**Overall Discussion**

Over the course of this thesis, we have presented research that has contributed towards our goal of understanding the cognitive mechanisms of medical diagnoses. In particular, we aimed to use the study of information seeking, hypothesis generation and confidence to build an integrative model of the diagnostic decision process. In this section, we first provide a brief summary of each of the previous chapter’s findings. We then synthesise these findings into an overall account of the diagnostic process, whilst contextualising this account in both medical practice and past research. We finally provide an evaluation of the strengths and limitations of this thesis, with both implications and future work for other researchers and medical educators.

In Chapter 2, we presented a scoping review of the existing literature on confidence during medical diagnoses. From this review, we found evidence that confidence judgements during medical diagnoses were rarely calibrated to objective performance/accuracy. We also found that confidence was linked to other aspects of the patient care process, such as referrals to specialists, prescribing medication and ordering tests. We used the past findings in the extant literature to propose a conceptual model of decisional, clinician-based and contextual factors that impact diagnostic confidence. We noted that the majority of past studies utilised textual patient vignettes to study diagnoses as single decisions, rather than more dynamic decisional processes.

In Chapter 3, we presented an online study that used more dynamic patient vignettes to look at how medical students seek information and manage a set of differentials over the course of a diagnostic decision. We found in this study that the breadth of differentials initially considered by participants (based on information on the Patient History) was predictive of how much information they subsequently sought, as well as being associated with gaining more confidence over the course of the case. We found that diagnostic accuracy was predicted by seeking more valuable information and being more standardised in the information that was sought across patient cases.

In Chapter 4, we presented a think-aloud study that recorded the verbalisations made by medical students whilst seeking information and recording confidence during the same patient cases as used in Chapter 3. By coding verbal utterances made by participants, we were able to detect different reasoning strategies used on each case. Despite recruiting medical students based at the University of Oxford (and hence controlling for educational experience), we found that students displayed a wide range of reasoning strategies that were not simply tied to differences between individuals or between cases. We also had findings that corresponded with those from the online vignette study, namely that students tended to put a lot of weight on generating differentials from the Patient History and then adopted a general pattern of broadening the differentials they were considering as they received more information.

In Chapter 5, we presented a study that used naturalistic paediatric scenarios within VR to study information seeking and confidence among medical students. We found that higher confidence earlier in the scenario was associated with more tests being sought later on. We also found that participants were more confident in their diagnosis at the end of the scenario, after they had administered more treatment during the scenario. Unlike the two preceding studies, we found that participants tended to narrow the range of differentials they considered over the course of scenarios.

In Chapter 6, we presented observations via a rapid ethnography approach within real medical settings, namely within an Adult Intensive Care Unit (AICU) and an Emergency Department (ED). We aimed to use these observations to assess the strengths and limitations of this work, particularly with regards to its applicability to real medicine. We found that situations of diagnostic uncertainty arose both in terms of a lack of immediately available information on the patient (in AICU) and in terms of projecting forward in terms of how a patient will develop in the future (in ED). We also found that information seeking, such as requesting tests, had a strategic aspect in terms of seeking tests to confirm/rule out a particular diagnostic hypothesis, which varied across clinicians in terms of their approaches. However, the information seeking process was also found to be affected by contextual factors, such as the availability of staff and time pressures, which brought with them differing diagnostic reasoning strategies (such as narrowing differentials as quickly as possible during busy shifts).

Across these chapters, we increased the naturalism of the methodologies used, capturing more aspects of real medical practice with each successive study. A key consideration for this research was to generate findings that could be directly applicable to medical decision making. Hence, we utilised a variety of experimental methodologies, including simulation-based and observation-based techniques. To our knowledge, this is the first work of this kind to study diagnostic decisions with such a variety of approaches, whilst maintaining a consistent focus on information seeking, hypothesis generation and diagnostic confidence across all studies. By utilising this variety of techniques, it increases the reliability of findings that are found to be concordant across these different methodologies.

**An Integrative Model of Diagnosis**

The inception for this research was the preponderance of past work that quantified the large scale of diagnostic error (Kohn, Corrigan & Donaldson, 2000, McGlynn, McDonald & Cassel, 2015), alongside other work that made links between diagnostic errors and cognitive biases (Crowley et al., 2012, Restrepo, Armstrong & Metlay, 2020). There is also a rich set of extant literature that has consistently found diagnostic confidence to be miscalibrated relative to the objective accuracy of clinicians across different experience levels (Friedman et al., 2001, Yang, Thompson & Bland, 2012, Meyer et al., 2013). We then aimed to understand how such miscalibrations occurred and whether they occur due to certain (perhaps suboptimal) information seeking patterns. As our research findings have evolved, our focus has broadened, with our aim being to better understand and model the diagnostic decision process as it develops over time and as more information is sought.

