to differences in subjective judgments or cognitive processes that are captured through the decision thresholds. This systematic scoping review sought to characterize the literature on non-expected utility decision thresholds in medical decision-making by identifying commonly used theoretical paradigms and contextual and subjective factors that inform decision thresholds.

Methods A structured search designed around three concepts—individual decision-maker, decision threshold, and medical decision—was conducted in MEDLINE (Ovid) and Scopus databases from inception to July 2023. ProQuest (Dissertations and Theses) database was searched to August 2023. The protocol, developed a priori, was registered on Open Science Framework and PRISMA-ScR guidelines were followed for reporting on this study. Titles and abstracts of 1,618 articles and the full texts for the 228 included articles were reviewed by two independent reviewers. 95 articles were included in the analysis. A single reviewer used a pilot-tested data collection tool to extract study and author characteristics, article type, objectives, theoretical paradigm, contextual or subjective factors, decision-maker, and type of medical decision.

Results Of the 95 included articles, 68 identified a theoretical paradigm in their approach to decision thresholds. The most common paradigms included regret theory, hybrid theory, and dual processing theory. Contextual and subjective factors that influence decision thresholds were identified in 44 articles.

Conclusions Our scoping review is the first to systematically characterizes the available literature on decision thresholds within medical decision-making. This study offers an important characterization of the literature through the identification of the theoretical paradigms for non-expected utility decision thresholds. Moreover, this study provides insight into the various contextual and subjective factors that have been documented within the literature to influence decision thresholds, as well as these factors juxtapose theoretical paradigms.

Keywords Decision-making, Decision thresholds, Thresholds, Ex-ante, Medical decision-making, Scoping review, Regret theory, Dual processing theory, Hybrid theory

Background

Decision thresholds play an important and understudied role in decision-making. Often, decision thresholds are viewed as the "linchpin" between evidence and decision-making [1, 2]. The concept of a decision threshold is often familiar to those with a basic understanding of the judicial system where standards of proof assume different evidentiary cut-offs such as, "'beyond a reasonable doubt' (typical of criminal court) and the less-stringent

*Correspondence:
Andrew Scarffe
ascar083@uottawa.ca
[1] Telfer School of Management, University of Ottawa, Ottawa, ON, Canada
[2] Ottawa Hospital Research Institute, The Ottawa Hospital, Ottawa, ON, Canada
[3] Bob Gaglardi School of Business and Economics, Thompson Rivers University, Kamloops, BC, Canada

'preponderance of evidence' (typical of a civil court)" [1]. Decision thresholds, be it for individuals or society, reflect the perceived value of the consequences (e.g., convicting an innocent person to prison versus letting a guilty person walk free) [1, 3–7]; effectively, a decision threshold dichotomizes a decision into taking or not taking an action [8–11]. Generally, differing decisions are attributed to individual differences in subjective judgements that are attributed to different decision thresholds [12]. Differences in assessments of the benefits and harms of particular decisions, or subjective risk-assessment judgements, help to explain the variation in decision thresholds [13, 14]. Within the context of medical decision-making, Djulbegovic and colleagues assert that the "development of [the] threshold model is considered as one of the most important advances in medical decision-making" [15]. Understanding the ways that individuals incorporate subjective judgements and values into decision thresholds [7] and the cognitive mechanisms they employ to inform decisions could suggest opportunities to understand variation within medical decision-making [8, 13].

While arguably of central interest to the decision making process, surprisingly little research is dedicated to decision thresholds [16]. Within the existing literature, several different theoretical paradigms have been identified as underpinning how an individual might arrive at a decision threshold [9]. A narrative review by Djulbegovic and colleagues [14] summarized theoretical paradigms underpinning decision thresholds that inform medical decision-making: 1) expected utility theory (EUT) models [10, 11], 2) regret based decision models [8, 17–21], 3) dual processing/dual system models [12, 22], and 4) other models [14]. Djulbegovic and colleagues argued/asserted that theoretical paradigms for decision thresholds have not been adequately explored or employed empirically, nor has the concept been meaningfully integrated into theoretical investigations of clinical decision-making [14]. Despite the perceived importance of decision thresholds in medical decision-making, the various papers bearing upon the topic have yet to be systematically reviewed. While EUT threshold models are well established within the medical decision-making literature (see Pauker and Kassirer [10, 11]) [14], a considerable body of literature recognizes that in practice different underpinning paradigms appear to be plausible and, on occasion, better matches to practice [14, 23, 24]. EUT and non-EUT paradigms differ in how they weigh probabilities and scale utilities [2]. Typically, an EUT approach does not account for contextual and subjective factors that inform an individual's decision-making, whereas non-EUT paradigms often account for affect, emotion, values, preferences and other contextual/ situational factors [2]. We chose to exclude EUT decision threshold paradigms from our systematic scoping review because a considerable body of literature has recognized that people do not always make decisions with a goal of maximizing expected utility [23–26]. For example, Djulbegovic and colleagues (2014) investigated which decision threshold paradigms (i.e., EUT, regret and dual-processing theory) most accurately reflected physicians' actions for pulmonary embolisms and acute myeloid leukemia [25]. Results from this study suggested that the EUT paradigm for decision threshold was a weaker predictor of physician decisions than regret-based and dual processing theory paradigms (the latter of which was the best predictor) [25].

We employed a scoping review approach to systematically review alternative theoretical paradigms underpinning decision thresholds. We seek to categorize the non-EUT paradigms (i.e., those do not share the same general structure as described in Pauker and Kassirer) [10, 11]. This scoping review adds to the body of knowledge by summarizing the most recent research on decision thresholds within medical decision-making, and by extending this corpus of knowledge to include literature on the paradigms that physicians and non-physicians (e.g., allied health professionals, lay-persons/ patients, etc.) use for non-EUT decision thresholds in medical decision-making. The following two objectives were driving the review described in this paper:

> **Objective 1:** Identify and categorize what theoretical paradigms have been developed to establish or estimate decision threshold(s) within medical decision-making.
> **Objective 2:** Identify what consideration an individual's subjective judgment(s) (e.g., attitudes, emotions, preferences, risk perceptions, values) have been given in a context of decision threshold(s) within medical decision-making.

Methods

Following Johanna Briggs Institute (JBI) methodology [27], we conducted a scoping review to systematically identify the non-EUT theoretical paradigms underpinning medical decision thresholds. The protocol, developed a priori, was registered on Open Science Framework [28] and PRISMA-ScR guidelines [29] were followed for reporting on this study. Our methods are summarized here. Full methodological details are included in the supplementary text.

