Decision-making processes in image guided radiotherapy: A think aloud study.

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ABSTRACT

Introduction

3D Image Guided Radiotherapy (IGRT) using Cone Beam Computer Tomography (CBCT) has been implemented for a range of treatment sites across the UK in the last decade. A paucity of evidence exists to understand how radiation therapists (RTTs) make clinical decisions during image interpretation as part of the IGRT process. The aim of this study was to investigate the decision-making processes used by RTTs during image interpretation of IGRT.

Method

Case study methodology was adopted utilising a think aloud observational method with follow-up interviews. 12 RTTs were observed and interviewed across three UK radiotherapy centres. Participants were observed reviewing and making clinical decisions in a simulated environment using clinical scenarios developed in partnership with each centres' Clinical Imaging Lead. Protocol analysis was used to analyse the observational data and thematic analysis was used to analyse the interview data.

Results

A range of approaches to decision-making was observed which varied in length from nine phrases to 57 (mean 24) per case. Six themes emerged from the data: Set Sequence, Site Specific Clinical Priorities, Initial Gross Review, Decision to treat, Compromise and experience. In addition, three cognitive decision-making processes were identified: Simple linear, Linear repeating and Intuitive decision-making process. The findings of the study align with general principles of expert performance, whereby experience in a specific scope of practice is more beneficial in developing expertise than overall experience.

Conclusion

This study has provided new and original insight in the decision-making processes of RTTs. The study has highlighted three process models to explain how RTTs make decisions during IGRT: Simple linear, Linear repeating and Intuitive decision-making process. Intuitive

processes are widely accepted to be error prone and linked to bias. When using this process, some RTTs followed this with a confirmation phase. This second phase of the process should be encouraged when teaching IGRT.

The results of the study support the concept of expert performance, where performance and expertise are only improved by exposing individuals to specific types of experiences.

RTTs, managers and Higher Education Institutions are encouraged to review these models and implement them into IGRT training. It is clear from the evidence base that understanding how we make decisions, enables us to develop expertise and reduce errors during the decision-making process.

INTRODUCTION

The technology used in Image Guided Radiotherapy (IGRT) has seen huge advancements since the wide-spread introduction of electronic portal imaging (EPID) in the early 2000s. [1] Radiotherapy centres have seen the phasing out 2D technology for many tumour types and replaced it with high quality KV 3D-Cone Beam Computer Tomography (CBCT). [2] When implemented safely, these advancements have the potential to improve treatment accuracy and ultimately patient quality of life and outcome. [3–5]

Studies by McNair et al. [6] and Hudson et al. [7] have demonstrated that during the IGRT process, radiation therapists (RTTS) can make acceptable clinical decisions similar to those of the medical team. However, what is not clear from these studies are the clinical reasoning processes and techniques used by the RTT and medical teams to reach their decisions. If IGRT capacity is to be grown with treatments being delivered safely and, in a time sensitive manner, it is vital that the decision-making processes of RTTs are understood in order that only the most efficient and effective approaches are adopted.

Understanding how humans make decisions has intrigued the academic community and wider society since the seminal work of Tversky and Kahneman in the 1970's [8].

Clinical reasoning is particularly well researched in medicine [9] with much of the research focusing on diagnostic errors. [10–12] There is a growing evidence base of literature relating to clinical reasoning in the Allied Health Professions, [9,13–16] but there is a noticeable lack of evidence relating to clinical reasoning involving RTTs. Several studies have been published that have investigated the decision-making processes of diagnostic radiographers, radiologists and medical physicists. [17–21] These provide a useful insight into how clinical staff use medical imaging to make clinical decisions, particularly in relation to diagnosis, but do not provide adequate evidence on the decisions made during the IGRT process.

Many authors have attempted to describe how individuals make decisions in a variety of scenarios by developing descriptive models. [22] The most common models cited are Hypothetico-deductive reasoning [23], Dual process theory [24] and Cognitive continuum theory. [25]

Despite the large number of models that have been proposed in the last four decades, there is little, if any consensus about one single model that meets the requirements of clinical reasoning for all individuals, in all situations and environments. [22,26] There are however, a number of similarities across the models, and fundamental to all of them is the dichotomy between intuitive thought and analytical thought, as well as the spectrum or continuum that exists between. [27,28]

Intuition has been described as 'understanding without a rationale' [29] or 'immediate knowing of something without the conscious use of reason'. [30] Intuitive thought 'involves rapid, unconscious data processing that combines the available information by 'averaging' it has low consistency and is moderately accurate'. [28] Intuitive thought is more likely to occur under conditions of uncertainty [31] and is commonly used by those seen as experts. [16,28,32,33]

In contrast, analytical thought 'is carried out slowly, consciously and consistently'. Analytic thought is normally accurate but can occasionally lead to large and systematic errors. [28] Analytical models assume that the decision makers' thought processes follow rational logic and these can be studied until a decision has been made. [22]

Although our understanding of how humans make decisions has increased significantly in recent decades, the interest in this field has highlighted how poor humans can be at making decisions. [11,34–36] In the clinical setting this is evident, where error rates at diagnosis are believed to be around 10-15%. [34] Concerns also exist about the number of errors occur during the IGRT process. The latest biennial radiotherapy error data analysis and learning report published by UK Security Agency [37] demonstrates that onset imaging continues to be an area of concern with "on-set imaging: approval process" and "on-set imaging: production process" being the two highest sub-categories of Level 1 incidents.

