**Overall Discussion**

Over the course of thesis, we have presented research that has aimed to understand 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 diagnostic decision processes. 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 limited 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 paper vignettes to study diagnoses as single decisions, rather than more dynamic decisional processes.

In Chapter 3, we presented an online study that used textual 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 breadth of differentials initially considered by participants (from information on the Patient History) was predictive of how much information they subsequently sought, as well as gaining more confidence over the course of the decisions. We found that diagnostic accuracy was predicted by seeking more valuable information and being more standardised in the information that was sought.

In Chapter 4, we presented a think-aloud study that recorded the verbalisations made by medical students whilst seeking information and recording confidence during textual patient vignettes. By coding verbal utterances, we were able to detect different reasoning strategies used by medical students. Despite recruiting medical students (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 findings 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 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 our previous two studies, we found that participants narrowed the differentials they were considered over the course of the scenario.

In Chapter 6, we presented observations via rapid ethnography approach within real medical settings, namely with 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 to how a patient will develop in the future (in ED). We also found that information seeking, such as 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 also brought with it to adopt differing diagnostic reasoning strategies (such as narrowing differentials as quickly as possible).

Across these chapters, we increased the naturalism of the methodologies used to capture 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 different approaches, whilst maintaining a consistent focus on information seeking hypothesis generation and confidence across all studies. By utilising this variety of techniques, it increases the reliability of our findings when they are 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 from 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 work has broadened to focus on creating a model of the diagnostic decision process as it develop over time and as more information is sought.

When we consider our key findings across studies, we can propose the following 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):

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.
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.
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.

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 qualitatively 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, 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 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).

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 and consideration of a broad range of etiologies (DeVries, 2017).

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 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. 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 previous thinking that broadening and narrowing differentials mark different types of diagnostic decision processes, but instead can be thought of different parts/stages of the same process.

**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) at different points in the diagnostic process. This brings with a question of how future cognitive interventions or frameworks can consider the point at which they can be administered to ‘prompt’ uncertainty.

In Figure 7.1 below, we again show the Decision Level of our conceptual model from our scoping review (see Figure 1.3). In this figure, we show how a clinician may experience uncertainty at each state of the decision process. We aim to show with this Figure that if aspects of the diagnostic process are standardised and codified, choosing the point at which uncertainty is prompting is key. Naturally, as clinicians adopt different reasoning strategies (as found in our studies), they may naturally ‘broaden’ their thinking (as opposed to focusing on a single option/hypothesis) at different points of the process.

A diagram of a patient's process

Description automatically generated

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.

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 situation 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. These prompts to reconsider a diagnosis may be especially 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).

**Limits to Generalisability**

Despite the efforts during this research to ensure that the methods used emulate real medical decisions, we explore the generalisability of our findings in this section, in light of limitations to generalisability within the field of psychology (Yarkoni, 2020). Across all studies however, 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 patient who is deteriorating (in our VR study). 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. It is likely that clinicians would behave different 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 study were able to focus on a single patient case at a time.

**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. We also note this as an example of using cognitive psychology to study a specific type of decision making that takes place in the real world. 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.

In terms of theoretical implications, we note that our results contribute to existing work on hypothesis generation and information seeking. 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 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.

Another aspect of note is how individuals consider multiple hypotheses at the same time.

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.

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). 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.

*“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)

Other non-medical tasks

Use of think aloud methodologies (and other qualitative approaches)

Do people consider multiple hypotheses in mind at once?

Evidence accumulation – does strategy/approach affect this process?

Evidence accumulation for complex strategic tasks (not just perceptual)

Can bring in metacognition here – information adequacy

Reasons for confidence

Bias blind spot

**Implications for Medical Practice and Education**

AI use in diagnosis (uncertainty)

Education tools for students – how reasoning and cognitive biases are taught

Uncertainty on patient side (safety netting)

Medicine as a complex system

Is there a gold standard diagnosis process?

Staff wellbeing/pressures, patient safety