Evaluating the usability of an X-ray imaging system in forensic pathology

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Declaration

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Abstract

Post mortem imaging (PMI) is increasingly being adopted as an alternative to invasive autopsies in forensic pathology. PMI can be used as a sole technique or adjunct to an autopsy. The Lodox Xmplar-dr is an X-ray imaging system that has been adopted for use in PMI. The purpose of this study was to evaluate the perceived usability of this imaging system by focusing on the satisfaction of forensic pathologists in use of the system. Assessment of satisfaction was guided by the subjective satisfaction characteristics of likability, pleasure, comfort and trust. Incorporation of user needs into updated system designs may lead to greater perceived ease of use, acceptance and adoption, resulting in increased device utilisation.

The study location was the Lodox Xmplar-dr installation site at the Salt River Forensic Laboratory, Cape Town. Five forensic pathologists were observed using the Xmplar-dr system and four were interviewed on their experience using the system. A qualitative research design which used thematic analysis with the aid of NVIVO11 qualitative data analysis software was used to extract key usability and satisfaction themes emerging from the data, to show the extent of user satisfaction.

Two key themes emerged. These were categorised as forensic pathologist-related, which focused on the hedonistic and subjective aspects of their satisfaction with the system, and system-related, which centred on the satisfaction users derived from the system's ability to meet their pragmatic and objective expectations in their use of the system. In general, the forensic pathologists were satisfied with the Xmplar-dr system and it exceeded their expectations. Pleasure was derived from the ability of the system to increase work throughput by reducing the need to perform a dissectional post-mortem unless it was deemed absolutely necessary, i.e. when cause of death could not be determined from the X-ray images generated by the system. Participants felt that the system was an indispensable device when performing post mortems. Likability came from the ease of learning to use the basic functions of the system; the study participants stated that the system aided them in determining cause of death and saved time, in line with the definition of the likability characteristic that is centred on the extent to which a user is satisfied with perceived achievements of pragmatic goals. Trust was derived from participants' views that the system worked as intended, although there could be improvements in terms of robustness, reliability and the imaging system`s support services. Image manipulation on the human-computer interface (HCI) and image representation were concerns highlighted. Most functions could be performed through the system's HCI rather than by manipulation of the body being examined; this increased the physical comfort satisfaction characteristic. The need for manual placement of bodies on the system`s table by assistants and the associated health consequences were however raised as a concern that diminished the comfort-in-use characteristic of satisfaction.

Understanding the user experience of the forensic pathologists who use the Lodox Xmplar-dr system to perform post mortems enabled the identification of areas for improvement. The improvements may increase user satisfaction resulting in better utilisation of the imaging system. The insights gained may be useful for the design of other imaging systems used in forensic pathology.

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1. Introduction

This report presents a qualitative research study to evaluate the usability of the Lodox Xmplar-dr imaging system in its forensic application. This introductory chapter focusses on the history and use of imaging systems in forensic pathology, the importance of performing a qualitative usability evaluation for the system and the aims and objectives of the study.

Conventional medicolegal autopsies involving dissection have been used for at least 3500 years as a method for identifying the underlying pathology leading to death, and/or for detecting unnatural deaths (King and Meehan (1973), (Blokker et al., 2016). There is an increasing interest in identifying alternatives to the conventional autopsy (Fryer et al., 2014). This interest is largely driven by cultural and religious objections and the need to reduce the risk of transmission of category three infections such as HIV from the corpse to the forensics personnel (Burton, 2003). The negative image of invasive postmortem examinations among the general public in the wake of organ retention scandals has also driven the need to find alternatives to autopsies (McLean et al., 2006).

Post mortem imaging (PMI) is an alternative that is increasingly being adopted. PMI is a relatively young field of forensic pathology and radiology (Flach et al., 2014, Karalis and Denton, 2016). It can be used as a sole technique or as an adjunct to a conventional autopsy in a medicolegal inquest, with evidence emerging to support its use as an alternative, rather than a supplement, to conventional autopsies (Roberts, 2012). The advantage of PMI is that it allows for documentation of abnormalities and injuries without the tissue disruption necessitated by the conventional autopsy (Bryce, 2013).

Magnetic resonance imaging (MRI) is an example of a full body imaging technique used in forensic pathology. MRI allows for three-dimensional (3D) scanning not available with conventional X-ray imaging. A benefit of MRI, when used in PMI, is that compared to X-ray based medical diagnostic techniques e.g. general radiography and computed tomography (CT), MRI does not employ ionising radiation but uses external magnetic fields and radiofrequency (RF) fields. Therefore, the modality is considered to have fewer negative health effects on system users when compared against imaging modalities based on ionising radiation (Ng et al., 2003). The high initial cost of MRI imaging in terms of equipment, training and logistics does, however, limit the adoption of the modality for forensic applications, particularly in resource deficient settings (Bryce, 2013).

X-ray imaging is another modality used in PMI and has, since the discovery of X-rays by Wilhelm Conrad Roentgen in 1895, been the most essential, necessary and frequently used imaging method in forensic medicine (Kucerova et al., 2014). Apart from detecting the presence of foreign (radiopaque) objects in the body and their localisation, X-ray generated images are also useful in the detection of a wide variety of traumatic and pathological changes that can be used as part of the chain of evidence in investigating the cause of death.

Computed tomography (CT) is an example of an X-ray imaging technique that can be used in PMI. CT uses X-ray imaging and computer processing to combine multiple X-ray images to produce high-resolution three-dimensional images. Its limitations, like those of MRI, are that CT imaging systems have high initial cost in terms of equipment and training and logistics, which typically limit the adoption of this imaging technique particularly in resource deficient settings (Bryce, 2013).

The Lodox Xmplar-dr X-ray imaging system, **Figure 1**, which uses linear slot scanning technology to provide radiographs of the entire body, is a relatively new PMI technique (Deyle et al., 2010a). Though unable to produce 3-dimensional images such as those produced by MRI and CT modalities, the system's benefits, when compared against conventional X-ray imaging systems, are its ability to provide full body images of subjects up to 1.82 metres in length in just 13 seconds, thereby reducing examination times. This makes it particularly useful when expedited processing is required or in mass casualty situations. As the system produces very low scattered radiation, the users of the system are exposed to quantities of radiation that are well below health and safety limits, with the exposure to radiation being inconsequential for PMI subjects (Knobel et al., 2006).

In South Africa, typical end users of the Lodox Xmplar-dr system in its forensic application are forensic pathologists. An assessment of the usability of the system by its end users and incorporation of their needs and preferences into updated system designs may lead to improved user safety and device effectiveness; reduced need for product recalls and modification; and greater acceptance and commercial success (Martin et al., 2006). Thus a usability assessment may benefit the producers of Lodox imaging systems by informing future iterations of their imaging systems produced for forensic applications.