The purpose of this study was to investigate the clinical decision-making processes used by RTTs when carrying out IGRT. Doing so will identify methods for the teaching of safe and efficient decision-making, that will ultimately lead to improved patient care.

METHOD

Ethical Considerations

Ethical approval was sought and gained from the University's Research Ethics Committee [redacted] This was followed by individual applications to three NHS Trust Research and Development Departments for local governance approval in participating radiotherapy departments, all of which were granted without amendments.

A process of informed consent was followed, and it was made clear to participants they could withdraw from the study at any time during or after data collection. It was acknowledged that some participants may view the observation as a test and so the researcher assured them of confidentiality and anonymity of the data that would be collected. Participants were also advised that any observations or opinions deemed to put patients at risk would be reported to the relevant person in their Centre.

Recruitment

Three UK radiotherapy centres participated in the study. They were chosen purposively to ensure a variation in size and experience of IGRT. The aim was to recruit between three and five participants from each centre, with a focus on recruiting participants with a range of experience in undertaking image analysis using linear accelerator imaging analysis software.

Data Collection

A multimethod approach [38] was adopted using the think aloud method [39] to capture observational data during a series of simulated IGRT cases. These observations were followed up with semi-structured interviews. The full process can be seen in Figure 1.0. Participants were involved in items coloured green.

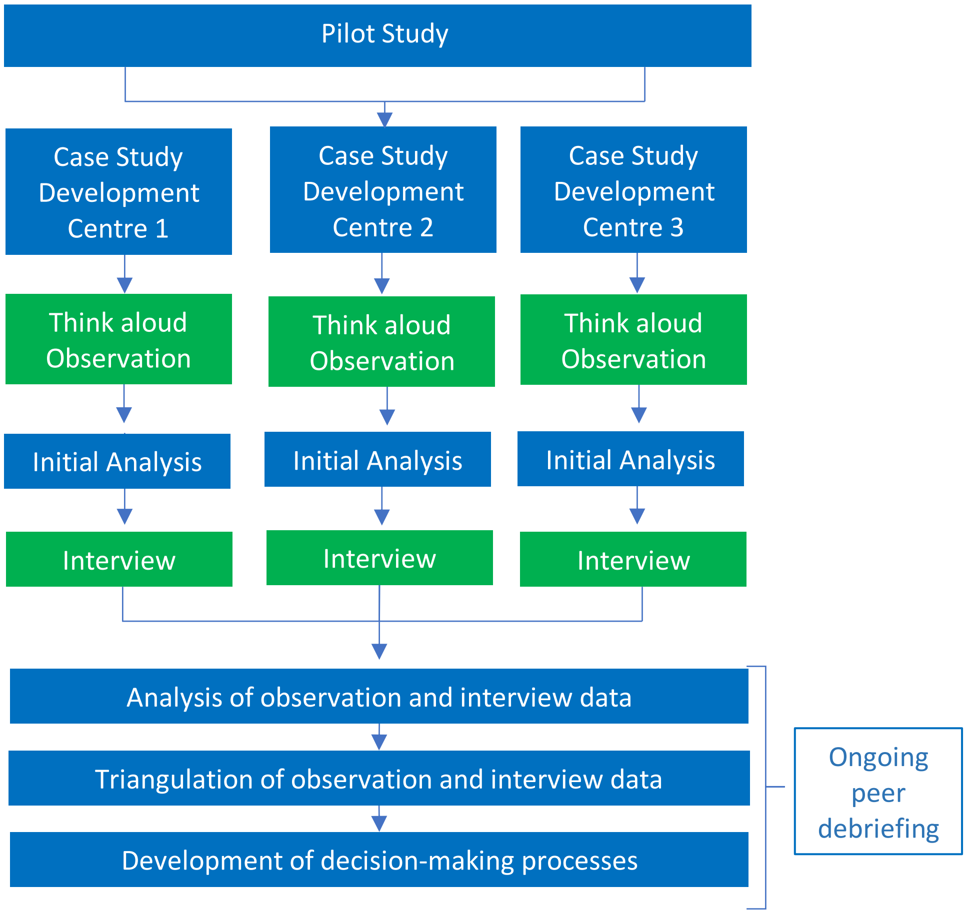

Figure 1.0. Research process

The think aloud method

The think aloud method has been widely used in other observational studies in a clinical setting [9,40–46] . Two in depth descriptions of the method have been published by Fonteyn, Kuipers, & Grobe [47] and van Someren et al. [48] and these were used along with a pilot study to adapt the think aloud method for an IGRT simulation.