Data sources

We designed a search strategy around three concepts: individual decision-maker, decision threshold, and medical decision. We sought to identify articles where the

term "decision threshold" and other like terms appeared within the title or abstract of an article in the context of "medical decisions" or other like terms. The search was piloted in MEDLINE (Ovid) and subsequently translated for Scopus search syntax. Both searches were completed in July, 2023. The ProQuest (Dissertations and Theses) database was searched in August 2023 using the phrase "decision threshold". Results of the search were deduplicated using the Zotero Duplicate Merger Plug-In (https://www.zotero.org/). We used Covidence software (https://www.covidence.org/) to facilitate article review and selection.

Study selection

We selected articles published in English that acknowledged theoretical paradigms for decision thresholds, and where medical or health related decisions were made by individuals (e.g., physicians, allied health professionals, lay individuals, etc.). We excluded articles that applied decision threshold models at the policy level (e.g., cost-effectiveness analysis and willingness to pay thresholds).

Since we wished to categorize the theories that have been conceptualized as underpinning decision thresholds (objective 1), our screening criteria were deliberately broad. As the literature on decision thresholds transcends disciplinary boundaries, we kept the title and abstract screening criteria purposefully conceptual rather than concrete to allow for fields using different terms to capture the same or similar ideas. We piloted screening criteria, summarized in Table 1, in a subset of studies prior to implementation and achieved high interrater agreement. Titles and abstracts of articles identified in our search were screened by two independent reviewers (AS and AC) and disagreements were discussed and

Table 1 Summary of Inclusion/ Exclusion Criteria Based on Screening Phase

Screening Phase	Inclusion	Exclusion
Abstract and Title	• Refers to, or implies, the cognitive process of using or establishing decision thresholds AND • Involves health-related decision-making processes by humans about humans	• Not in English OR • Decisions do not involve humans OR • Article tests the performance or quality of clinical parameters or tests without a human subjective element OR • Article refers to purely to economic evaluation
Full-Text	• Is **focused on** understanding/ explaining/ informing how individuals make health related decisions when faced with uncertainty AND • The **process/ theory/ calculation** in which the decision threshold is estimated is **explicitly stated and/or referenced** relative to the decision OR • Discusses the influence that individual **subjective judgments** (e.g., **attitudes/ emotions/ preferences/ risk perceptions**) has/have on an individual's decision threshold relative to the decision	• Not available online through the University of Ottawa library, the Clarkson University library, or available for download on the internet OR • Not in English OR • Is solely about a **standard of practice** or **clinical guideline** for which the concept of a decision threshold(s) is mentioned but not thoroughly discussed and/or is arbitrarily chosen OR • Is solely about a **clinical outcome assessment/ clinical test/ prediction model** and/or the decision threshold(s) is arbitrarily chosen OR • Is solely about the development/ evaluation of a **software/ tool/ decision aid** for a specific disease OR • Is solely about economic evaluation and establishing a decision threshold based on a willingness-to-pay for an intervention at a population level that is not specific to an individual and/ or does not explore how the willingness to pay threshold ought to be established OR • Discusses decision thresholds within the context of an **individual experiencing impaired cognition** impacting the individual's ability to make decisions (e.g., concussion, anxiety, etc.) OR • Calculates/explores the concept of decision threshold(s) solely based on **expected utility threshold models** OR • Calculates/ explores the concept of decision threshold(s) solely based on **linear programming**

resolved through consensus. Full text of articles passing initial screening were reviewed by the two independent reviewers (AS and AC) using the full text screening criteria summarized in Table 1 following a pilot screening process where, again, high inter-rater agreement was achieved. Disagreements on full text screening assessments were resolved through a consensus discussion.

Reference lists of all articles included after full-text review were screened using title and abstract criteria. Potentially suitable articles were assessed using full-text inclusion and exclusion criteria.

A total of 2,358 articles were identified through database and reference list searching. After de-duplication, 1,618 articles entered the two-stage screening process. Ultimately, 95 articles were included in the review. Details of study selection are depicted in Fig. 1.

Data extraction

A data extraction form designed to capture details about each article was pilot tested by a single researcher (AS) on a subset of included articles. Team discussions helped to streamline the form. Extracted characteristics included: author details, title of the journal, country of study (where applicable), the objective of the article, article type (e.g., empirical, conceptual/ theoretical, review, etc.), theoretical foundations (if any), contextual/ subjective factors (if any), types of decision threshold (e.g., treat/ not treat; test/ not test, etc.), decision threshold mathematical formulation (if any), the decision-maker (e.g., physician, nurse, patient, guardian/ caregiver, etc.), type of medical decision (e.g., coronary artery disease, stroke, COPD, etc.), authors' conclusions, as well as relevant references (see *Identifying Additional Literature*). All data extraction was performed by a single researcher (AS); team discussions were called for difficult or ambiguous extractions.

Identifying additional literature

The reference lists of all articles that met the full-text inclusion criteria were scanned using title and abstract criteria and potentially suitable articles were assessed using full-text inclusion/exclusion criteria. Data was charted from included articles as detailed above.

Synthesis of results

Selected characteristics of the included articles are tabulated in the supplementary text. Extracted data were evaluated thematically to identify the theoretical paradigms represented in the literature. We narratively summarized the literature within each paradigm and illustrate the distribution of records within each paradigm in tabular form. We also tabulated summary data from articles that discussed contextual and subjective factors associated with decision thresholds and summarize these narratively.

Results

Of the 95 included articles, 27 discussed the concept of decision thresholds in medical decision-making applications but did not reference or explicitly state a theoretical paradigm as conceptually underpinning the decision threshold, while the remaining 68 did. Here we discuss these remaining 68 articles (Table 2).

The most common ex-ante theoretical paradigms (i.e., estimating a decision threshold prior to the decision being made) used to determine an individual's decision threshold are regret theory, hybrid theory, and dual processing theory. The most common ex-post methodological approach (i.e., estimating a decision threshold after a decision has been made) used to estimate an individual's decision threshold involves regression techniques (e.g., ordinal, logistical, etc.).

Regret theory

Regret theory is the most common theoretical paradigm for non-EUT decision thresholds (mentioned/discussed in 24 out of 68 articles ~ 35%). Shortly after regret theory was first propounded [23, 24, 89], Feinstein [35] tailored the concept to the medical decision-making setting by identifying regret as a factor in "qualitative decision analysis" which he referred to as the "chagrin factor" [35]. Djulbegovic and colleagues [8] propose two different regret based processes for specifying decision thresholds: 1) they revise the EUT model to incorporate regret, and 2) they also propose the concept of "acceptable regret" (i.e., described as the "level of regret which the decision maker can comfortably tolerate" [8]), which simplifies to a distinct decision threshold equation. In the case of dual processing theory, the concept of regret is incorporated into other theorical paradigm [12].