***Figure 1*.** The Lodox Xmplar-dr Imaging system (Lodox, 2018).

According to Frøkjær et al. (2000), the importance of research in usability is increasingly becoming recognized. Considerable confusion however, still exists over the meaning of the term usability. This is due to usability being defined narrowly on the one hand and distinguished from, for example, utility, but on the other hand also being defined broadly as being synonymous with quality in use. Current usability assessments describe the usability of a device as being measured by metrics such as task times, completion rates and satisfaction scores (Sauro, 2016). The International Organization for Standardization (ISO, 1998) broadly defines usability as having three distinct aspects: effectiveness, efficiency and satisfaction. Research on medical and health technologies is often focused on the effectiveness and efficiency aspects of the system`s usability, however research on how clinician end users react to already implemented medical and health technologies is limited (Holden and Karsh, 2010). These experiences can be assessed through an examination of satisfaction with devices and technologies. Satisfaction in the context of usability has been defined as the "freedom from discomfort, and positive attitudes towards the use of the product [system, service or environment]" (ISO, 1998). It is important to evaluate the satisfaction of users as it is a large component of usability which directly affects acceptance and adoption of the system or service.

1.1. Aims and objectives

The aim of this study was to assess the usability of the Lodox Xmplar-dr imaging system in post-mortem imaging by qualitatively evaluating the extent to which trained and qualified healthcare professionals (forensic pathologists) experienced satisfaction in their use of the system.

The aim was achieved through the following objectives:

- Determining a set of characteristics that explore the satisfaction aspect of usability in the context of post mortem imaging which would be suitable for investigating features that may result in user satisfaction or dissatisfaction with the Lodox Xmplar-dr system, when performing tasks; and
- Using these characteristics to determine the level of satisfaction that forensic pathologists have with the Lodox Xmplar-dr imaging system.

The study would enable the identification of user needs and allow recommendations to be made with regard to making Lodox imaging systems more user-centred in their forensic application and inform future designs of imaging modalities in the forensic context.

1.2. Overview

Chapter 2 presents a literature review focusing on usability, its definition in the available literature, its application in the medical context, and finally, the limitations in how usability has been approached. Chapter 3 presents the prominent theories that have underpinned the concept of satisfaction and provides a basis for evaluating the satisfaction of Lodox Xmplar-dr system users in the forensic context. Chapter 4 presents and motivates the methodology used in the project. Chapter 5 presents the findings related to user satisfaction. The final chapter concludes the report.

2. Literature Review

This literature review examines published studies evaluating the usability of medical devices; the focus on medical devices arises because the imaging system whose usability is the topic of the study falls into this category. A broad literature search was done to ascertain if any research had been conducted on the usability of imaging devices for forensic pathology purposes. The absence of literature on the topic was attributed to imaging being a relatively new method of diagnosis in forensic pathology (Levy, 2015) and that imaging systems used in forensic pathology were an adaptation of imaging modalities derived from clinical practice or trauma applications (Grabherr et al., 2016). The chapter provides a description and critical evaluation of relevant usability studies and considers the implications for usability evaluations of medical devices.

2.1. Defining usability

A universal definition of usability that is applicable to all contexts does not exist. The International Organization for Standardization (ISO, 1998), has defined usability broadly as "the extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use". This definition is based broadly on four categories which Bevan (2001) argues are different but interlinked:

- The use of the product; i.e. its effectiveness, efficiency and satisfaction in a context of use;
- The user interface and interaction;
- The process used to develop the product; and
- The capability of and extent to which product developers and manufacturers apply user-centred design in product development.

Maguire (2001) suggests that this broad categorisation may be due to different stakeholders having different perceptions of usability as well as to the need to define the specific context (for example with regard to the users, task, and environment) in which the concept of usability is applied. Bevan and Holdaway (1993) also cite the rapid advancements in technology which can render the definition of usability in certain contexts obsolete or only appropriate for a limited set of users and tasks.

As a result, scholars and other standards organisations have attempted to conceptualise usability without a precise specification, instead concentrating on the principles that need to be applied to meet user tasks and needs depending on context. Bevan and Holdaway (1993) group the standards into two categories, the top-down approach and the bottom-up approach. Standards using the top-down approach define usability with a focus on broad quality objectives, while standards using the bottom-up approach define usability with their focus being more product oriented and concentrating on the design of specific attributes of the product. An example is the ISO 9241-11 standard (ISO, 1998) which takes the bottom-up product-oriented approach.

The technology acceptance model (TAM model) which emphasizes two factors essential to product acceptance, perceived usefulness and perceived ease of use (Davis, 1985) could be used as the basis of a framework to evaluate the perceived usability of a product. The model however has shortcomings. First, as Karsh (2004) has observed, TAM research has examined technologies that are used voluntarily whereas in the medical field, many technological implementations are mandatory. Second, the evidence available seems to suggest that what predicts end user satisfaction or acceptance of a technology changes over time with greater use of the technology (Karahanna and Straub, 1999). Lastly as the TAM model emphasizes two factors, perceived usefulness and perceived ease of use which are direct indicators of efficiency and effectiveness (Chang et al., 2012), use of the TAM framework reduces usability to just these two dimensions of usability.

2.2. Medical device applications of usability

A field concerned with the study of usability is that of human factor engineering (HFE). Stramler (2013) provides a definition of HFE as, “The field of science which is involved in research regarding human psychological, social, physical, and biological characteristics, maintaining the information obtained from that research, and working to apply that information with respect to the design, operation, or use of products or systems for optimising human performance, health, safety, and/or habitability.” North (2015) states that HFE places a focus on the interaction of a system`s users with its interface, through the application of knowledge in human capabilities and limitations. This is done by performing tests and evaluations of both user and system performance in terms of quality of use based on the three usability dimensions, namely effectiveness, efficiency and satisfaction, outlined by (ISO, 1998).

A case study conducted by Gosbee (2002) for the purpose of illustrating the crucial role of HFE in patient safety, emphasised HFE as part of the design process that focuses on the needs, physical and physiological characteristics of users and end-user testing of the human-machine interface. The study also emphasized that the design process was iterative and needed constant refining throughout the design cycle based on the feedback from the users (usability testing) as a means of ensuring the design met its intended purpose and operated in its intended manner. The Gosbee study used HFE analysis to evaluate the usability of a transport monitor and to understand why it had been left in demonstration (demo) mode by the personnel transporting a patient to the ICU. Demo mode is software integrated into the transport monitor to generate data and continuously display waveforms and numbers, demonstrating the capabilities of the monitor. The measurement metrics used to determine the usability of the transport monitor were learnability and the level of satisfaction with the use of the monitor. A summary of the results showed that the transport monitor was less than optimally designed and its human-computer interface (HCI) was overly complex for its intended use (monitoring the patient's vital signs) by the transport personnel. The case study concluded that it was imperative that HFE principles be applied by all parties who are involved products that are required to incorporate patient safety into their design.