The think aloud method involves participants verbalising whatever thoughts enter their mind while performing a task. These verbalisations are recorded and transcribed verbatim to produce hard data (protocols). This data is then analysed to determine what process were used. During the task, there should be minimal interruptions or suggestive prompts from the researcher, which allows the participant to focus purely on the task at hand. [49]

The pilot study was conducted with two academic members of staff with experience in IGRT. The equipment was set up in accordance with the study protocol. They were presented with two anonymised case and were asked to review the cases whilst thinking aloud. This pilot allowed the researchers to check the functionality of the software and adapted the data collection process.

Simulated IGRT scenarios

Due to the variety of clinical systems in the three departments, it was not possible for the same case studies to be used in each of the departments. Three patient case scenarios were developed with the radiotherapy centre imaging leads in each of the centres. Each centre developed scenarios that included treatment to the thorax, pelvis and head and neck, which covered a range of technical complexity and anatomical sites.

Study participants were provided with all the documentation they would expect to see during routine review of on-treatment images and asked to review the images using local protocols, whilst verbalising their thought processes.

Participants were observed reviewing the scenarios on an imaging terminal in their departments. The think aloud data was collected using high-definition video and audio equipment (Figure 2.0).

A nationally recognised IGRT expert was recruited to review each case and stated what decision they would make if presented with the data in the clinical environment. This individual was deemed an expert due to their experience and the positions they held on several national groups that influence on IGRT policy. The expert was asked to state one of three decisions based on the images presented: 1. Treat the patient; 2. Not treat the patient (this included re-positioning the patient or asking them to modify their bladder or bowel status); 3. Seek additional advice from a colleague. In addition, they rated each case on its complexity raging from 1: simple to 5: very complex.

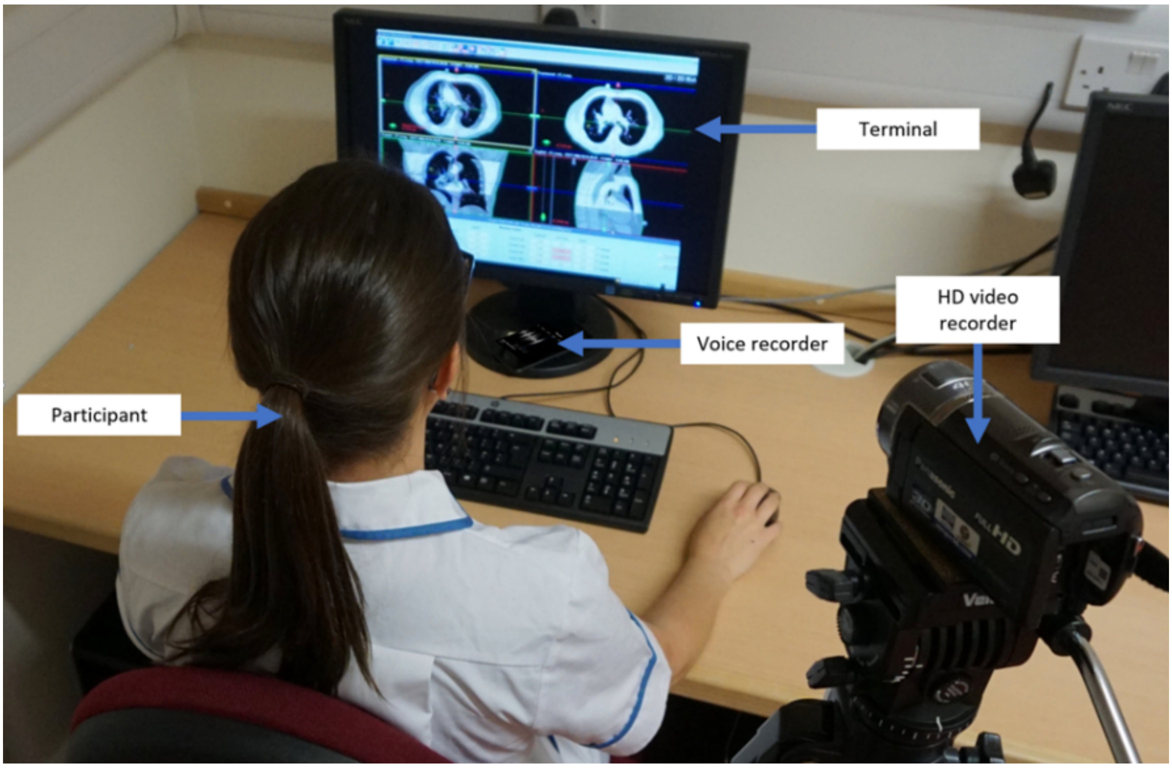

Figure 2.0 Observational set-up

Most of the participants verbalised their thought processes comfortably and with little effort, however short prompts using the terms “keep talking” or “what are you thinking” were used during each simulation when required. The researcher consciously kept these to a minimum, and only spoke when it was apparent the participant had stopped verbalising thought processes.