Hybrid theory

The hybrid theory is another common paradigm for non-EUT decision thresholds, discussed in 16 of 68 articles in our review (~ 24%). Although hybrid theory sometimes shares similar structures to EUT decision-thresholds, as it is often slightly modified version of EUT decision threshold [43], it merits separate consideration as a non-EUT decision threshold paradigm. What constitutes a "hybrid theory" is poorly defined despite relatively frequent use of this term. For example, Djulbegovic and colleagues [43] articulate a hybrid theory paradigm that incorporates a mechanism how concepts such as a patient's "relative value" for specific outcomes can modify the expected value calculation (i.e., commonly incorporating utilities) to arrive at the optimal clinical decision [43].

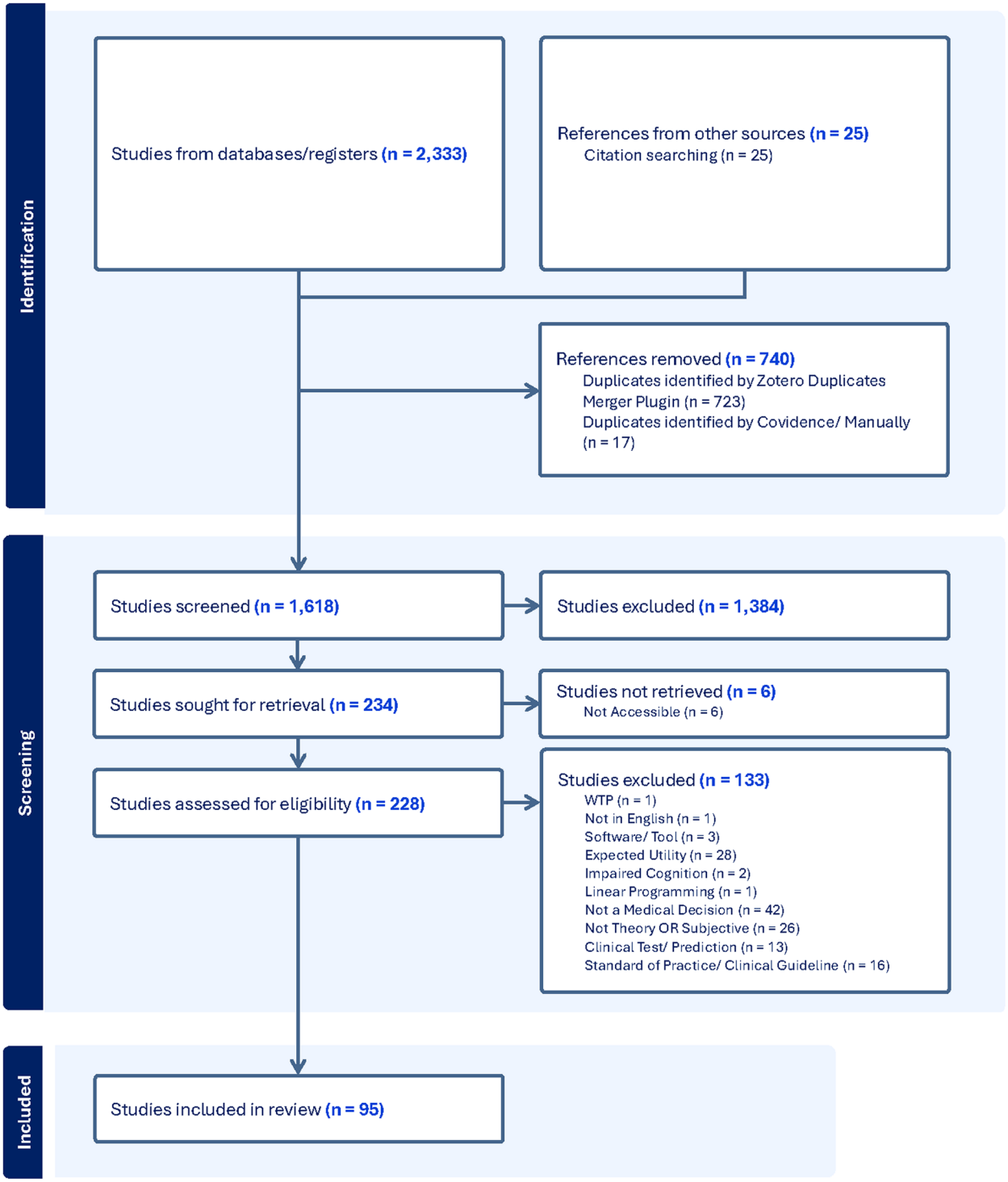

Fig. 1 PRISMA flow diagram

Alternatively, other scholars have stated that, within the hybrid model, individuals are believed to "use a kind of intuitive threshold they cannot explicate but that is based on their knowledge and/or perception about the harm and benefit of a treatment" [51]. In broad terms, the literature describes the hybrid threshold model as retaining "the original EUT formulation but invites the decision-maker to weigh health outcomes (morbidities

Table 2 Common Theoretical Paradigms of Non-Expected Utility Decision Thresholds

Article	Regret Theory	Dual Processing Theory	Hybrid Theory	Information Theory	Signal Detection Theory	Regression (Logistic/ Ordinal) Method	Net-Benefit	Other	Decision Maker
(Christensen-Szalanski et al., 1982) [30]						X			MD
(Eisenberg & Hershey, 1983) [31]						X			MD
(Hartz et al., 1986) [32]						X			MD
(M. J. Young et al., 1986) [33]						X			MD
(M. Young et al., 1987) [34]						X			MD
(Feinstein, 1985) [35]	X								MD
(Asch et al., 1990) [36]				X				X	MD
(Sainfort, 1991) [37]								X	MD
(Plasencia et al., 1992) [38]						X			MD
(B. Djulbegovic et al., 1995) [39]				X					MD
(Glasziou & Irwig, 1995) [40]							X		MD
(Verp & Heckerling, 1995) [41]			X						P
(B. Djulbegovic et al., 1999) [8]	X								MD
(Hozo & Djulbegovic, 1999) [42]			X						MD
(B. Djulbegovic et al., 2000) [43]			X						MD
(Van Hoe & Miserez, 2000) [44]			X						MD
(McAlister et al., 2000) [45]						X			MD; P
(Coenen et al., 2000) [46]	X								MD
(Sinclair et al., 2001) [47]								X	MD
(Cotler et al., 2001) [48]						X			MD; P
(Sonnenberg, 2004) [49]								X	MD

Table 2 (Continued)