The results from the case study undertaken by Gosbee agree with those of the research conducted by Sawyer et al. (1996), who identified errors in the use of medical devices which were the result of flaws or oversights in the design of the user interface, through which healthcare practitioners and lay users interact when operating a medical device. The errors identified by Sawyer had the capacity to compromise both medical personnel and patient safety. To reduce errors arising from the use of medical devices, emphasis must be given to the importance of designing systems to improve safety, as well as the application of HFE principles as they are essential in the reduction of complexity and the optimisation of information on the part of the user (Nolan, 2000).

The application of HFE principles for usability of a device, particularly its user interface, can be evaluated through a heuristic evaluation, which Nielsen and Molich (1990) define as an expedited usability testing method for uncovering flaws in the design of interfaces in order to address them as part of an iterative design process. User testing is considered the ideal method for usability evaluations as the findings are derived directly from the experience of users. However, the considerable amount of time and resources needed to recruit participants and to coordinate, test and analyse data, limit user testing as it may not be affordable (Chan et al., 2012). Heuristic evaluation alternatively provides a less complex method of garnering user insights and requires fewer resources when identifying system design shortcomings and prioritizing the resolution of these discrepancies particularly during the design and testing phases of a medical device.

A heuristic evaluation involves a set of evaluators examining the interface and judging its compliance against established usability principles (the "heuristics"), (Nielsen, 1992). The use of heuristics to evaluate the safety of medical devices by identifying and assessing usability issues is well documented. A study conducted by Chan et al. (2012) aimed at demonstrating the use of heuristic evaluation for the radiotherapy community and device manufacturers for the purpose of assessing and improving usability of current and future systems. The study confirmed that heuristic evaluations were an effective tool to identify usability issues of a treatment delivery system, as well as to assist in making recommendations for the purpose of improving user interfaces and enhancing safety. The study conducted by Chan et al. measured usability through a set of fourteen usability heuristics described in **Table 1**, modified by Zhang et al. (2003) specifically for the evaluation of medical devices.

The Chan et al. study involved the observation of an experienced radiation therapist performing a list of regular tasks during treatment delivery, by two HFE evaluators who independently assessed any usability issues that violated the Zhang et al. usability heuristics during the course of the therapist completing the tasks. The study resulted in the identification of usability issues which were classified according to severity and analysed by the investigators who then compiled a list of recommendations.

Chan et al. (2012) demonstrated that heuristic evaluation was advantageous as the method was useful in gaining usability insights for a medical device or system without the complexity of user

Table 1: HFE usability heuristics, (Zhang et al.2003).

1.	**Consistency and standards**	The meaning of words, situations, or actions should be clear to users. Standards and conventions in product design should be followed.
2.	**Visibility of system state**	Appropriate feedback and information must be displayed by the system during operation.
3.	**Match between system and world**	The perception of the system by the user should match the model the users have about the system.
4.	**Minimalist**	Any unnecessary information displayed will be distraction.
5.	**Memory**	Users should not be expected to commit to memory a great deal of information when operating the system, as this will reduce their ability to carry out the main tasks.
6.	**Feedback**	Rapid and informative feedback should be given to users about their actions.
7.	**Flexibility and efficiency**	Users should be given the flexibility to customise and create shortcuts to enhance their performance.
8.	**Message**	Informative messages should be displayed that allow users to understand the nature of their errors, and to learn from and recover from these errors.
9.	**Error**	Interfaces designed to prevent errors from occurring are best.
10.	**Closure**	Clear notification about the completion of a task should be given to the user.
11.	**Undo**	Actions should be reversible. Users should be able to recover from errors.
12.	**Language**	Language should be understandable by the system's intended users.
13.	**Control**	Users must not be given the impression that the system is controlling them.
14.	**Document**	Help that is situation sensitive should be available.

testing, and required few resources. The investigators also noted that although usability heuristics testing was more effective if implemented early in the design process to identify usability issues and improve their prototypes, the method could also be used post-procurement after the device or system was implemented and used clinically.

Lang et al. (2013) explored the user requirements of adolescent users of the acapella® physiotherapy device for the treatment of cystic fibrosis. They examined the role of the device's design in terms of real world effectiveness as well as to identify design priorities. The study used interactive and thematic interviews to evaluate the usability of the device against performance and satisfaction metrics. The study qualitatively assessed task, effectiveness, ease of use and aesthetics in order to determine the factors that affected how, and how often, the device was used. Results showed that confidence in the clinical effectiveness of the device was one of the factors important in improving satisfaction in the use of the device. The study by Lang et al. (2013) concluded that it was essential for medical device producers to have an understanding of complex user-device-interfaces in order to avoid the medical device not adequately meeting user requirements, which would result in reduced real-world effectiveness of the device. The study also advocated for a broader user-centred approach to medical device design that aims to consider both clinical and non-clinical user requirements in the development of the medical device or technology.

A usability study conducted by McCrory et al. (2013) used the top-down approach to usability by applying HFE techniques to do a comparative evaluation of surgical instruments using performance and satisfaction metrics. Performance metrics were task completion, errors and success rates and the satisfaction metric was ease of use. The usability of the different devices was assessed to determine which surgical devices were the most efficient and effective as well as user-friendly. The authors were able to compile a list of recommendations for key features that could enable device designers and manufacturers to improve the devices in question.

Gallo et al. (2010) applied usability in a study on inexpensive graphical manipulators compared to more expensive graphical manipulators when used by radiologists. The study measured usability of the different devices through the measurement of performance and satisfaction as metrics. The satisfaction metric was assessed from a user point of view, with the results showing that the inexpensive manipulator was perceived as being easy to learn and was considered to be comparable with one of the expensive graphical manipulators in terms of user-friendliness.

2.3. Summary and implications

A summary of the usability approaches, metrics and results of the five studies reviewed above is shown in **Table 2**. The studies reflect the assertion by Maguire (2001), that the metrics of usability are dependent on stakeholders' perceptions, as well as the context in which the usability concept is considered. The studies are also in line with the assertion by Bevan (2001) that there are two broad categories of usability standards. The first approach is the "top-down" approach which is concerned with usability as a broad quality objective and focuses on the ability to use a product for its intended purpose, i.e. quality of use, which Bevan (2001) asserts has its origins in HFE. The second, product-oriented, "bottom-up" view is concerned with factors that make a product or system easier to use.