When we consider our key findings across studies, we can propose an account of the diagnostic process as it emerges in medical practice, which builds on the account provided during the Discussion section of Chapter 3 (on our online study). In Table 7.1 below, we detail the main stages of the diagnostic process, alongside with a summary of the corresponding findings from our studies that support each of these stages.

|  |  |  |
| --- | --- | --- |
| **Stage of the Diagnostic Process** | **Description** | **Associated Study Findings** |
| 1 | Clinicians take a history of the patient that, based on past experience with patients and knowledge of prototypical (or ‘textbook’) cases of certain condition, bringing to a mind an initial set of differentials. | Medical students’ initial diagnostic breadth is predictive of subsequent information seeking and changes in confidence  *(Online Study, Figures 3.6A and 3.6B, Chapter 3)*  Medical students report a tendency toward gradual investigation that builds on the patient history  *(Think-aloud Study, Thematic Analysis section ‘Heuristics when Making Diagnostic Decisions’, Chapter 4)*  Medical students made more appropriate diagnoses when seeking more useful information about the patient’s medical history  *(VR Study, Figure 5.7, Chapter 5)* |
| 2 | Clinicians then seek information to broaden the differentials they are considering, such that they aim to consider a wide enough range of potential hypotheses for the patient’s condition. | Medical students tended to broaden the differentials they were considering with more information  *(Online Study, Figure 3.5, Chapter 3 & Think-Aloud Study, Figure 4.1A Chapter 4)*  Medical students reported an awareness of the importance of being open-minded when considering new differentials  *(Think-aloud Study, Thematic Analysis section ‘Avoidance of Anchoring’, Chapter 4)* |
| 3 | After reaching a point of (perceived) sufficient broadening, clinicians then seek to either narrow their set of differentials or adopt a ‘pattern recognition’ approach based on their broad set of differentials. They do this by seeking either directed hypothesis-driven tests or by beginning certain kinds of treatment. The feedback from both (in terms of the patient’s reaction in the latter case) are then used to determine a narrower set of differentials (or a single differential) to focus on as a ‘primary diagnosis’. Other differentials may be simultaneously considered by clinicians as secondary (or, in the back of their mind), but this tends not to exceed three or four differentials. | In a scenario where a patient could be treated, medical students tended to narrow the differentials that they were considering with more information  *(VR Study, Figure 5.5, Chapter 5)*  The number of tests performed by medical students was positively associated with the final confidence reported in their understanding of the patient’s condition  *(VR Study, Information Seeking and Confidence section, Chapter 5)*  Clinicians were observed to seek tests in a hypothesis-driven manner, by looking to rule in or rule out a particular condition/differential *(ED Observations, Information Seeking section, Chapter 6)* |

*Table 7.1: Integrative model of diagnostic decisions, with respect to information seeking and hypothesis generation, based on findings from our studies. The Description column details the three stages of the diagnostic decision process. The main findings from our studies that support each of these stages is provided in the Associated Study Findings column, including the section/figure of the thesis from which these findings are taken.*

On step 1 of this process, we found that the influence of early differentials generated from the Patient History during the online vignette study (Chapter 3). We also found, from qualitative thematic analysis, that medical students tended to adopt an approach of progressive investigation, starting from history taking for a patient (Chapter 4). This corresponds with past findings that history taking contributes to around 70%-80% of final diagnoses, relative to physical examinations and laboratory investigations (Hampton et al., 1975, Peterson et al., 1992, Tsuakamoto et al., 2012) (or 56% when using a more conservative estimate from Sandler, 1980). Adopting an approach that stems from history taking also has clear advantages, as clinicians have been found to be more accurate in their diagnoses when presented with a patient history first during a case rather than other information (Tio et al., 2022). It has also been found that differentials are more influential when considered earlier on in the decision process (Kourtidis et al., 2022), which would speak to the importance of early history taking and the differentials generated from said history. History taking, when done well, could also lead to more selective and cost-effective choices for specialised tests (Muhrer, 2014). While beginning with information from the patient’s history makes intuitive sense for a clinician seeking to understand a patient’s condition, it also seems to have benefits for diagnostic accuracy and is noted a key consideration for medical students from our research.

On step 2 of this process, we found evidence that medical students tended to broaden the differentials they were considering in both the online vignette study (Chapter 3) and the think-aloud study (Chapter 4). Consideration of a broad set of differentials has been cited as a positive result of history taking, leading to a consideration of a broad range of etiologies/pathophysiological systems (DeVries, 2017). We found in our online study that confidence was positively associated with both the amount of information sought and how much the number of differentials being considered changed over the course of the decisional process. This confidence was in terms of readiness to treat, and the following step of this integrative model is related to using patient treatment to narrow diagnostic differentials. With this in mind, this step involves clinicians being as comprehensive as possible (in terms of considering differentials) up until the point of beginning treatment for the patient. This is also seen in medical practice. Within primary care, common strategies that have been identified for diagnoses and treatment plans among physicians include staying open to alternative diagnoses, taking actions to minimise the chance of missing critical diagnoses and allowing symptoms to develop to gain more information (Hewson et al., 1996). Maintaining an open minded approach to diagnoses is also important for avoiding premature closure, whereby a clinician closes off their thinking for other diagnostic possibilities too early, ignoring incoming but crucial information (Eva & Cunnington, 2006). This indicates that before treatment is able to provide feedback to the clinician, remaining as open minded is important for safe and accurate diagnoses.