Article	Regret Theory	Dual Processing Theory	Hybrid Theory	Information Theory	Signal Detection Theory	Regression (Logistic/ Ordinal) Method	Net-Benefit	Other	Decision Maker
(Ng et al., 2004) [50]						X			MD
(Basinga et al., 2007) [51]			X						MD
(Hozo & Djulbegovic, 2008) [20]	X								MD
(Hozo et al., 2008) [52]	X								MD
(Moreira et al., 2009) [53]	X		X						MD
(Thompson et al., 2008) [54]					X				RN
(Ben-Haim et al., 2009) [55]								X	MD; P
(Boland & Lehmann, 2010) [56]						X			MD
(Tsalatsanis et al., 2010) [21]	X								MD
(Tsalatsanis et al., 2011) [57]	X								MD
(Cheyne et al., 2012) [13]					X			X	MD;MW
(B. Djulbegovic et al., 2012) [12]	X	X							MD
(Mohan et al., 2012) [58]					X	X			MD
(Pines et al., 2012) [59]			X						MD
(Vickers et al., 2013) [60]							X		MD
(B. Djulbegovic et al., 2014) [61]	X	X							MD
(Felder & Mayrhofer, 2014) [62]			X						MD
(Hernandez et al., 2014) [63]	X								MD
(Sreeramareddy et al., 2014) [64]	X		X						MD
(Tsalatsanis et al., 2015, p. 201) [22]		X							MD

Table 2 (Continued)

Article	Regret Theory	Dual Processing Theory	Hybrid Theory	Information Theory	Signal Detection Theory	Regression (Logistic/ Ordinal) Method	Net-Benefit	Other	Decision Maker
(Cucchetti et al., 2015) [65]	X								MD; P
(B. Djulbegovic, Hamm, et al., 2015)* [9]	X	X	X						MD
(B. Djulbegovic, van den Ende, et al., 2015)* [14]	X	X	X						MD
(Ebell et al., 2015) [66]						X			MD
(Sonnenberg, 2015)* [67]			X						MD
(Courbage & Rey, 2016) [68]			X						MD
(Sheldrick et al., 2016) [69]	X							X	MD
(Vickers et al., 2016)* [70]							X		MD
(Tsalatsanis et al., 2017) [71]	X								P
(Hozo et al., 2017) [72]	X				X			X	MD
(Hozo et al., 2018) [19]	X								MD
(Ebell et al., 2018) [73]						X			MD
(Felder & Mayrhofer, 2018) [74]								X	MD
(Fujii & Osaki, 2018) [75]	X								P
(B. Djulbegovic et al., 2019) [76]			X						MD
(Boyles et al., 2020)* [77]	X	X							MD
(De Alencastro et al., 2020) [78]						X			MD
(M. Djulbegovic et al., 2020)* [79]			X						MD
(Patel et al., 2021) [80]						X			MD

Table 2 (Continued)

Article	Regret Theory	Dual Processing Theory	Hybrid Theory	Information Theory	Signal Detection Theory	Regression (Logistic/ Ordinal) Method	Net-Benefit	Other	Decision Maker
(Courbage & Peter, 2021) [81]			X						MD
(van Overbeeke et al., 2021) [82]						X			P
(Cai et al., 2022) [83]						X			MD
(Wen et al., 2022) [84]	X								C/G
(Sevim & Felder, 2022) [85]			X						MD
(Cucchetti et al., 2023) [86]	X								MD
(B. Djulbegovic et al., 2023) [87]	X							X	MD
(Taylor et al., 2023) [88]						X			MD
Total	**24**	**6**	**17**	**2**	**4**	**18**	**3**	**10**	

*Denotes a review or commentary, *MD* Physician, *P* Patient, *MW* Mid-wife, *C* Caregiver, *G* Guardian

and mortalities) differently when they occur in patients with and without disease" [14].

Verp and Heckerling [41], the earliest proponents for a hybrid theory approach to decision thresholds (in the context of medical decision-making), describe a decision threshold approach that considers patients' preferences for pre-natal testing [41]. Basinga and colleagues [51] provide an example of how a hybrid threshold model would calculate the associated decision threshold that incorporates a weighed value of morbidity with respect to mortality and weighed value of provoked death relative to natural death to incorporate a decision-maker's preference. Within other hybrid theories, the element of patient choice is incorporated into the threshold equation [76, 79]. For example, Djulbegovic and colleagues [79] propose a modified threshold formulation where the quotient of absolute risk of a major adverse event occurring and relative risk ratio is multiplied by a constant that "refers to the patient's relative value of avoiding treatment harms[…] with respect to the impact of disease without treatment" [79].

Dual processing theory

Six of the reviewed articles adopted a theoretical paradigm of dual processing or dual systems theory (hereafter, dual processing theory). Djulbegovic and colleagues [12] were the first to apply dual processing theory to medical decision thresholds. In this paradigm, it is presumed that people make decisions by drawing on a combination of "type I system" reasoning (i.e., affectively driven, fast, intuitive) and "type II system" reasoning (i.e., analytical, calculative, deliberative) [12]. Djulbegovic and colleagues [61] posit that physicians do use the threshold model to inform their decisions, and they claim that the dual processing model may best explain physicians' decision thresholds [61].

Of the six articles that identify dual processing theory as a theoretical underpinning for decision thresholds, two explored dual processing theory from a theoretical or conceptual perspective using hypothetical vignettes to illustrate its potential application [12, 22], three articles were reviews [9, 14, 77], and one article reported on the explanatory power of dual processing theory relative to EUT and regret theory decision threshold models [61].

Information theory

Information theory is used infrequently in the medical decision-making literature and is most commonly used in fields such as economics or engineering [90]. We identified two articles that used information theory in relation to decision thresholds. Within information theory, uncertainty, or "entropy" as it is known in the field of thermodynamics [39], can be expressed in terms of the benefit to risk ratio of a particular therapy [39], effectively incorporating a measure of choice [39]. The articles by Asch and colleagues [36] and Djulbegovic and colleagues [39] theoretically incorporate information theory into the classic EUT model by Pauker and Kassirer [10, 11].

Signal detection theory

We identified four articles that referenced Signal Detection Theory (SDT) relative to medical decision thresholds. SDT extends the concept of decision thresholds by providing a mechanism to contrast "signal" or "hit" (i.e., true positives and false negatives) and "noise" or "miss" (i.e., false positives and true negatives) relative to a decision [13, 54, 58, 72].

Three of the four articles used SDT as a methodology to elicit an individual's decision threshold when presented with hypothetical vignettes [13, 54, 58]. In the fourth article, Hozo and colleagues [72] addressed to the role of SDT from a theoretical perspective and identify the link between decision threshold models and SDT, fast-and-frugal decision trees (FFT) and evidence accumulation theory (EAT) [72].

Regression (Logistic/ Ordinal)

Our review identified 18 articles referencing a regression model for decision thresholds (~27%). Linear or logistic regression was a common method to estimate decision thresholds. Unlike many of other theories for informing decision thresholds in an ex-ante fashion, those thresholds that are identified through regression (commonly, logistic or ordinal) are almost exclusively decision thresholds that are determined ex-post.