The reviewed studies reflect a limitation in how usability is approached, namely with a focus on comparing the usability of different devices or aiming at finding flaws in the design of medical devices. As argued by Nielsen (2012), there are several measurable quality attributes that combine to form the bigger construct of "usability"; one of these is subjective satisfaction, which is a measure of preference based on the users' experience in use. In both the top-down and bottom-up approaches to usability, the studies have focused mainly on the performance aspects of the medical devices with users' satisfaction receiving little attention or being seen as a secondary result. The effectiveness and efficiency dimensions of usability have been the outcomes that most studies have emphasised, with satisfaction being viewed mainly as a result of these two dimensions of usability (Aigbavboa and Thwala, 2013). The measure of satisfaction used by four out of the five studies has been ease of use, a usability characteristic that falls under the "top-down" approach to usability and is only one of the broader quality in use characteristics (Bevan, 1999). A framework that puts a focus on evaluating the subjective satisfaction of medical device users through analysis of users' internal, personal and affective states when using the devices, has not been outlined in the literature.

Table 2: Approaches, metrics and results of the five studies on medical device usability.

	Gosbee. 2002	**Gallo. et al 2010**	**McCrory. et al 2013**	**Chan. et al 2012**	**Lang. et al 2013**
Approach to usability	Top-Down	Bottom-up	Bottom-up	Bottom-up	Bottom-up
Metrics	HFE analysis to assess learnability and satisfaction.	Performance (task completion) satisfaction (ease of use).	Performance (task completion, error, success rates) and satisfaction (ease of use).	14 usability heuristics identified by Zhang et al. (2003)	Performance (task completion, effectiveness) and satisfaction (ease of use and aesthetics).
Outcomes	Showed the importance of HFE analysis as part of usability testing of a device /design before it is implemented in the medical device industry to improve safety.	Showed that expensive devices` performance and ease of use are not necessarily better than less expensive devices.	Quantitative comparison of performance and satisfaction of the devices.	Identification of heuristics violated based on usability issues and recommendations for improvement.	Identification of device and non- device aspects that improve the users` satisfaction.

3. Conceptual framework for measuring user satisfaction

This chapter examines the prominent theories that have underpinned the concept of satisfaction, for the purpose of selecting appropriate elements for evaluating the user satisfaction of Lodox Xmplar-dr system users in the forensic context.

The International Organization for Standardization (ISO, 1998) broadly defines usability as consisting of three distinct aspects: effectiveness, efficiency and satisfaction. As alluded to in chapter 2, despite the importance of satisfaction in usability, no univocal definition of satisfaction exists in the literature (Szymanski and Henard, 2001). The presence of different definitions for satisfaction makes the measurement of satisfaction a confusing process with little agreement in the literature on the nature of satisfaction and whether it is an affective or a cognitive construct or a combination or both (Vaezi, 2013). Applegate (1993) argues that in the literature on usability, the satisfaction dimension is not clearly defined nor have its various forms been considered. As a result, a definition of satisfaction applicable to all contexts does not exist. This is evident in the variety of ways in which the concept of satisfaction has been defined by scholars. Based on the different definitions, Tse and Wilton (1988) have attempted to model satisfaction as the evaluation of perceived discrepancy by forming a comparison between prior expectation and the actual performance of the product.

In an attempt to explain the relationship between satisfaction (positive disconfirmation) and dissatisfaction (negative disconfirmation), a number of theoretical approaches have been developed (Aigbavboa and Thwala, 2013). Parker and Mathews (2001b) have suggested two basic approaches in attempting to define the concept of satisfaction: the first approach as an outcome of a consumption activity or experience; and the second approach as a process, where the focus is on antecedents to satisfaction rather than on satisfaction itself. These classifications however, are complementary, as often one depends on the other (Aigbavboa and Thwala, 2013). Vaezi (2013) attempts to clarify the difference between the two approaches to satisfaction further by giving the theoretical origins of the approaches. The consistency theory serves as a basis for the first approach, which views satisfaction as resulting from a coupling of the emotions surrounding disconfirmed expectations, with the consumer's prior feelings about the consumption experience (Oliver and Linda, 1981); this approach is less concerned with the processes involved in the formation of satisfaction. The second approach, which uses discrepancy theory as a base, is concerned with the processes that are involved in satisfaction formation and involves determining and understanding the underlying mechanisms that lead to the formation of satisfaction/dissatisfaction.

In order to understand better the factors influencing satisfaction, the underlying theories supporting the two dominant approaches that have been used in studies to explain user satisfaction are reviewed in the next section.

3.1. Satisfaction theories

This section describes the theories underpinning the approaches to defining satisfaction found in the literature.

3.1.1. Consistency theory

Consistency theory is defined by Aigbavboa and Thwala (2013) as conceptualising that when there is a mismatch between expectations and the performance of the actual product , the users will feel some degree of dissatisfaction. To relieve this dissatisfaction, the user will adjust their expectations or their perceptions of the product's performance. Assimilation and assimilation-contrast theories that view satisfaction as an outcome are derived from or are variations of the consistency theory (Peyton et al., 2003).

3.1.1.1. Assimilation theory

Assimilation theory holds that users of a given product make a form of cognitive comparison between expectations and the perceived performance of a product. If their expectations are not met, they will experience a resulting psychological discomfort (Anderson and Fornell, 1994). To overcome this, users will attempt to alleviate this discomfort by minimizing the difference between their product expectations and their experiences (Haas, 1999). The theory has shortcomings highlighted by Peyton et al. (2003), who argue that the theory makes assumptions that a relationship exists between expectation and satisfaction, yet does not stipulate how disconfirmation of an expectation results in satisfaction or dissatisfaction.

3.1.1.2. Contrast theory

The contrast theory posits that, when the actual performance of a product fails to meet the user's expectations of the product, the user will exaggerate the discrepancy between the expectation and the outcome. (Yüksel and Yüksel, 2008). This theory is opposed to the assimilation theory in that it magnifies discrepancies in expectation and experience. The theory has come in for criticism by scholars such as Isac and Rusu (2014) who state that the theory will exaggerate the difference between expectation and the performance of the product.

3.1.1.3. Assimilation-contrast theory

The assimilation-contrast theory was proposed in Anderson (1973) in an attempt to overcome the shortcomings of the assimilation and contrast theories. A combination of both theories, assimilation-contrast theory holds that if performance is within a user's range of acceptance, performance will be deemed acceptable, even though it may fall short of expectation, with discrepancies being disregarded and assimilation occurring. If however, performance falls within the user's rejection range, contrast will prevail and the difference between expectations and product performance will be exaggerated, deeming the product unacceptable. (Peyton et al., 2003).

3.1.2. Discrepancy theory

The discrepancy theory has been described by Boyd et al. (2007) as a theory that claims that satisfaction is related to the extent to which actual outcomes of product use match the expectation of the user. Large negative gaps between outcome and expectation result in dissatisfaction, while smaller gaps will result in satisfaction, implying that the closer the match, the higher the user's satisfaction with a product. Scholars who have generated theories of satisfaction that model the concept as some "form of comparison" have used the discrepancy theory as a base (Parker and Mathews, 2001a). The main theory is discussed below.