On step 3 of this process, we posit that the act of administering treatment and hypothesis-driven tests is key to narrowing the differentials being considered from the broad range being considered just prior. As noted for both the online (Chapter 3) and the think-aloud (Chapter 4) studies, we showed that the vast majority of participants broadened their differentials with more information (with a small minority tending to narrow their differentials on average across cases). This marks a key difference from our VR study (Chapter 5), during which participants tended to narrow their differentials over the course of the scenarios. We note a few main differences in the methodology of our VR study relative to both vignette studies:

* Participants could visually inspect a patient and even talk to them in real time.
* Participants could request a wider range of specific tests/investigations.
* The present patient deteriorated over the course of the scenario if no action/intervention was taken.
* Participants could administer treatment to improve the patient’s current state.

These differences provide an account for why participants narrowed their differentials, unlike during the vignette studies. Participants could use the administration of treatment and the requests for specific hypothesis-driven tests to narrow their differentials, especially given that a patient’s reaction to treatment (i.e. whether they improve or not) is useful as a marker for whether the clinician’s diagnostic thinking is correct or not. This corresponds with the view that treatment is not only as end goal of diagnosis, but is itself a form of diagnosis (Brody & Waters, 1980). As the vignette studies did not contain an observable patient who could be treated, as well as the same tests (that were relatively general) across all cases, participants did not gain enough specific knowledge that could help narrow their differentials. This is similar to the decision process found by Arocha and Patel (1980) for intermediate medical students, who would broaden their differentials but then lack the knowledge to use the information provided to narrow their differentials. Taken together, this marks a deviation from our thinking based on our vignette studies that broadening and narrowing differentials mark different types of diagnostic decision processes or reasoning strategies, but instead can be thought of different parts/stages of the same process.

**Constraints on Generalisability**

Given our efforts during this research to ensure that our findings are applicable to real medical decisions, we now explore the generalisability of our findings in this section, in light of limitations to generality within the field of psychology (Yarkoni, 2020). Across all of our studies, we emulated some key aspects of real medical practice, such as the re-evaluation of diagnoses in the face of new information (in our vignette studies) and the urgency of some medical scenarios prompted by a visible patient who is deteriorating (in our VR study). We believe we have utilised methodologies that emulate diagnosis as an evolving decisional process, rather than a single decision. As noted during observations in real medical settings (see Chapter 6), there are aspects of medical practice that are not emulated within our empirical paradigms. Broadly speaking, it is likely that clinicians would behave differently in the workplace compared to how they would behave in a controlled experimental environment. For example, healthcare staff can often be balancing competing tasks and multiple patients during their work, whilst participants in our studies were able to focus on a single patient case at a time. Whilst our VR study comes closest to emulating real medical scenarios (e.g. when a patient is severely deteriorating in front of a clinician, demanding action to be taken), the wider healthcare context has been demonstrated to impact decision-making on the part of individual clinicians, such as shift busyness and time pressures (Yang, Thompson & Bland, 2012, Soares et al., 2019, Gupta et al., 2023). Staff also tend to have access to more resources than are made available during our experiments, such as help from other colleagues and online resources (e.g. guidelines, frameworks, best practices etc.). We do emphasise however, that this research has emulated many aspects of the diagnostic process as it is exhibited in real medical practice (based on observations in AICU and ED). As a result, not emulating some aspects of medical practice does not diminish our findings. We also note that studying how clinicians make decisions in an individual context allows us to isolate aspects of the decision and clinician (as per our conceptual model, Figure 1.3) that affect diagnostic accuracy and confidence. This then allows us to posit how environmental factors may impede this process, which has implications for healthcare practitioners.