The researcher positioned himself out of view behind the participant, but in a position where he could see the screen. The researcher took concurrent notes throughout each verbalisation and attempted to note down anything of interest. This included any non-verbal cues as well as any concepts or ideas that required further investigation at interview.
Following the observation, the data was anonymised, and the audio recording uploaded for professional transcription.

Semi structured interviews

Follow-up semi structured interviews were conducted to further investigate the processes the participants used during the observations and to gain greater insight into the factors that impact clinical decision-making during the image analysis process. These interviews were also recorded and professionally transcribed verbatim.

Triangulation process

A triangulation protocol proposed by Farmer et al. [50] was used to combine the data collected in the observation and interview phases.

Reflexivity

During all phases of the study and write up, a reflexive approach was adopted. A reflexive account was documented prior to data collection and regularly returned to during the research process. The reflexive process highlighted that the author had a significant amount of experience in the field of study and therefore it is not inconceivable to suggest that this brings with it a number of pre-conceived ideas around best practice during the IGRT process. The reflexive account was present in the mind of the author when carrying out the observations, interviews and during the data analysis process. During the interviews, the researcher was conscious not to ask leading questions that may bias any data towards his preconceptions.

Data Analysis

All the transcripts were imported into the qualitative analysis software Quirkos 1.4 (Quirkos Ltd) for analysis.

The think aloud data was analysed using the method of protocol analysis which is fully described by Fonteyn and Grobe [51]. The process has three steps:

1. Referring Phrase Analysis- identification concepts used by participants.
2. Assertional Analysis- identification of assertions made to determine how relationships were being formed between concepts.
3. Script Analysis- overall description of the reasoning processes being used.

The interview phase of the study was analysed using thematic analysis as described by Braun and Clarke. [52] This method has six steps: Familiarization of data, Generation of codes, Combining codes into themes, Reviewing themes, Determine significance of themes, and finally, reporting of findings.

Peer debriefing of the analysis within the research team was carried out throughout the coding and analysis phase. This included cross checking, discussion and agreement of themes.

Analysed data from the observations and the interviews were triangulated using the process described by Farmer et al. [50]

RESULTS

Twelve RTTs were consented to participate in the study. The demographics of the 12 participants is shown in Table 1.0.

Participant	Case Centre	Experience as a RTT (Years)	Experience with 3D-IGRT (Years)
1	One	2-5	< 2
2	One	>20	2-5
3	One	5-10	2-5
4	One	>20	2-5
5	One	10-15	2-5
6	Two	10-15	>5
7	Two	2-5	<2
8	Two	2-5	<2
9	Two	5-10	2-5
10	Three	>20	>5
11	Three	10-15	>5
12	Three	15-20	>5

Table 1.0 Participant demographics

The decision-making process

All twelve participants verbalised their thought processes whilst reviewing three cases each (36 cases in total) in a simulated environment. Protocol analysis was used to determine their thought process for each case.

Each phrase spoken by the participants was analysed using protocol analysis. This highlighted six concepts: *Describe, Optimise Image, Evaluate, Explain, Correction* and *Treatment* (Table 2). These concepts were then combined to describe the process.

Concepts	Description	Example
Describe	When participants described or narrated the setting or patient	*Okay, so this is a lung patient, looking at day two image* (Participant 1) *So, this is head and neck mid-course* (Participant 8)
Optimise Image	When participants optimised the imaging software	*Just going to change those window levels* (Participant 2) *Change my contrast to medium and I'm starting on the isocentre slice* (Participant 7)
Evaluate	When participants evaluated the information	*Okay there doesn't seem to be any more gas or anything in there* (Participant 3) *Yes, so the bladder volume looks slightly bigger, bigger than the GTV* (Participant 6)
Explain	When participants interpreted information, or provided a rationale	*I can start to look at that because although I am doing a bony match, it's not really the bony match I am totally interested in because we are interested in what soft tissues are in the target here* (Participant 2) *My first thoughts are to check the spine position* (Participant 6)
Correction	When participants made a correction to the treatment parameters	*I'm just going to move us slightly post for better coverage* (Participant 7) *It just alters the contrast so it's a bit more clear* (Participant 1)
Treatment	When participants referred to the delivery of treatment	*I can obviously go ahead and treat online because it's covered by the PTV* (Participant 6) *I'd get someone to come and look at that online. To me, we can't be sure we're actually covering what we need to cover there* (Participant 8)

Table 2.0. Processes during decision making

Each transcribed phrase for each participant was coded to a concept and mapped onto a colour-coded model. [51] The map can be read by working across each case from left to right and using the coloured legend to determine the order of processes. An example process is shown in Figure 3.0.