3.1.3. Expectancy disconfirmation theory

Isac and Rusu (2014) have argued that the main paradigm that should mark the literature dedicated to satisfaction is the expectancy disconfirmation theory. This theory, which combines aspects of the consistency and discrepancy theories, may overcome shortcomings of the two preceding satisfaction theories by incorporating both process and outcome oriented qualities of satisfaction. First propounded by Oliver (1980), the theory proposes that a user's satisfaction level is a result of the difference "between expectations about perceived product performance, and expectations as predictions of future performance". User expectations affect the functionality, content and performance of an interactive system and can be evaluated both qualitatively and quantitatively (Smith et al., 2001). As with the theories described above, expectancy disconfirmation theory views satisfaction as a series of clearly defined stages through which a user forms expectations about the performance of the product, assesses the actual performance of the product, and then makes a comparison of the products performance against their expectations. If user expectations and product performance are equal, users experience confirmation of their expectations; if performance is higher than their expectations, users experience positive disconfirmation; and if performance is lower than their expectations, users experience negative disconfirmation. This is in line with the outcome-oriented theories of satisfaction in which expectations are adjusted depending on the level of disconfirmation experienced and also considers process-oriented theories by allowing for comparison between expectations of perceived product performance, and expectations as predictions of future performance. Expectancy disconfirmation theory has become the dominant framework for explaining user satisfaction as it useful for determining the satisfaction response for product categories for which is appropriate to focus on the implications of consumption with regard to function (Phillips and Baumgartner, 2002).

Figure 2 shows how the different satisfaction theories are interlinked and how they have evolved into the expectancy disconfirmation theory.

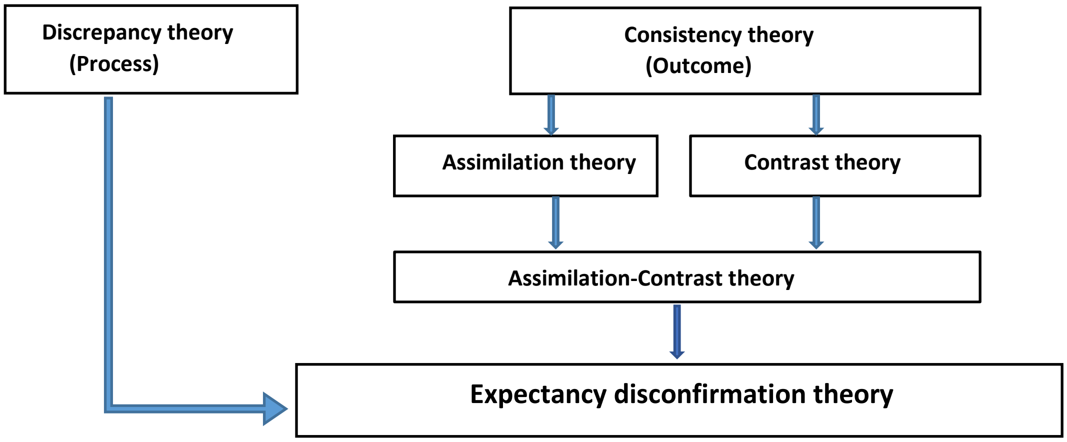

***Figure 2**:* Satisfaction theories**.**

3.2. Applications of expectancy disconfirmation theory

Mano and Oliver (1993) have observed that research on product relevance and satisfaction has mostly focused on two dimensions. The first dimension encompasses the traditional notion of utilitarian or instrumental performance, which views the product as having a useful function. This dimension focusses on the efficiency and effectiveness of the product rather than on user satisfaction, although it considers them to be antecedents to overall satisfaction and is in line with the expectancy disconfirmation theory which considers satisfaction/dissatisfaction a result of product performance.

The second dimension is that of hedonic (pleasure) or aesthetic performance (Hirschman and Holbrook 1982), which values products for their appealing properties and as an outcome of a consumption activity or experience. This is in line with the expectancy disconfirmation theory where satisfaction is a result of the emotions related to disconfirmed expectations being coupled with the prior feelings of the user about the consumption experience (Parker and Mathews, 2001b). This dimension comprises consumption emotions, which are the set of emotional responses elicited during consumption activities (Westbrook and Oliver, 1991). The emotional responses comprise categories such as joy, anger and fear. Alternatively they can also represent some fundamental emotional categories, including pleasantness/unpleasantness, relaxation/action, or calmness/excitement (Plutchik, 1962) and (Izard, 2007). Bevan (2008) reinforces this dimension by adding likability, comfort, and trust to these emotional responses.

This two-dimensional approach to satisfaction is frequently typified as one of thinking (cognitive) versus affect (emotion). According to Phillips and Baumgartner (2002), the cognitive process is primarily responsible for the formation of satisfaction judgements in which users form expectations about the performance of a product based on functional qualities (efficiency and effectiveness), evaluate how the product actually performs on these qualities, and make a comparison between perceived performance and prior expectation. Consequently, the interaction with the system becomes secondary to the achievement of external goals.

In line with the second dimension of hedonic and aesthetic performance proposed by Mano and Oliver (1993), Phillips and Baumgartner (2002) argue that emotions evoked by the consumption also have an important influence on satisfaction. This accords with the argument by Cronin et al. (2000) that emotion is a fundamental attribute of satisfaction and that user satisfaction should include a separate emotional component. In support of emotions being critical to satisfaction, Applegate (1993) has proposed the Emotional Satisfaction Model-Multiple Path (ESMMP) model of user satisfaction that incorporates both the process view of satisfaction, which bases satisfaction on the product`s performance against expectations, and the outcome view, which is subjective and based on the emotions exhibited during consumption. Applegate`s ESMMP model posits that satisfaction occurs when users' questions have been answered both materially and emotionally. The users' affective state is dependent not only on questions answered but also on factors such as setting and expectations. It is thus necessary to understand the product's context of use to determine the goals of the user community, task and environment in which the product will be used (Maguire, 2001).

3.3. Relationship between user satisfaction and user experience

ISO (2009) defines "user experience" (UX) as a "person's perceptions and responses resulting from the use and/or anticipated use of a product". UX encompasses all aspects of the end user's interaction with a given organization's services and products (Nielsen, 2013).

There is a general consensus by scholars that the concept of UX has a temporal component, as the amount of user interaction with a product affects people's overall experience (Borsci et al., 2015).