**Implications for Cognitive Psychology Research**

Before considering this work’s implications for medical practice and education, we first consider its implications within the field of cognitive psychology. Whilst previous work has looked at confidence within medical diagnoses, this thesis marks one of the first attempts (to our knowledge) to understand the cognitive mechanisms of the diagnostic process using such a variety of methodologies and approaches, with increasing realism in each successive study. We also note this as an example of using cognitive psychology to study a specific type of safety-critical decision making that takes place in the real world (Boag et al., 2023), which improves our confidence in the validity of the field’s theories and methods. Increasingly, methods and theories from psychology should be used to understand naturalistic decision making (Hunt et al., 2021), particularly when those decisions have high stakes and high degrees of uncertainty (Shortland et al., 2020). Whilst we focus on medical decisions during this thesis, one could also apply this kind of approach to studying other safety-critical decisions. For example, military decisions are often made with similar conditions of uncertainty and incomplete information to medicine (Zhou et al., 2020). Future work could apply similar methodologies to those used in this thesis to other types of decisions, particularly those with multiple hypotheses and a vast space of available information. For example, previous research within problem solving used think-aloud methodologies (de Groot & de Groot, 1978) and memory tasks (Chase & Simon, 1973) to understand expertise and problem solving in chess. One could also use similar methods for more common and important decisions with a rich set of options and information, such as deciding on which house to buy or which candidate to vote for in an election. These represent examples of important life decisions that psychology could emulate and use to develop ecologically valid theories of decision making (Hechtlinger et al., 2024). In particular, the use of think-aloud and simulation-based methods allows for much richer data on how individuals make important decisions by providing ongoing insight into one’s thought process. Classifying unstructured verbal data into strategies used to perform tasks can be useful for developing cognitive models and testing psychological assumptions (Ostrovsky & Newell, 2024). In addition to such think-aloud methodologies, we also recommend future work make use of simulation-based methodologies, be they using VR or high-fidelity simulations (e.g. using actors and patient mannequins). As shown by the difference in behaviour between vignette-based and VR studies (in terms of broadening versus narrowing differentials respectively), participants in research studies may exhibit different behaviour in a controlled, lab-based testing environment when compared to a more naturalistic study. Whilst this does not necessarily call into question past results using simpler methodologies, this highlights the importance of utilising naturalistic experimental procedures in order to make claims as researchers that any findings are applicable to real-life decisions. This is especially important for specialised, safety-critical contexts such as medical decision making.

In terms of theoretical implications, we note that our results contribute to existing work on hypothesis generation and information seeking. An aspect of note is how individuals consider multiple hypotheses at the same time. We found that medical students (in the vignette studies) were able to have in mind several hypotheses based on the patient history and then considered even more hypotheses with more information. We find in our research that medical students are able to consider multiple hypotheses/differentials at the same time. Past work has shown that individuals fail to eliminate hypotheses from consideration (Wason, 1960) or to have their mind changed (Akaishi et al, 2014) especially when highly confident (Rollwage et al., 2020, Pescetelli, Hauperich and Yeung, 2021). What we find in our work is that individuals can pull away from previously considered hypotheses if they have specific enough information to help rule them out (in the VR study). In the real world, it can be difficult to obtain information that is ‘diagnostic’ enough to help one’s process of elimination. The lack of helpful information is what they explain previous findings of resistance to changes of mind. Whilst information seeking has been studied in previous work, it has not tended to focus on the value of information, even though the expected value of information has been cited as guiding our attention (Manohar & Husain, 2013). In the context of diagnosis, the identification of critical information (in amongst other, less useful, information) is important to improve diagnostic accuracy (Kostopolou et al., 2008). Future work could then consider information seeking for contexts in which not all information is equal in terms of their value (which is more analogous to the real world).

This work also contributes to ongoing research on metacognition, which has been previous defined as the thoughts that one has about their own thoughts (Flavell, 1979). Decision making can be thought of as a cycle between states of monitoring and control (Nelson & Narens, 1990). Decisions, even the simplest ones, usually come with the ability to self-reflect and monitor how the decision is made. For example, a doctor may decide on a diagnosis for a patient, prescribe a corresponding course of treatment and then monitor how the patient develops after this treatment. If the patient does not improve, the doctor might reconsider their initial diagnosis. This is an example of how we may monitor our decisions after we make them and then use this monitoring to change our behaviour. More generally, when we believe we have made an error on a decision, we slow down on subsequent decisions in order to minimise future errors in a phenomenon known as ‘post-error slowdown’ (Rabbitt, 1968). Similarly, we may speed up when we perceive ourselves to be making few errors. This trade-off between speed and accuracy is a common example of how monitoring our own performance influences future behaviour. This monitoring of our own performance can be thought of as an example of metacognition, with confidence being an example of our thoughts about our own thoughts.

In our vignette studies, we found that medical students provided confidence judgements that were calibrated to objective accuracy, indicating an ability to accurately, metacognitively introspect. In our VR study however, we did not find evidence that confidence judgements were calibrated to objective accuracy. These divergent findings could be explained by the different measures used to operationalise accuracy across our studies. Each of these measures were chosen based on the specific study and the types of decision being made. When considering these findings together, there is scope for future work to establish a common best practice for defining accuracy and confidence during diagnosis studies (and other decision making studies). As we found during our VR study, ‘accuracy’ as a concept can be hard to establish in a context such as medical diagnosis. For research on metacognition, particularly confidence, a ‘ground truth’ is usually needed to ascertain the quality of one’s metacognition. Future work could then use naturalistic decisions to consider what would constitute high accuracy/performance in situations where ‘ground truth’ is not as easy to define as in controlled lab experiments (where findings related to accuracy may not be as ecologically valid).