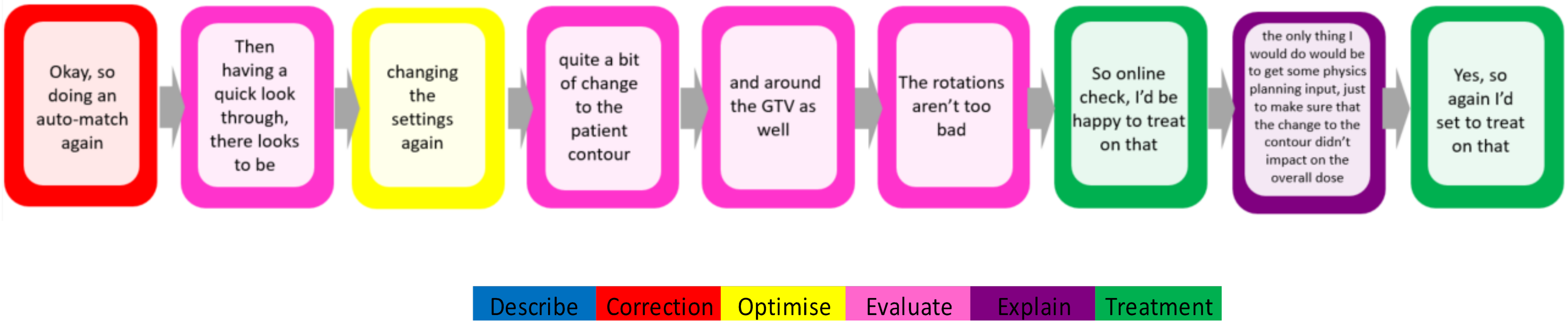

Figure 3.0 Example process

Several patterns emerged from the analysis which have been developed into three decision making processes: *simple linear, repeating linear* and *intuitive.*

The simple linear process (Figure 4.0) is the basis for all three decision-making processes and involves an early description and correction followed by an explanation and/or an optimisation, before a variable period of evaluation. The intention to treat or not treat is not verbalised until the end of the process.

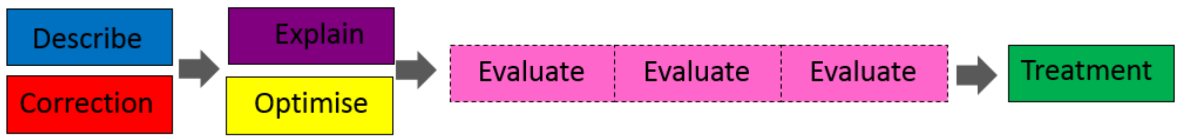

Figure 4.0. Simple linear process

The most common process was the repeating linear process. Using this process, a correction was made almost immediately, followed by a period of evaluation before making further corrections. This cylindrical process continued until a decision to treat or not treat was made. This pattern was observed on 23 occasions across 10 participants (Figure 5.0). On most occasions, participants would explain the rationale for their decisions, but this was not always the case.

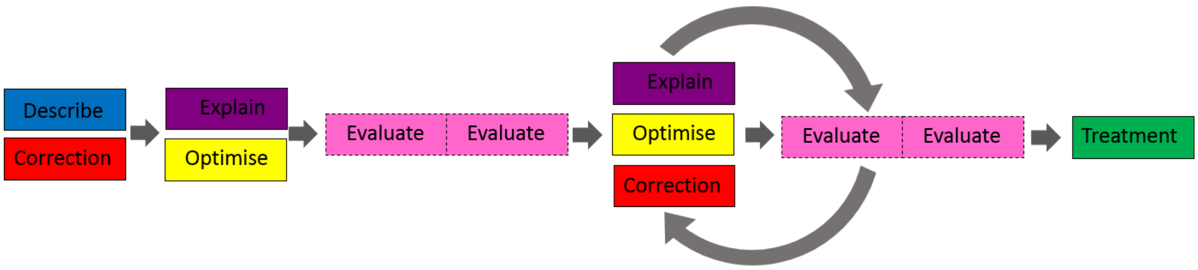

Figure 5.0 repeating linear process

The intuitive process is defined by an intent phase and a confirmation phase. The intuitive process was used by Participants 1, 3, 5, 6, 7 and 8 and used on more than one occasion by Participants 1, 5, 6 and 8. All participants followed the intuitive phase that resulted in a quick decision to treat or not treat. On some occasions the processes ended at this point. On most occasions, the participants then spent the remainder of the process checking to see if their initial decision was appropriate (the confirmation phase). This process in some circumstances was identical to the simple linear process.