Within articles that use a regression, Eisenberg and Hershey [31] are commonly cited for their four-step method for calculating the test and test-treatment thresholds within medical decision-making. Young and colleagues [33] build on Eisenberg and Hershey [31] and propose three different approaches to estimating the decision threshold: 1) modal distribution, 2) the unweighted midpoint, 2) the weighted midpoint. Plasencia and colleagues [38] elaborate on the logistic function as proposed by Hartz and colleagues [32], and reduce the dependencies on the approach proposed by Young and colleagues [33]. Specifically, Plasencia and colleagues [38], provide a regression paradigm that can account, "for other factors that may influence disease probability, or threshold, at which a particular proportion of physicians makes a decision" [38]. More recently, Ebell and colleagues [66] modify the logistic model proposed by Plasencia and colleagues [38] to estimate thresholds for both testing and treatment decisions. They explore testing and treatment thresholds for: influenza, acute coronary syndrome, pneumonia, deep vein thrombosis, and

urinary tract infection [66]. Ebell and colleagues [66] are commonly cited for their use of online clinical vignettes, which (at the time) provided a novel way to explore test and treatment thresholds for common conditions.

Net-Benefit

We identified three articles that specifically explored the concept of decision thresholds through a net-benefit approach. Although commonly the net-benefit approach is synonymous with EUT, the articles included in this review adopt a modified net-benefit approach. For example, Glasziou and Irwig [40] propose a net-benefit approach to decision thresholds that incorporates a weighting function for specific patient values for specific outcomes. This approach shares similar properties to typical EUT models but does not explicitly reference EUT [40]. Vickers and colleagues [60, 70] explore a net-benefit approach relative to the selection of diagnostic tests and incorporate a decision threshold approach into the net-benefit equation alongside specificity and sensitivity.

Other theoretical paradigms

Our review identified several other theoretical paradigms (i.e., classified as "Other" in Table 2), however each of these paradigms was associated with just one publication and therefore is not discussed in greater detail here. These "other" approaches include linear information theory [36], info-gap theory [55], generalized linear receiver operator characteristic (GROC) curves [37], rituals [49], social judgement theory [13], general assessment and decision making model [13], systems dynamics [69], fast-and-frugal decision trees [72], evidence accumulation theory [72], therapeutic risk thresholds [74], and the smooth ambiguity model [85].

Contextual and subjective factors

Our review sought to identify what consideration an individual's (patient or provider) subjective judgment(s) (e.g., attitudes, emotions, preferences, risk perceptions, values) have been given in a context of decision threshold(s) within medical decision-making (i.e., Objective 2).

Of the 95 articles included in the scoping review (Fig. 1), 44 consider contextual or subjective factors that may influence an individual's decision threshold (~46%). Contextual and subjective factors were infrequently grounded within a theoretical paradigm for decision thresholds (24 out of 44 articles- ~55%). Of the articles that included theoretical paradigm, regression techniques were most used (11 out of 24 articles- ~46%) to determine decision thresholds in an ex-post fashion and to identify the factors associated with heterogeneous decision thresholds. Where theoretical paradigms were not cited or regression techniques were not employed, studies relied on a variety of parametric (e.g., t-tests, ANOVAs) and non-parametric (e.g., Wilcoxon singed rank test) tests to quantify the decision threshold.

Contextual factors

Two broad categories of contextual factors were discussed in the literature as potentially influencing an individual's decision threshold: person-specific factors, and occupation-related factors (see Table 3). We categorize "person-specific factors" as those that provide contextual understanding of the individual (e.g., age, gender, country, education level, patient vs. physician). The studies with "person-specific factors" capture both physicians and lay individuals. Alternatively, the "occupation related factors" are specific to studies that have investigated the influence of various contextual factors relative to physician decision thresholds.

Across the identified articles there were mixed results regarding the statistical significance of several contextual factors associated with an individual's decision threshold. Interpretation of these various contextual factors can be found in the supplementary text. We also highlight that aside from regression models, signal detection theory [13, 54, 58] and regret theory [64, 65, 86] were the most common theoretical paradigms sited relative to contextual factors influencing decision thresholds.

Subjective factors

While we identified several subjective factors that influence decision thresholds, their potential influence relative to decision thresholds was mentioned but not necessarily quantified. We categorize these factors in three broad categories: 1) health related factors, 2) personal factors, and 3) perceptive factors (see Table 4).

Similar to the findings associated with contextual factors, the statistical significance associated with various subjective factors was inconsistent across studies. With a greater frequency than with contextual factors, studies discussed (but did not measure) the potential influence that subjective factors have on an individual's decision threshold. Aside from regression models, we observe that hybrid theory was often used as a theoretical paradigm relative to subjective factors and decision thresholds (5 articles [41, 62, 67, 81, 85]). A plausible explanation for use of a hybrid theory being is that this theory incorporates decision-maker preferences and choices into the estimation of the decision threshold.

Table 3 Contextual Factors that may Influence Decision Threshold

Contextual Factor	Source	Result	Theoretical Paradigm
Person-Specific Factors			
Age	(M. Young et al., 1987) [34]	[a]	Regression
	(Steel, 2000) [91]	[a]	-
	(Brundage et al., 2001) [92]	[a]	-
	(Cahan et al., 2003) [93]	NS	-
	(H. Douglas, 2012) [94]	NS	-
	(Nair et al., 2017) [95]	NS	-
	(De Alencastro et al., 2020) [78]	[a]	Regression
	(van Overbeeke et al., 2021) [82]	[a]	Regression
Gender	(Steel, 2000) [91]	[a]	-
	(Brundage et al., 2001) [92]	NS	-
	(Cahan et al., 2003) [93]	NS	-
	(H. Douglas, 2012) [94]	NS	-
	(Mohan et al., 2012) [58]	[a]	Signal Detection Theory; Regression
	(Lahaye et al., 2014) [96]	NM-D	-
	(Nair et al., 2017) [95]	NS	-
	(De Alencastro et al., 2020) [78]	[a]	Regression
Education Level	(Brundage et al., 2001) [92]	[a]	-
Country	(Ng et al., 2004) [50]	NS	Regression
	(Sreeramareddy et al., 2014) [64]	[a]	Regret Theory; Hybrid Theory
	(Thompson et al., 2008) [54]	[a]	Signal Detection Theory
	(Ebell et al., 2015, 2018) [66, 73]	[a]	Regression
	(De Alencastro et al., 2020) [78]	[a]	Regression
Physician vs. Patient	(Cotler et al., 2001) [48]	[a]	Regression
	(H. Douglas, 2012) [94]	[a]	-
	(van der Keylen et al., 2022) [97]	[a]	-
Occupation Related Factors			
Academic Practice vs. Non-Academic Practice	(Winkenwerder et al., 1993) [98]	[a]	-
	(Ng et al., 2004) [50]	NS	Regression
Differences in Speciality	(M. Young et al., 1987) [34]	[a]	Regression
	(Winkenwerder et al., 1993) [98]	[a]	-
	(Hanson et al., 1996) [99]	[a]	-
	(Steel, 2000) [91]	[a]	-
	(Cahan et al., 2003) [93]	NS	-
	(Ng et al., 2004) [50]	[a]	Regression
	(Mohan et al., 2012) [58]	[a]	Signal Detection Theory; Regression
	(H. Douglas, 2012) [94]	[a]	-
	(Cheyne et al., 2012) [13]	NS	Signal Detection Theory; Social Judgement Theory
	(Cucchetti et al., 2015, 2023) [65, 86]	[a]	Regret Theory
	(Taylor et al., 2023) [88]	[a]	Regression
Trainee/ Resident/ Fellow vs. Attending Physician/ Consultant	(Winkenwerder et al., 1993) [98]	NS	-
	(Connors & Siner, 2015) [100]	C	-
	(Di Stefano et al., 2021) [101]	[a]	-
	(Stojan et al., 2022) [102]	[a]	-