When modelling decisions, confidence is usually considered to be fuelled by the relative strength of evidence accumulated in favour of a decision alternative/choice (Vickers & Packer, 1982). This process is closely related to the time it takes to respond, such that quicker decisions usually correspond with higher confidence (Kiani, Corthell & Shadlen, 2014). This evidence accumulation process is thought to be affected by the rate at which information is used to updates one’s beliefs (Kloosterman et al., 2019). In our think-aloud study, we found participants utilised a range of reasoning stratagies that were not simply tied to individual decision makers or cases. Given our focus on understanding the reasoning strategies used by clinicians, we should consider whether such strategies are observable for more general tasks and whether they affect the accumulation of evidence. For instance, if an individual adopts a more thorough reasoning strategy (e.g. scheme induced), they can expect to receive much more information given the thoroughness of the process. We would expect then that each piece of information would be weighted less and update beliefs to a smaller extent than for decision processes with more selective information seeking. We also consider here a type of decision with many alternatives. Models of evidence accumulation have tended to consider two competing options for a decision (McMillen & Holmes, 2006), but could be extended to decisions with several options (Brown, Steyvers & Wagenmakers, 2009). We believe that study of reasoning strategies could aid with this, as it could be that individuals do not actually consider hypotheses at once for a decision (as in a pattern recognition) even if there are several potential options. This offers a novel path for future work on the cognitive psychology of decision making.

One other aspect of diagnoses that has broader relevance to other decisions in cognitive psychology is about how we decide that we have enough information. Individuals may have a bias towards assuming that they have adequate information to make a decision rather than seeking more (Gehlbach, Robinson & Fletcher, 2024) and evaluate less information than we might expect before making a decision (Klein & O’Brien, 2018). Having agency over information seeking also has been shown to have an impact on confidence. Individuals have been found to report a ‘boost’ in their confidence when they get to decide when to stop seeking information (and make a decision based on this information), which is not present when this decision point is forced upon them (Wei, 2021). When asked to seek information for a decision rather than being provided all information up front, clinicians reported lower confidence in their diagnoses (Gruppen, Wolf & Billi, 1991). In our vignette studies, participants were given freedom to choose when they had sufficient information to proceed from one stage to another. Clinicians may not be afforded complete freedom in medical contexts, where they may have to make decisions in a time-critical manner. But when there are not overt time pressures, it seems counterintuitive to not seek as much information as it available. Taken together, how individuals decide to stop seeking information is an interesting path for future work.

Future research can also consider how information seeking relates to hypothesis generation. As we have reflected in this Discussion, the diagnostic process can be thought of as comprising different stages of broadening and narrowing of differentials. This would then imply differing goals for information seeking. It has been found that individuals prefer confirmatory information when there is more information available, whilst they prefer contradictory information when less information is available (Fisher, Schulz-Hardt & Frey, 2008). With this mind, when clinicians are broadening their differentials, they may seek information to confirm (rather than rule out) differentials (referred to as a ‘positive test strategy’ by Klayman & Ha, 1987), meaning they seek more information. As we found in the online study, higher information seeking was associated with higher gains in confidence. When narrowing differentials however, clinicians seek less information, but select such information to be disconfirmatory of certain differentials. What is considered ‘enough’ information is likely to be quite different depending on which of these types of decision stages the individual is going through. For instance, do individuals decide they have enough information sooner when narrowing their hypotheses, rather than broadening them? Future work could consider psychological tasks that demand a broadening or narrowing of hypotheses, and how these might affect information seeking patterns.

Considering uncertainty using this informational account could help improve metacognitive awareness (i.e. how calibrated our judgements of confidence/certainty are), as such judgements could be prone to biases that do not weigh up the available information in a more rational, systematic matter. Understanding how uncertainty relates to the available balance of information when information differs in value and goal (affirming or contradicting) could help us understand how uncertainty is studied within psychology, which has historically been a difficult area for research:

*“All the social sciences, in different measure and manner, have been struggling with the place of uncertainty as an aspect of their research and theory.”* (Fiddle, 1980, p. 6)

**Implications for Medical Practice and Education**

We now turn to the implications of our work for future medical education and practice. Firstly, our results have implications for how medical educators think about clinical reasoning and how it is taught. In our think-aloud study, we showed that medical students did not have a conscious awareness overall of the reasoning strategies that they tended to use when making diagnoses. It has been shown in past research that individuals tend to be much better at seeing cognitive biases in others when compared to themselves (Pronin, Lin & Ross, 2002), indicating that individuals may lack insight into their own decision process. It has been suggested that teaching about cognitive biases and reasoning can help reduce diagnostic errors (Royce, Hayes & Schwartzstein, 2019). What belies the focus on such education interventions is that there is a single, optimal approach to diagnostic reasoning that should be taught (Kassirer, 1983). As our findings suggest however, medical students vary in how they approach diagnoses even when relatively homogenous in terms of their medical education (i.e. being educated within the UK). When resolving diagnostic uncertainty, there can be room for both structured, analytic approaches and more intuitive approaches to clinical reasoning (Custers, 2013). Rather than teaching a single approach to clinical reasoning, we recommend that medical students are taught a number of approaches that they could choose to utilise depending on the situation at hand. Our research currently does not provide a clear answer as to what properties of a patient case prompt a particular strategy to maximise diagnostic accuracy. For example, should a clinician seek to broaden their differentials (and not rule any differentials out) if they are not very confident? If a patient case is complex, should clinicians adopt a pattern recognition approach (i.e. identifying if the patient condition resembles a ‘textbook’ case of a common condition)? This could be a promising avenue for future work: determining when clinicians should utilise a particular strategy and integrating multiple reasoning strategies into medical curricula.