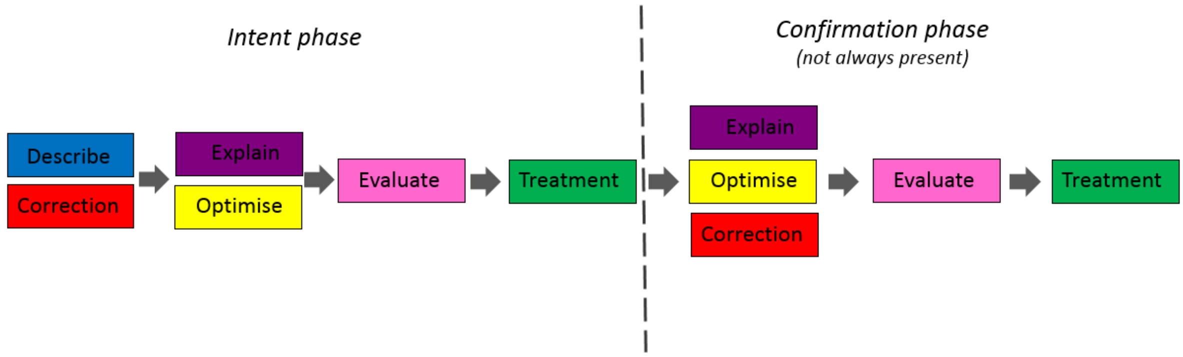

Figure 6.0. Intuitive Process

Length of decision-making process

A range in the number of phrases were seen across the participants. The maximum number of phrases was 57, the minimum 9 and the mean 24. Five case studies were carried out with less than 15 phrases (Participant 3 and 6-8). Three participants used more than 30 phrases, all practiced in centre three.

Correlation of decisions with the IGRT expert

The final decision made by each participant, for each case was correlated with that of the IGRT expert (Table 3.0).

Participant	**Case 1** Complexity: 4 Cancer: Cervix	**Case 2** Complexity: 3 Cancer: Lung	**Case 3** Complexity: 3 Cancer: Head and Neck
1	Treat	Treat	Treat
2	Not Treat	Treat	Treat
3	Not Treat	Not Treat	Treat
4	Not Treat	Treat	Treat
5	Treat	Treat	Treat
Expert	Not Treat	Treat	Treat
	Case 4 Complexity: 2 Cancer: Prostate	**Case 5** Complexity: 4 Cancer: Lung	**Case 6** Complexity: 3 Cancer: Head and Neck
6	Treat	Treat	Not Treat
7	Treat	Treat	Not Treat
8	Treat	Treat	Not Treat
9	Treat	Treat	Not Treat
Expert	Treat	Treat	Not Treat
	Case 7 Complexity: 4 Cancer: Head and Neck	**Case 8** Complexity: 3 Cancer: Lung	**Case 9** Complexity: 3 Cancer: Bladder
10	Seek advice from a colleague	Treat	Not Treat
11	Treat	Treat	Treat
12	Treat	Treat	Treat
Expert	Seek advice from a colleague	Treat	Treat

Table 3.0 Correlation of decisions with the IGRT expert

In centre one there was an 80% agreement with the decisions made by the RTTs, 100% in centre two and 67% in centre three.

In two cases (1 and 7), some of the participants would have treated the patient when the expert would not.

In case 1, the expert felt that the bladder in the verification image was too small, and that the patient should be asked to drink more fluid and allow the bladder to fill further.

In case 7, the IGRT expert felt that the weight loss was significant, and they would have sought advice from a colleague in treatment planning.

Results of the interview and observations combined

Six themes emerged from the observational and interview analysis: *Set Sequence, Site Specific Clinical Priorities, Initial Gross Review, Decision to treat, Compromise and Experience.*

Set sequence

Most of the participants talked about following a set pattern, which always started with an automatic-match. Not everyone followed the same process, but participants seemed to have their own sequence. The comments from Participant 8 and 5 are typical of discussions from participants.

> *It's kind of a set process, so always run the auto-match first and look what the errors actually are, so his are all quite small I think and then generally just eyeball, is the contour okay, is the bony match good? (Participant 8)*

Site specific priorities

When discussing how they prioritised the clinical information on the images, a clear site-specific theme emerged. Participants discussed having set priorities for each anatomical site. In head and neck treatments where the tumour is often close to critical structures, the participants talked about the OARs being priority, whereas in images of the pelvis, the participants talked about the target volume being the priority.

> *"Okay, okay. So, for head and neck for instance, your priority would be your spinal cord over your PTV coverage (Participant 2)*

> *"It depends on what we are treating…. we could look at a plan and think oh the dose is coming really close to the cord here" (Participant 1)*

Initial gross review

All the participants talked about carrying out a quick or gross review initially and then focusing on specific areas of interest. This typically involved quickly scrolling through the images and often all three planes (axial, sagittal and coronal)

> *"I think I would always do a general overview first, a general kind of look around… Kind of look at the bigger picture then cone down to the minutiae". (Participant 2)*

Decision to treat

Participants 3, 6, 10 and 11 felt that they quickly made a decision about accepting treatment position and whether to allow treatment to progress.