Table 3 (continued)

Contextual Factor	Source	Result	Theoretical Paradigm
Years in Practice	(Winkenwerder et al., 1993) [98]	[a]	-
	(Hanson et al., 1996) [99]	[a]	-
	(Thompson et al., 2008) [54]	[a]	Signal Detection Theory
	(Sreeramareddy et al., 2014) [64]	NS	Regret Theory; Hybrid Theory
	(Di Stefano et al., 2021) [101]	NS	-
	(Cai et al., 2022) [83]	[a]	Regression
	(Taylor et al., 2023) [88]	[a]	Regression
Volume of Practice	(H. Douglas, 2012) [94]	[a]	-
	(Cucchetti et al., 2023) [86]	[a]	Regret Theory
Primary Care vs. Non-Primary Care	(Cahan et al., 2003) [93]	NS	-
	(Ebell et al., 2018) [73]	[a]	Regression
	(Cai et al., 2022) [83]	[a]	Regression
Proximity to Tertiary Care Centres/ Acute Services	(Mohan et al., 2012) [58]	[a]	Signal Detection Theory; Regression
	(Cheyne et al., 2012) [13]	[a]	Signal Detection Theory; Social Judgement Theory
	(Ebell et al., 2018) [73]	[a]	Regression
	(Di Stefano et al., 2021) [101]	[a]	-

[a] Statistically Significant, *NS* Not Statistically Significant, *NM-D* Not Measured, Discussed, *C* Commentary

Discussion

Classification of theoretical paradigms: descriptive, normative and prescriptive

Theoretical models for decision-making can be classified as descriptive, normative, or prescriptive (see Table 5) [2, 110–112]. Descriptive and prescriptive approaches provide an alternative view of "rationality" compared to the normative approach which is most often consistent with EUT [113].

The decision-theoretical classification of theoretical paradigms provides guidance as to how the theoretical paradigms ought to be evaluated [114]. In our review, included studies often commented on the duality or plurality of possible classifications of their theoretical paradigm, emphasizing how the authors conceptualized their contribution and sought to evaluate their study. For example, Djulbegovic and colleagues (1999) discuss that the concept that "acceptable regret may have prescriptive as well as descriptive value" [8] and Asch and colleagues (1990) noted that their threshold models, informed by information theory, "are neither solely descriptive nor solely normative" [36]. While the regression method for decision thresholds may be commonly considered a descriptive decision-theoretical classification, it can also be considered normative owing to its connection to EUT. Dual processing theory has typically been characterized as a descriptive theory [12], yet hybrid theory, essentially a version of dual processing theory [14], has been previously classified as a prescriptive theory [51]. To further complicate efforts to categorize these models, not all authors provide reflections on/ identification of the decision-theoretical classification they associate with their research. Although classifying models and paradigms as descriptive, prescriptive, or normative could augment our understanding of their potential applications, accurately doing so will require future researchers to reflect and report on this in their publications.

Regret theory: a larger body of literature

We have identified regret theory as the most common non-EUT paradigm used to inform decision thresholds within the context of medical decision-making. Importantly, regret theory extends beyond the medical decision-making literature; regret research appears in many different fields, including economics, psychology, medicine, law, organizational behaviour, to name few [115].

Regret is often identified as a driver of 'irrational' decision-making given its tendency to influence people to make decisions that are inconsistent with EUT [116]. Under the traditional approach to decision-making, decisions are expected to be driven by EUT [117] where a 'rational' decision is one that maximizes the expected utility of the final assets [23, 24]. Other scholars maintain that because anticipated regret causes people to think more elaborately before making their decision, that regret can also induce rational decision-making [118].

Regret is a cognitively based emotion that refers to the affective reaction of unfavourable outcomes [119, 120]. Specifically, regret can be measured as "the difference

Table 4 Subjective Factors that may Influence Decision Thresholds

Subjective Factors	Source	Result	Theoretical Paradigm
Health Related Factors			
Health Status	(Cotler et al., 2001) [48]	[a]	Regression
Perceived Severity/ Risk of Disease	(Lahaye et al., 2014) [96]	[a]	-
	(Connors & Siner, 2015) [100]	NM-D	-
	(Nair et al., 2017) [95]	NM-D	-
	(Taylor et al., 2023) [88]	[a]	Regression
Perception of Adverse Events Associated with Treatment	(Hartz et al., 1986) [32]	NM-D	Regression
	(McAlister et al., 2000) [45]	NM-D	Regression
	(Cotler et al., 2001) [48]	[a]	Regression
	(Greenfield et al., 2005) [103]	Q	-
	(Ost & Gould, 2012) [104]	R	-
	(Connors & Siner, 2015) [100]	NM-D	-
	(Sonnenberg, 2015) [67]	NM-D	Hybrid Theory
	(Nair et al., 2017) [95]	[a]	-
Familiarity with the Disease/ Previous Experience	(Coenen et al., 2000) [46]	Q	Regret Theory
	(McAlister et al., 2000) [45]	NM-D	Regression
	(Brundage et al., 2001) [92]	NS	-
	(Ng et al., 2004) [50]	[a]	Regression
	(H. Douglas, 2012) [94]	NS	-
	(Donner-Banzhoff et al., 2020) [105]	Q	-
	(Billington et al., 2020) [106]	[a]	-
	(Di Stefano et al., 2021) [101]	M-NR	-
Personal Factors			
Patient Preferences	(Verp & Heckerling, 1995) [41]	Q	Hybrid Theory
	(Coenen et al., 2000) [46]	Q	Regret Theory
	(McAlister et al., 2000) [45]	NM-D	Regression
	(Brundage et al., 2001) [92]	[a]	-
	(Cotler et al., 2001) [48]	[a]	Regression
	(Man-Son-Hing et al., 2005) [107]	R	-
	(Minami et al., 2020) [108]	R	-
Time Pressures	(Coenen et al., 2000) [46]	Q	Regret Theory
	(Thompson et al., 2008) [54]	[a]	Signal Detection Theory
Perceptive Factors			
Risk Attitude	(Ost & Gould, 2012) [104]	R	-
	(Lazarus & Ost, 2013) [109]	R	-
	(Felder & Mayrhofer, 2014) [62]	NM-D	Hybrid Theory
	(B. Djulbegovic et al., 2012) [12]	NM-D	Regret Theory; Dual Processing Theory
	(Connors & Siner, 2015) [100]	NM-D	-
	(Courbage & Peter, 2021) [81]	NM-D	Hybrid Theory
	(Sevim & Felder, 2022) [85]	NM-D	Hybrid Theory
Culture/ Religion & (dis)Incentives	(Mohan et al., 2012) [58]	NM-D	Signal Detection Theory; Regression
	(Sonnenberg, 2015) [67]	NM-D	Hybrid Theory
	(Ebell et al., 2015) [66]	NM-D	Regression
	(Nair et al., 2017) [95]	[a]	-
	(Minami et al., 2020) [108]	R	-
	(De Alencastro et al., 2020) [78]	NM-D	Regression