Our work also underscores the importance of studying uncertainty in medical decision making. As reflected during observations in ED (Chapter 6), diagnostic uncertainty has an impact on patients too. The lack of a definitive diagnosis can lead to delays in treatment and it can be distressing for patients to not understand the source of their symptoms. From thematic analysis of interviews following patient vignettes, Cox, Hatfield & Fritz (2024) found that doctors were hesitant to express diagnostic uncertainty to patients during the safety netting process (i.e. advising patients on what to do going forward, especially if symptoms persist or worsen), as this was viewed to be likely to cause distress. This may lead doctors to display overconfidence to patients relative to their actual diagnostic uncertainty. Diagnostic uncertainty can also have an impact on the wellbeing of clinicians. Stress stemming from the management of uncertainty has been linked to lower resilience amongst trainees (Simpkin et al., 2018), with medical students varying in how much they can tolerate uncertainty and ambiguity (Hancock & Mattick, 2019). For both patients and clinicians, education around uncertainty is crucial for improving wellbeing. As put by Osler (1968), “medicine is a science of uncertainty and an art of probability.”

One recommended focus for medical education is on the role of information seeking in formulating clinicians’ uncertainty. Wray & Loo (2015) differentiate this as informational uncertainty (i.e. from deficits in knowledge) as opposed to intrinsic uncertainty (i.e. from the natural complexities of anatomy and pathologies). We have found in our own work and in past work (Gruppen, Wolf & Billi, 1991, Ko et al., 2022) that having more available information increase confidence. As discussed in the previous subsection (*Implications for Cognitive Psychology Research*), a key decision for clinicians to make is when they feel they have enough information to make a decision. Whilst decision aids and frameworks have tended to focus on reducing diagnostic error in the first instance (Dave et al., 2022), an intermediate (and more tangible) goal could be to design interventions to aid clinicians’ judgements of whether their current information (on patient history, examinations, tests/investigations) is enough to make any diagnosis (be it accurate or not). What may be underlying overconfidence in diagnoses is clinicians seeking insufficient information before making a decision (Meyer & Singh, 2017), with further information then being interpreted to fit that decision. More appropriate expressions of uncertainty in diagnoses could stem from fostering greater humility (Fischer, Hause & Huff, 2024) about what information is both unknown and cannot be known (Gehlbach, Robinson & Fletcher, 2024). Past psychology research has also shown that appropriate confidence judgements can be provided when asking individuals to provide both confirmatory and contradictory reasons for their decisions (Koriat, Lichtenstein & Fischhoff, 1980). Prompting clinicians and medical students to consider their current balance of information for and against their diagnostic differentials may help aid judgements of whether further information seeking is required. Such an intervention would have a positive effect. For example, one study found that the use of a cognitive framework known as SNAPPS (**S**ummarize relevant patient history and findings; **N**arrow the differential; **A**nalyse the differential; **P**robe the preceptor about uncertainties; **P**lan management; and **S**elect case-related issues for self-study) increased the expressions of uncertainty among medical students during clinical rounds (Wolpaw et al., 2012). This shows the promise of prompting uncertainty in facilitating discussions between clinicians, which can contribute to spotting potential diagnostic errors earlier on in the decisional process.