> *"I personally make a decision quite quickly". (Participant 3)*
> *"It is almost instant." (Participant 6)*

Compromise

The need to use clinical judgement and make compromise was also a feature of the decision-making process discussed by the participants. This was mainly apparent when talking about head and neck treatments.

> *More with, probably most with the head and necks, because the head and necks are the ones that we review, rather than reviewing, we generally review at different levels (Participant 11)*

Experience

There were varying views on the impact of RTT experience on the image analysis process. Participants 1, 2, 5, 7 spoke about the importance of having experience as a RTT before being able to do image analysis and the impact it has on their decision-making abilities.

> *I wouldn't expect a Band 5 RTT to be making decisions on their own.* (Participant 2)
>
> *I think it was just on 2 years when I got mine and I felt like I was ready then. Then I'd probably say, probably 8 to 12 months. It is*

knowing what you can do to problem-solve it. So just knowledge base really. (Participant 7)

Conversely, Participants 4, 6 10, 11 and 12 felt experience as a RTT had less influence than other attributes.

> *[image analysis] should be competency based rather than band based, because you do have, even though people are different levels, doesn't necessarily mean… they're either comfortable doing it or they're happy to do it.* (Participant 10)

> *Well that's a bit of a difficult one because, just because you've got lots of years of experience as a RTT doesn't mean that the imaging comes naturally for you.* (Participant 12)

Unlike general RTT experience, there was agreement across all the participants that experience of image analysis influences their current practice. Participants spoke about image analysis experience affecting General problem solving, Pattern recognition, Speed and Confidence.

Participants 1 and 8 felt that as they get more experienced they were able to deal with more *problems* that occur.

> *I think I'm more able to cope with problems. I think generally, my abilities probably have improved slightly, but I think I'm better at overcoming problems and knowing why problems arise and knowing who to consult if there is a problem. I suppose, you get quicker and I suppose probably more confident. (Participant 1)*

> *When I was first signed off I was calling physics round a lot because you're never fully happy to make that decision…. If you've seen something before, even if it was two years ago then you're much more… if you've seen it before you're much more comfortable making that decision again. (Participant 8)*

Several participants including participants 2, 8 and 11 spoke about how they think back to past experiences when making clinical decision.

> *But the tumour itself, I'd be happy, the reason I'd be happy treating is because it is one that I've seen similar on previous ones.* (Participant 8)
>
> *So, if it happens again, if I see something and think oh that looks a bit like the patient who had pneumonia. So yes, again it's a building up of experience, a knowledge of things that have happened in the past and what happened and why they are like they are.* (Participant 11)
>
> *Yes because, you know, more… you develop that bank of knowledge about what you expect to see but also, you're more alert to things you're not expecting to see.* (Participant 2)

Most of the participants commented that experience increases the *speed* at which they make decisions.

> *I am a lot quicker. So, I know that I can be quick enough to check if there's glaring errors. (Participant 7)*

There was also a clear link between experience and Confidence.

> *going back to confidence, you know, I've done a lot of cone beam scans, I've had a lot of placements so I am happy with what I am doing. (Participant 6)*
>
> *I used to be a bit, is this right, is this right, even though you've passed, no one is holding your hand any more so be like if I did something wrong. Whereas now I am a lot more confident in myself and that, and I am confident to say if I need physics or not as well, or confident to call somebody else. (Participant 7)*

DISCUSSION

Several processes emerged from the analysis, the basis for all of which was the simple linear model. During this process, participants would make a correction and describe the situation very quickly, followed by an explanation and then optimisation. Participants would then evaluate the image before making a final decision.

Where the repeating linear model was observed, this process recurred with very little deviation in the order of the repetition. It should be noted that the data was coded in relation to phrases rather than time and so, although the two are closely linked, there was some variation in the length of phrases, varying from one or two words up to around 10. The key factor in identifying the use of the simple and repeating linear models over the intuitive process was that the decision to treat or not was only made at the end of the process.

The final process observed was the intuitive process and this was defined by a decision to treat very early in the process. At an early stage, participants would typically state an intention to treat or not treat, with the remainder of the process being taken up by evaluation and optimisation of the image to confirm or disagree with their initial thoughts.

Intuition has traditionally been linked to experience and experience linked to expertise [16,28,32,53], but this does not seem apparent in this small cohort. The experience of the four participants who used the intuitive model the most was notably varied. Four of the participants were advanced practitioners and none of them were observed to use the intuitive model.