Hassenzahl and Tractinsky (2011) state that UX can be broken into three components, the user's internal state (expectations, needs, motivation, mood and other intrinsic and subjective factors), the system's operating characteristics (complexity, usability, functionality) and the circumstances in which the interaction occurs. The authors argue that the term 'user experience' is associated with a variety of meanings, which cover usability in its traditional sense as well as hedonic, affective or experiential aspects of technology use. Their assertion that UX also has hedonic and affective aspects suggests that UX goes beyond the purely cognitive and task-oriented components that usability is commonly associated with and into subjective aspects that can be used to determine how valuable and desirable a product will be to a user.

The view that the concept of usability must go beyond cognitive and task oriented aspects in the design and evaluation of systems is compounded by Dillon (2002) who suggests that other than process and outcome, affect must be one of the three key issues of users' interaction with systems that must be emphasised. Dillon (2002) and Petrie (2009) define affect as what the user feels which includes not only the concept of satisfaction from the definition of usability but goes beyond this to include all emotional reactions of users. Including affect will allow for an increased understanding of users' emotional interaction with products and what the interaction means for the users.

Hornbæk and Hertzum (2017) argue that incorporating the experiential component and psychological needs into usability is essential as they allow for a better understanding of motivations behind experiential and utilitarian aims of use. The addition of this component allows for a better understanding of the experiential component of human computer interactions. The incorporation of cognitive and affective elements, such as emotions and experiences, into usability models, is important as they have an influence on the hedonic qualities of a product; in addition, the experiential component is central to evaluating usability as well as providing an understanding of its role in the product's adoption and use.

Saariluoma and Maarttola (2003) argue that emotional research, aimed at creating a better understanding of emotional concepts, theories, and measurement practices, is now important in human-technology interaction research. Emotional research allows for better comprehension of the emotions elicited when people interact with technology. As a result, emotions are beginning to play a significant role in the design of products, as usability becomes more of a product differentiator (Spillers, 2004). Emotional satisfaction characteristics that Bevan (2008) argues can be used to incorporate user experience in a usability evaluation are:

- Pleasure, the extent to which users are satisfied with their perceived achievement of the hedonic goals (stimulation, identification, evocation) and associated emotional responses in use of a product.
- Likability, the extent to which users are satisfied with their perceived achievement of pragmatic goals, encompassing acceptable perceived results and consequences of use.
- Comfort, the extent to which users are satisfied with physical comfort when using a product.
- Trust, the extent to which users are satisfied that products will perform as intended during use.

3.4. Satisfaction characteristics

User experience (UX) is primarily about the actual experience of usage, and the theories outlined in Section 3.2 can be used as a base to understand the how users form satisfaction judgments. The judgements can be formed before usage (expectations), during and post usage through experience of using the product (UX). UX has pragmatic and emotive dimensions that can be used to determine user satisfaction. Based on the satisfaction characteristics proposed by Bevan (2008) definitions for the two main satisfaction characteristics and 3 sub characteristics of satisfaction adapted for and applied in this study are given in this section.

3.4.1. Physio-pleasure

Physio-pleasure is derived from the pragmatic attributes of the imaging system related to the achievement of pragmatic goals. This was conveyed by the efficiency and effectiveness of the system in enabling an action to be performed and is manifested in the users' ability to accomplish their goals or tasks with ease and simplicity and in the learnability of the system's basic functions (Porter and Porter, 2004). In this study, likability, comfort and trust were considered as sub-characteristics of the physio-pleasure satisfaction, as they placed emphasis on the extent to which the system to allow users to achieve their pragmatic goals. Likability focused on the capability and functionality of the system. Comfort placed emphasis on extent to which the imaging system maximized or reduced physical comfort in users' achievement of pragmatic goals. Trust focused on the extent to which the imaging system allowed users to achieve their pragmatic goals based on technological and user based factors. The three physio-pleasure subcategories are expanded on below.

3.4.1.1. Likability

A definition of likability derived from that of (Bevan, 2008) the extent to which users are satisfied with their perceived achievement of pragmatic goals, which encompass acceptable perceived results and consequences of use.

Li et al. (2009) posit that when technology enables users to perform necessary tasks, users are most concerned with whether the technology has the functionality and capability required to complete a job. The belief in the competence of the imaging system would have an impact on the degree to which the users are satisfied with their perceived achievement of pragmatic goals. Pragmatic objectives are influenced by the utility of the system as a result of its functionality in terms of the perceived usefulness of its features and capabilities as well as the perceived ease-of-use of the system.

3.4.1.2. Comfort

Derived from the definition by (Bevan, 2008), comfort is defined for this study as the extent to which users are satisfied with their physical comfort when using the imaging system based on their user experience. Satisfaction/dissatisfaction may be derived from the extent of comfort the users experienced from the electronic and physical operation of the system.

3.4.1.3. Trust

Trust is defined by Bevan (2008) as the extent to which the users believe that the product will behave as intended. For the purpose of this study, this definition was adapted to also encompass:

Technology factors

Trust in technology has been defined by Mcknight et al. (2011) as "a belief that a specific technology has the attributes necessary to perform as expected in a given situation in which negative consequences are possible". The scholars posit that trust of technology is based on the user’s perception of a given technology’s functionality, helpfulness and reliability, which are parallel to the trust elements of benevolence, competence, integrity and predictability. A lack of trust in the technology would prevent the users from utilizing the system to its full extent, leading to a decrease in productivity and as a result throughput of examinations carried out through use of the system (Xu et al., 2014).

User factors

User factors refer to the individual and situational factors influencing users of the imaging system, who may be the active users who have direct control over the system, and passive users (e.g. assistants) who do not have direct control but interact with both the system and the active users (Montague and JieXu, 2012).

3.4.2. Psycho-pleasure

Psycho-pleasure is derived from the hedonistic and subjective aspects of the user’s experience with the system. This is related to the cognitive demands of using the system and the emotional reactions engendered through the experience of using it, which would result in pleasure as a result of the system largely working as it should (Porter and Porter, 2004). Diefenbach et al. (2014) posits that pragmatic goals need to be fulfilled in order to achieve hedonic goals, consequently psycho-pleasure as a hedonic emotion may be derived from the ability of the imaging system to meet or exceed the users’ expectations by satisfying the system-related, pragmatic satisfaction characteristics, namely physio-pleasure, likability, trust and comfort, of satisfaction. **Table 3** gives a summary description of the satisfaction characteristics and their associated sub-characteristics.

Table 3: Summary of satisfaction/dissatisfaction characteristics influencing psycho-pleasure.