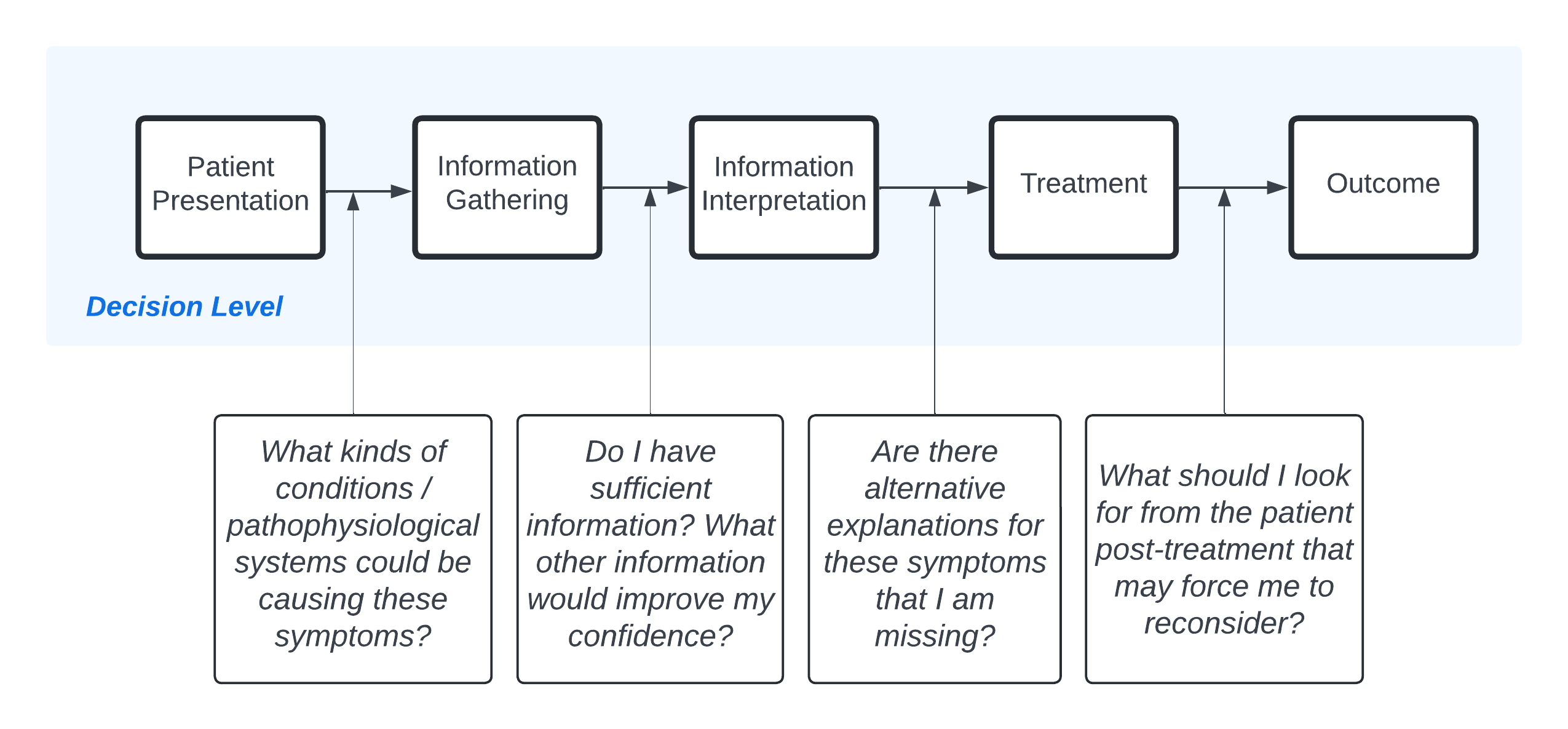
A starting point for medical education would be to clearly differentiate diagnostic accuracy and diagnostic confidence among trainees and students, to promote discussion about how further tests/information could improve either or both (Santhosh, Chou & Connor, 2019). This is especially given past findings that show confidence and accuracy to be decoupled during diagnoses (Friedman et al., 2001, Yang, Thompson & Bland, 2012, Meyer et al., 2013, Garbayo et al., 2023). Explicit teaching interventions on cognitive biases have not been shown in past research to be sufficient in addressing such biases in actual medical decisions (Fraundorf et al., 2023). Future work could then consider interventions embedded within clinical practice that prompt clinicians to monitor their own decisions and consider their uncertainty.

Enhancing our understanding of how clinicians make diagnoses and express uncertainty is of wider relevance to the growing adoption of AI tools for medical diagnoses. Large Language Models (LLMs), such as ChatGPT, have been found not to improve diagnostic accuracy even if the LLM alone outperforms most individual clinicians (Goh et al., 2024). In fact, the use of AI during decisions (of several types/contexts) has not been found to consistently improve the accuracy of human decision makers (Vaccaro, Almaatouq & Malone, 2024). Research on AI-aided medical decision making will only grow in stature as LLMs are developed and optimised specifically for medical diagnoses (McDuff et al., 2023). Therefore, understanding how clinicians themselves express uncertainty is important for understanding how such AI tools can express uncertainty in their own diagnoses, given there are several ways that this can be implemented (Savage et al., 2024). Our research showed that diagnostic confidence was predicted by either the receipt of information or by the provision of specialised tests, if available. This indicates that in order for AI tools to provide readouts of confidence/certainty that are aligned with how clinicians provide diagnoses, they should take into account how much information is made available, whether it is sufficient and whether any tests have been conducted that have had an appreciable effect on the patient. AI models that express uncertainty in their decisions should be trained to avoid the same biases and tendencies towards miscalibrated confidence that clinicians have.

**Prompting Uncertainty During the Diagnostic Process**

One potential implication for our work is that clinicians may adopt an approach of increasing uncertainty (i.e. broadening differentials, lower confidence) at different points in the diagnostic process. This brings with it a question of how future cognitive interventions or frameworks consider the point in the decision process at which they are administered to ‘prompt’ uncertainty.