[a] Statistically Significant, *NS* Not Statistically Significant, *NM-D* Not Measured, Discussed, *R* Review, *Q* Qualitative Study, *C* Commentary, *M-NR* Measured but not Reported

Table 5 Decision-Theoretical Classifications

Decision-Theoretical Classification	Interpretation	Evaluation Criterion
Descriptive	"Descriptive theories attempt to describe and explain how people actually make their decisions address this 'is' versus 'out to' phenomenon" [2]	Empirical validity [114]
Normative	"Normative theories are based on mathematical and statistical axioms addressing the question of what people 'should or ought to do'" [2]	Theoretical adequacy [114]
Prescriptive	Prescriptive theories are evaluated based on their ability to improve decision-making [114]. Typically, prescriptive theories use, "ideas from descriptive theories to modify normative decision theories" [2]	Pragmatic value [114]

between the utility of the action taken and the utility of the action that in retrospect should have been taken" [19]. Unlike other emotions, regret is uniquely tied to decision-making [115]. Regret can be *experienced*, ex-post, once the outcomes of a decision have become known, or can be *anticipated*, ex-ante, before the decision is made and is a reflection of how a person anticipates feeling if an undesirable outcome were to occur [118, 121]. Within medical decision-making most decisions cannot be reversed (e.g., surgery cannot be undone, a vaccine cannot be ungiven) and consequently decision-making is informed by anticipatory (ex-ante) regret [25]. Although decision thresholds are not specifically referenced, some of the early research on regret in medical decision-making was led by Ritov and Baron on vaccine hesitancy and omission bias [122, 123].

Regression: is it a novel theoretical paradigm?

Regression models are commonly employed to estimate decision thresholds in an ex-post fashion (i.e., after the decision has been made) in the medical decision-making literature. Within our scoping review we classified "regression" as a theoretical paradigm for decision thresholds to capture the articles that discuss decision thresholds and use regression models within the context of a medical decision. However, on a conceptual level, we maintain that "regression" should not necessarily be a considered a theoretical paradigm that is distinctive from EUT. To the extent that our inclusion and exclusion criteria were established a priori (as is appropriate for scoping review methodology) we could not exclude these articles because they do not explicitly reference an EUT theoretical paradigm These articles used regression as a method of analysis to estimate an individual's decision threshold. To this end, the articles that leverage regression models explore various factors that may inform a decision threshold or use scales to derive a quantifiable decision threshold, but do not propose a novel theoretical construct (beyond EUT) to understand such a threshold.

Hybrid theory, net-benefit, information theory and personal preferences

Our review identified several different theoretical paradigms for decision thresholds. The theoretical paradigms for decision thresholds of: "hybrid theory", "information theory" and "net-benefit" are distinctive in their own-right but often have similarities. Importantly, each of these paradigms are referred to as distinctive theoretical paradigms within the literature. However, within each of these theoretical paradigms the incorporation of the concept of "choice" or "values" was a common theme. To this end, while the underpinning mathematical equations to derive the associated decision threshold respective of each of these theoretical paradigms may be different, the consideration of an individual's preferences (choices) differentiates these theoretical paradigms from those of regret theory, dual processing theory, signal detection theory and regression techniques.

Dual processing theory

Outside of the medical decision-making literature (e.g., sociology, cognition, etc.) the dual processing theory is, "widely accepted as a dominant explanation of cognitive processes that characterizes human decision-making" [12]. Within the fields of sociology and cognition the dual processing approach to decision-making is recognized as the dominant mechanism for reasoning [124–127]. Specifically, the dual processing theory adds a decisions threshold that is calculated through a combination of affective reasoning (i.e., "type I") and analytical reasoning (i.e., "type II") [12, 22]. Effectively, the DPM incorporates "type I system" reasoning by using anticipated regret as a proxy of the affect or emotion that is commonly used in "type I system" reasoning [12]. The DPM also incorporates "type II system" reasoning through an EUT approach [12]. It is the combination of "type I" and "type II" system reasoning to estimate a decision threshold that differentiates dual processing theory from regret theory and EUT. We, again, reflect that it has been claimed that

the dual processing theory of decision thresholds has been demonstrated to be more consistent with physician decision-making than thresholds determined by EUT and regret theory [25]. It is also worthy of highlight that the hybrid theory is generally considered a version of the dual processing theory of decision-threshold analysis [14]. In this review we classified "dual processing theory" and "hybrid theory" as distinct theoretical paradigms for decision thresholds. However, if we accepted these theoretical paradigms as one and the same then dual processing theory would become the most frequently used theoretical paradigm for non-EUT decision thresholds within medical decision-making. It is important to note that in the literature dual processing theory and hybrid theory are recognized as distinct theoretical paradigms. Dual processing theory incorporates "type I" and "type II" system reasoning, whereas hybrid theory suggests that decision-makers should incorporate weighting/ preferences relative to the identified possible outcomes and does not consider a balance between "type I" and "type II" system reasoning. To this end, there may be the potential for hybrid theory to be incorporated into dual processing theory by way of the "type I" system reasoning.