Satisfaction Characteristic	Description	Sub-characteristics
1.Physio-pleasure	Conveyed by the efficiency and effectiveness of the system in enabling an action to be performed; is manifested in users' ability to accomplish their goals or tasks with ease and simplicity and in the learnability of the system's basic functions.	**Likability:** Degree to which users are satisfied with their perceived achievement of pragmatic goals. Influenced by utility and functionality in terms of the perceived usefulness of its features, capabilities and perceived ease-of-use. **Comfort:** Satisfaction/dissatisfaction can be derived from the extent of comfort the users experience from the electronic and physical operation of the system. **Trust:** The extent to which the users believe that the product will behave as intended. Encompasses trust in the technology and user factors.
2.Psycho-pleasure	Derived from the hedonistic and subjective aspects of the user's experience with the system and the emotional reactions engendered through the experience of using it.	Derived from the ability of the imaging system to meet or exceed the users' expectations by satisfying the system-related, pragmatic satisfaction characteristics, namely physio-pleasure, and its sub-characteristics of likability, trust and comfort.

The expectancy disconfirmation theory's two main aspects of process and outcome, have an effect on the cognitive and affective dimensions of the user experience. Cognitive and pragmatic consumption emotions that influence satisfaction during use of a product encompass physio-pleasure which places emphasis on the perceived performance of a product through the sub-emotions of likability, comfort and trust. These have an effect on the hedonistic and subjective satisfaction characteristic of psycho-pleasure.

In summary, expectations as anticipations have a direct influence on satisfaction and physio-pleasure as a consumption emotion is directly affected by the expectations in terms of the perceived performance during use of a product based on the sub consumption emotions of likability, comfort and trust. These expectations are then confirmed or disconfirmed during experience of using the product and psycho-pleasure as a subjective consumption emotion is determined by the level of positive or negative affective responses to the user experience (Vaezi, 2013). **Figure 3** illustrates the relationship between the antecedents of satisfaction.

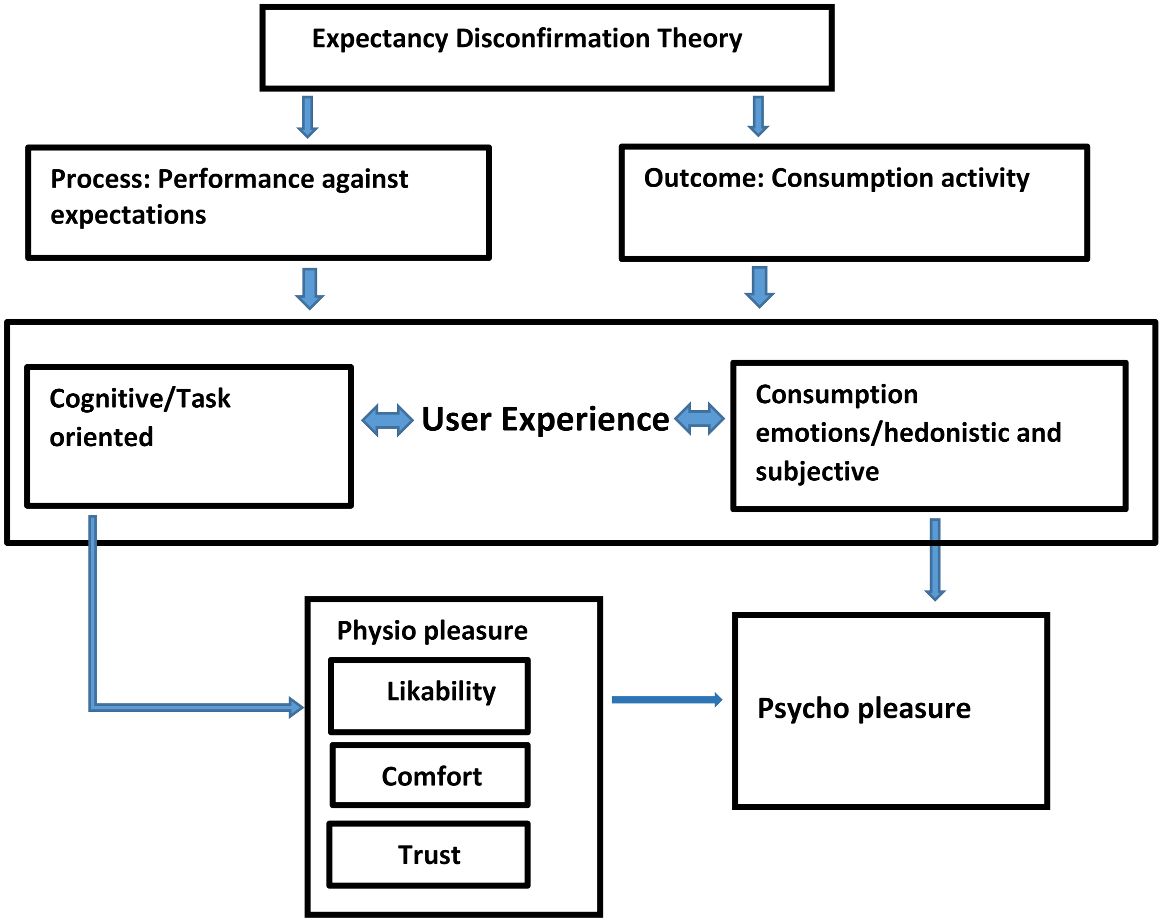

Figure 3: Expectancy disconfirmation theory, user experience and consumption emotion flow diagram.

4. Methodology

This chapter describes and motivates the research approach. The specific strategy of inquiry, the tools used to collect data, as well as the data analysis technique, are described, and ethical considerations pertinent to the study are discussed.

4.1. Qualitative research approach

A qualitative approach was chosen for the study as it is appropriate for small sample sizes and would offer a comprehensive description and analysis of the experiences of research participants. A qualitative approach also would not limit the scope of the research and the nature of the participants' responses (Collis and Hussey, 2013). In recent years, the qualitative approach has gained interest and is increasingly being adopted in the academic medicine, healthcare and technology fields (Bunton, 2016). Auta et al. (2016) are of the view that this is a result of increasing value placed on qualitative research in exploring people's experiences, emotions and behaviours, for the purpose of comprehending the participants' perspectives of a phenomenon.

4.1.1. Data Analysis

The study used thematic analysis as a qualitative approach to analyse the data. Thematic analysis allows for flexibility and is useful for the generation of unanticipated insights (Clarke and Braun, 2014). Thematic analysis begins with a deductive or theory-driven coding system, but with the additional option of adding new codes inductively as they are discovered (Miles and Huberman, 1994). The thematic analysis process involves recording or identifying passages of text or images that are linked by a common theme or idea allowing the researcher to index the text into categories and therefore establish a framework of thematic ideas (Gibbs, 2008). Thematic analysis was used with a combination of the inductive and deductive approaches. For this study, the sources of data were participant observations and interviews. With the aid of Nvivo11, a software package for qualitative data analysis, data from observations, interview transcripts and corresponding audio files were reviewed and coded. The coded data were classified into the four satisfaction characteristic themes that (Bevan, 2008) has argued could be used to interpret satisfaction, namely physio-pleasure, its sub-characteristics of comfort, likability and trust, and psycho-pleasure.