In Figure 7.1 below, we provide examples of what prompting uncertainty might look like at different stages of the decisional process (using the stages outlined in the Decision Level of our conceptual model in Figure 2.3). Whilst past work has reviewed cognitive interventions that aim to reduce diagnostic error (Graber et al., 2012, Lambe et al., 2016, Dave et al., 2022), such work has not considered when during the decisional process to best administer these interventions. Given that diagnosis is an evolving process, clinicians can be prompted to ‘broaden’ their thinking at different points during the process. As found during our research, clinicians can utilise different reasoning processes that bring with them different focuses on narrowing or broadening the differentials being considered. We also found that broadening and narrowing of diagnostic differentials can happen at different points within the same diagnostic decision. Ensuring that clinicians not be prematurely close off their thinking from considering other diagnostic possibilities has been highlighted as a goal for research on diagnosis (Krupat et al., 2017).



*Figure 7.1: Decision Level of our conceptual model, developed from our scoping review (as shown in Figure 2.3). Here we provide examples of prompts of uncertainty that could take place between different stages of the process. For example, the first of these prompts (“What kinds of conditions...”) would take place after the clinician has been presented with the patient but before they have started gathering more information on the patient. The goal for these prompts would be for clinicians to broaden their thinking to consider other diagnostic possibilities that are beyond what they are considering at that point in the process.*

When proposing cognitive interventions that invite a degree of uncertainty on the part of the clinicians (e.g. deliberate reflection, Norman et al., 2014, Lambe, Hevey & Kelly, 2018, Costa Filho et al., 2019, Kuhn et al., 2023), past work has not considered when in the process to administer such interventions. This is important, because, as found in our think-aloud study with medical students, clinicians may use different reasoning strategies whilst making diagnoses. As a result, they would focus on narrowing their differentials at different points in the process. When using pattern recognition, a clinician is seeking to narrow their differentials as quickly as possible by only considering a single differential at a time that most resembles the patient’s current symptoms. When using a scheme inductive approach, clinicians are aiming to consider as broad a set of differentials as possible by systematically considering each possible pathophysiological system that could be implicated in the patient’s condition. An example of this is the VITAMINSABCDEK mnemonic proposed by Zabidi-Hussin (2016), which guides clinicians through potential etiologies/causes (e.g. vascular, infectious, trauma, autoimmune etc.) for a patient condition with the express purpose of broadening differentials. Future work should then consider how diagnostic accuracy and confidence changes depending on when in the process clinicians are asked to reconsider their thinking, and what reasoning strategy clinicians are using to make their diagnosis.

In the same way that frameworks using theory and research around metacognition have been used to design better revision techniques for students (Dunlosky, 2013, Putnam, Sungkhasettee & Roediger, 2016), the same could be applied for medical students. Where this line of work would have most value is considering cognitive interventions in a manner that is dependent on the reasoning strategy being used. For future work, an ideal goal for research would be determining the properties of a patient case that should necessitate a particular reasoning strategy and a particular time point to prompt reconsideration of one’s diagnostic thinking. This also involves detecting when clinicians may narrowing on a diagnosis too soon. The prompts of uncertainty to reconsider a diagnosis (discussed above) may be especially useful for individuals prone to ‘diagnostic momentum bias’ (Ryan, 2021, Aron et al., 2024), where a diagnosis harder to pull away from if more investigations/time has been put into pursuing it. This is related to the more general phenomenon of ‘decision inertia’ cited in the psychological literature (Akaishi et al, 2014).

Taken together, our work has implications for both the fields of cognitive psychology and medical education. We note that our work is not without limitations, especially with regards to some remaining questions around when diagnostic reasoning strategies are considered optimal. The use of different methodologies with different levels of naturalism also allow us to consider how contextual factors within healthcare settings impact decision making, which is crucial for future work to incorporate and consider.

**Conclusion**

This work was started based on results from past work that found high incidences of both diagnostic error and miscalibrations of diagnostic confidence. This thesis aimed to study the cognitive mechanisms of medical diagnoses by considering how confidence that clinicians have in their diagnosis is related to patterns of information seeking and hypothesis generation. The research presented in this thesis provides ample evidence, from a mixed-methods approach, that the diagnostic process comprises of different stages of broadening or narrowing differentials. In addition, the initial information on the patient history and its associated differentials were found to have a large influence on the subsequent diagnostic process in terms of information seeking and confidence. We found that diagnostic confidence, and the narrowing of diagnostic differentials from a broader set, is related to treating the patient and observing the patient’s state change as a result of this treatment. As we find, the link between information seeking and confidence is an important part of medical diagnoses and indeed other decisions that we as individuals make. From our findings, we propose a model of the diagnostic process that future researchers and medical educators can use to design decision aids to improve calibration of confidence by considering what information is sought.