Intuitive thought is considered to 'involve rapid, unconscious data processing that combines the available information by 'averaging' it, has low consistency and is moderately accurate' [28] It is linked to mental short-cuts known as heuristics [54–56] and is often considered to be "error-prone" [34]and a cause of "diagnostic error" [36,57]. Norman [58] argues against the view that "analytic reasoning is good'' and "intuitive reasoning is bad'' and suggests that this view exists to provide satisfactory solutions to problems, considering the constraints of the human ability to process information. He argued that heuristics are not sloppy shortcuts to be avoided but are instead efficient strategies to overcome limitations of memory. These opinions are supported outside of the clinical environment with chess players. Burns [59] measured overall chess skill, and skill under speed conditions (blitz chess) and found that speed performance using intuition was strongly related to overall ability in the speciality.

Pattern recognition is intrinsically linked to the intuitive decision [9,46,60]. Studies by Jefford et al. [61] and Simmons et al. [46] found that pattern recognition was the most used heuristic in their studies of midwives and geriatric nurses and was linked to expertise. The patterns that emerged in relation to the diagnosis and management of patients on a ward, or during labour are very different to those found in IGRT. Arguably, the patterns that emerge during IGRT involve fewer cues than those found in the ward environment. This is in part supported by the interviews in the study, where most of the participants spoke about the use of pattern recognition during decision-making regardless of experience.

Ranges in time taken to make clinical decisions during IGRT was seen in a recent study by Clark et al.[62] They timed RTTs during the IGRT process and highlighted a large range from 0:17 to 7:24 mins and in doing so, demonstrated a corelation between speed and different anatomical sites. They found that sites involving bony anatomy had the shortest decision making times. Li et al. [63] in a similar study, reported a smaller range in decision making times 79.1 ± 52 s, but observed that longer decisions were related to larger isocentre discrepancies. Neither of the studies sought to investigate decision making processes, however it would not be unreasonable to hypothesise that participants may have been using intuitive decisions on the cases where fast decisions were made.

Experience clearly plays a role on some level, and this was shown during the interviews of experienced participants. Participants spoke about how their decisions have changed over time and how that is likely to be partly influenced by seeing lots of cases with similar parameters. However, in contrast to this, participant 8 had fewer than two years of experience of IGRT and only 2 to 5 years of experience as an RTT. They were one of the participants who made intuitive decisions and in fact had the shortest number of phrases of all participants (11) during one of their cases.

The debate within the evidence base on the impact of experience continues. The principal literature in healthcare around expertise comes from nursing and is largely based on the seminal work by Benner[29] which is based on the earlier studies by Dreyfus & Dreyfus[64]. This model is largely focused on the concept that expertise is achieved by years of experience and categorises professionals into five skill categories of practice: *novice, advanced beginner, competent, proficient,* and *expert nurse*.

Ericsson, Whyte, and Ward[53] approach the impact of experience in a different way to Benner. Citing earlier work[65] they argued that individuals improve their performance during training and initial experience until they have reached an acceptable level of performance. Beyond this experience, performance may plateau, and experience becomes a poor predictor of outcome.

They call this concept 'expert performance' and argued that performance can only be improved by seeking out kinds of experience, namely, deliberate practice—activities which are designed by a teacher, with the sole purpose of effectively improving specific aspects of an individual's performance. Key to this is the offering of opportunities to reach performance goals with repetition, immediate feedback, and time for reflection and problem solving.

The concept of expert performance describes the results found in this study and fits well with routine radiotherapy practice. RTTs often work in treatment areas that treat a small number of specific anatomical sites, thus allowing them to quickly develop their expertise in a specific area of practice.

Conclusions

This study has provided new and original insight in the decision-making processes of RTTs. The study has highlighted three process models to explain how RTTs make decisions during IGRT: Simple linear, Linear repeating and Intuitive decision-making process. Intuitive processes are widely accepted to be error prone and linked to bias. When using this process, some RTTs followed this with a confirmation phase. This second phase of the process should be encouraged when teaching IGRT.

The results of the study support the concept of expert performance, where performance and expertise are only improved by exposing individuals to specific types of experiences.

RTTs, managers and Higher Education Institutions are encouraged to review these models and implement them into IGRT training. It is clear from the evidence base that understanding how we make decisions, enables us to develop expertise and reduce errors during the decision-making process.

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STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No.	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported
Objectives	3	State specific objectives, including any prespecified hypotheses
Methods		
Study design	4	Present key elements of study design early in the paper
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection

Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias	9	Describe any efforts to address potential sources of bias
Study size	10	Explain how the study size was arrived at

Continued on next page

Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy
		(*e*) Describe any sensitivity analyses
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
		(b) Indicate number of participants with missing data for each variable of interest
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time
		Case-control study—Report numbers in each exposure category, or summary measures of exposure
		Cross-sectional study—Report numbers of outcome events or summary measures
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period

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Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
Discussion		
Key results	18	Summarise key results with reference to study objectives
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability	21	Discuss the generalisability (external validity) of the study results
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.