Contextual and subjective factors: limited theoretical underpinning

This scoping review identified several contextual and subjective factors that have been reported in the literature to inform or influence an individual's decision threshold. Importantly, the evidence on almost every contextual and subjective factor is inconsistent and the effects of the identified factors on decision thresholds is not certain. For example, five studies identified that age was a significant factor in determining an individual's decision thresholds [34, 78, 82, 91, 92], whereas three other studies found age to not be a significant factor [93, 95, 128]. Part of the heterogeneity observed in the literature on the contextual and subjective factors influencing decision thresholds may be a result of poor theoretical conceptualization of decision thresholds. In the majority of studies where contextual or subjective factors were explored, there was little, if any, theorization of decision threshold and instead there was a reliance on regression models. Consequently, it may be possible that contextual and subjective factors have different levels of influence depending on how the decision threshold is theorized.

Contributions

The 2015 narrative review by Djulbegovic and colleagues [14] offered a comprehensive description of the research on decision thresholds in medical decision-making at that time. A decade later, we decided to re-examine the full extent of this research using a rigorous and systematic approach. Notably, the literature on decision thresholds in medical decision-making has matured and almost doubled in volume since 2013 – a limiting date used by Djulbegovic and colleagues in their review [14].

Djulbegovic and colleagues identified regret theory, hybrid theory, and dual processing theory as the theoretical paradigms for physician's decision thresholds. While this finding remains true today, our review also revealed several other theoretical paradigms for decision thresholds were used by physicians and lay individuals. We also identified various contextual and subject factors that may influence an individual's decision thresholds.

Limitations

Although our scoping review followed best methodological practices, it still has a few limitations. First, our review was limited to articles in English language that were indexed on SCOPUS, MEDLINE (Ovid), or ProQuest (Theses and Dissertations). Consequently, it is possible that our review failed to identify relevant articles that were not written in English and/or not indexed on either of the identified databases. Second, while our search strings and selection criteria were intentionally broad and used the most frequently employed terms, decision thresholds can be referred to by a wide variety of names (e.g., test threshold, diagnostic threshold, isolation/ quarantine threshold, thresholds for specific diseases, etc.). Thus, our review may have failed to identify relevant articles; however, we believe this is likely a small minority of articles which would not meaningfully change the overall findings of our systematic scoping review. Third, our review excluded decision thresholds that pertained to a clinical outcome assessment/ clinical guidelines/ prediction models (e.g., studies that sought to quantify the safety and accuracy of a diagnostic clinical aid) as well as policy thresholds (e.g., willingness-to-pay thresholds) as they are not informative of how individual's make decisions. Fourth, within the included articles we reflect that there is a concentration of authors who are repeatedly included in the review. For example, Dr. Benjamin Djulbegovic is listed as an author on 21 of the 68 articles that discussed various theoretical paradigms for decision thresholds. While we do not perceive this to be a methodological limitation of our scoping review, the concentration of authors is an important consideration relative to the intellectual heterogeneity within the corpus of the literature. Fifth, our review did not attempt to interrogate the intricate differences between the different theoretical paradigms as it was beyond the scope of our review. It is possible that some of theoretical paradigms may share similar structures to EUT paradigms (e.g., regression, information theory, etc.). However, to the extent that these theoretical paradigms are uniquely

identified within the literature, they warrant identification as non EUT theoretical paradigms within this review. Sixth, our review included articles that were indexed as of July 2023. Consequently, there may be new articles that were published since this time that are not captured in our review; ultimately, this is an unavoidable limitation of any systematic scoping review within an active and evolving field. Finally, our review had a relatively narrow focus on medical decision making. Given, decision thresholds are explored within other contexts (e.g., insurance [129–131], risk perception [132–134], law [3–7, 135] econometrics [110], etc.), it is possible that there may be additional theoretical paradigms and contextual/subjective factors (i.e., identified in other bodies of literature) than were discussed within this review.

Implications for practice and future research

From the perspective of clinical practice, decision thresholds have been called the "linchpin" between evidence based medicine and decision-making [2]. Yet, despite their significant role in clinical decision-making, there is a lack of consensus on which theoretical paradigm should be used to determine patient or physician decision thresholds [136]. Consequently, greater consideration should be given for choosing the theoretical paradigm used to inform ex-ante decision thresholds. From a practical perspective, if a physician can better understand a patient's implicit decision threshold (e.g., perhaps through a regret theory or dual processing theory lens), they can improve patients' decision-making by focusing on specific anticipated regrets of false positives or false negatives.

From a future research perspective, we have several recommendations. First, authors should be cognisant of the multiplicity of like-terms that are often used to reference decision thresholds (e.g., diagnostic thresholds, treatment thresholds, testing thresholds, etc.) which can only be resolved through a convergence within the academic community to adopt consistent terminology. We propose "decision thresholds" to be sufficiently flexible to capture the breadth and scope of related terms. Consistency in language allows for easier identification of literature and may help to avoid duplicative or redundant research effort. Secondly, we encourage authors to consider, and identify, within which decision-theoretical classification their paradigm should be interpreted (i.e., descriptively, normatively, and/or prescriptively). Third, we call for more research on how decision thresholds inform individual medical decisions. Specifically, it would be advantageous for future scholarship to conduct additional research on which theoretical paradigm for decision thresholds best explains an individual's decision threshold for medical decisions. Consequently, this would help to narrow the number of theoretical paradigms that are used to inform decision threshold analyses [25, 71]. Finally, we encourage additional methodological research on the contextual and subjective factors that inform an individual's decision threshold; additional research is required to better understand the impact these factors might have on decision thresholds.

Conclusions

To our knowledge, this is the first review of non-EUT decision thresholds used in medical decision-making that adopts a rigorous systematic search and reporting methodology (i.e., PRISMA-ScR). As the body of literature on the role of decision thresholds in medical decision-making continues to grow in popularity, this study offers a critical, systematic, characterization of the existing literature. Importantly, this study will help to ensure that authors of future scholarship to appropriately situate their work within the body of literature and leverage appropriate and relevant theoretical paradigms to underpin their understanding of decision thresholds.

Regret theory, hybrid theory, and dual processing theory were identified as the most common theoretical paradigms that are used to inform an individual's ex-ante decision threshold, but other theories have been introduced in recent years. Further, although a substantial set of studies examine contextual and subjective factors that impact decision thresholds, we note considerable heterogeneity in the reported effect of these factors. We also observe a striking infrequency of theoretical grounding in these studies.

Supplementary Information

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Supplementary Material 1.

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Authors' contributions

Study concept and design: AS, AC, KB, WM; acquisition of data: AS, AC; critical revision of manuscript: AS, AC, KB, WM; final approval of the version to be published: AS, AC, KB, WM; agreement to be accountable for all aspects of the work: AS, AC, KB, WM.

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Availability of data and materials
The search strategies used to inform this scoping review are available in the supplementary text. Summaries of included articles are also available in the supplementary text.

Declarations

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