4.2. Research Setting

South Africa has nine forensic pathology service sites spread across three provinces. For this study, the research site was the Salt River forensic installation of the system in the city of Cape Town, Western Cape Province. The site services the Cape Town metropolitan area and nearby urban and rural areas, and uses the Lodox Xmplar-dr system for forensic imaging.

4.3. Study participants

The sample selected for the study were health care professionals qualified in forensic pathology, with pathology being the use of scientific techniques to study disease and tissue injury (Buikstra, 2007), which in a legal framework relates to the effects on the deceased of trauma, occupational hazards, poisoning, and natural disease (Watt (1997). Homogenous purposive sampling (Sargeant, 2012) was used in the selection of the study participants. This sampling technique involves identifying and selecting individuals or groups that have desired knowledge and experience of the phenomenon being studied (Creswell, 2011). All participants were forensic pathologists who use the Lodox Xmplar-dr imaging system for forensic purposes with the same objective of utilising it to assist in post mortem examinations. Of the ten forensic pathologists invited to participate, five consented to be observed, four consented to be interviewed about their experience and use of the Lodox Xmplar-dr system.

4.4. Data collection

Two data collection tools were used for the study, observations and semi-structured interviews with open ended questions. Implementation of these tools was guided by the satisfaction characteristics likability, pleasure, comfort and trust, identified by Bevan (2008) as usability characteristics that can be used to interpret satisfaction. These satisfaction characteristics were defined in the context of medical device use in forensics, in particular with regard to the use of the Lodox Xmplar-dr system as explained in section 3.4.

Observation was used as a data collection tool for the purpose of performing a contextual inquiry to gain an understanding of how the forensic pathologists interacted with the Lodox Xmplar-dr system when carrying out post mortem examinations, as a guide to determining questions for the interviews and as a reference during subsequent data analysis. Five forensic pathologists consented to be observed before, during and after their use of the Lodox Xmplar-dr system to perform a post mortem examination. Observation in qualitative research involves spending a period of time in the setting with field notes being taken throughout the observation period (Baker, 2006). The researcher had what has been coined by Gold (1958) as the complete observer role and was present but passive in his participation. This allowed not only observation of the forensic pathologists' use of the system within the restrictions of their actual work, but also collection of data about ongoing rather than summary experiences (Kantner et al., 2003).

During the observations, field notes were taken by the researcher to record the behaviours, activities, events and other features of the observation (Schwandt, 2014).The purpose of the field notes was to assist in understanding the context in which the Lodox Xmplar-dr system was used and to determine the questions that would be asked in the interviews. The field notes also assisted in interpreting observations towards answering the research questions during subsequent data analysis.

The second data collection tool used in the study were semi-structured interviews. Harrell and Bradley (2009) state that Interviews in qualitative research are discussions, usually one-on-one, between an interviewer and an individual, through which information is gathered on a specific set of topics. In the context of assessing health technologies, qualitative research interviews are useful to help understand the scope and complexity of ideas and concepts applied by individuals and groups involved in health technology implementation (Murphy et al., 1998). Semi-structured interviews were conducted with the forensic pathologists to explore their user experience with the Lodox Xmplar-dr system in its forensic application. Semi-structured interviews allow for depth of understanding by providing the researcher with an opportunity to probe the interviewee's responses and seek expansion (Hitchcock and Hughes (1995).

Guided by the field notes taken during observation of the forensic pathologists, open-ended questions were formulated for the semi-structured interviews. Open-ended questions were used as they allowed for the possibility of discovering spontaneous responses, and thus would avoid possible bias from suggesting responses to individuals (Reja et al., 2003). Questions were asked relating to participants' user experience and level of satisfaction with the system guided by the satisfaction characteristics of pleasure, likability, comfort and trust. The seven open-ended questions asked were:

- **i.** Do you have any previous experience with the use of any imaging modality in PMI?
- **ii.** What is your overall experience in your use of the Lodox Xmplar-dr system?
- **iii.** Do you find it easy to get familiar with the Lodox Xmplar-dr system? Please elaborate.
- **iv.** Do you think you are fully utilising the Lodox Xmplar-dr system and its capabilities? Please elaborate.
- **v.** Does the Lodox Xmplar-dr system meet or exceed your expectations in your use of it for forensic examinations? Please elaborate.

vi. What aspects of the Lodox Xmplar-dr system's human-computer-interface and electromechanical system do you think could be improved on and how?

vii. Anything you would like to ask pertaining to the study?

Participant responses from the interviews were recorded, transcribed, and coded for systematic analysis through NVivo11, a software package used for qualitative data analysis.

4.5. Ethical considerations

Approval to conduct the research study was obtained from the Human Research and Ethics Committee (HREC) of the Faculty of Health Sciences, the University of Cape Town, the Division of Forensic Medicine at the University of Cape Town and the Salt River Forensic Pathology Service of the Western Cape Provincial Government. Forensic pathologists who agreed to participate in the research study were requested to sign consent forms for the observations and interviews. The consent forms were stored in a separate location from the recorded and transcribed interview schedules for security and confidentiality. An information sheet stating the research study's aims and objectives was provided and it was made clear to participants that participation in the study was voluntary and any information provided would be used solely for the purposes of this study.

5. Results

This chapter discusses the results from the five observations and four interviews that were used in the collection of data. Thematic analysis was used to code data and identify patterns extracted from the field notes taken during observations and interview participant excerpts based on the predetermined initial themes of physio-pleasure, the theme`s sub-characteristics of comfort, likability and trust and psycho-pleasure. During analysis additional sub-themes were produced for the sub-characteristics of likability, trust and psycho-pleasure.

5.1. Physio-pleasure

This theme centred on the satisfaction users derived from the system's ability to meet their pragmatic and objective expectations in their use of the system. Excerpts from the observational field notes and interview transcripts that indicated forensic pathologist's satisfaction/dissatisfaction with the functionality of the Lodox Xmplar-dr system and encompassed the subcategories of likability, comfort and trust characteristics of satisfaction were coded to this category.

5.1.1. Likability

Field notes and interview quotes that mentioned The Lodox Xmplar-dr system`s features and capabilities and the ease-of-use of the system were coded to this sub-theme of physio pleasure. Codes extracted were used to evaluate the extent to which forensic pathologists were satisfied/dissatisfied with the consequence/ results of using the system. Patterns identified from the extracted codes led to the generation of three sub-themes, positively perceived features, negatively perceived features and absent features.

5.1.1.1. Features positively received

The four forensic pathologists interviewed expressed high levels of satisfaction that came from the functionality of the Lodox Xmplar-dr system; they cited how the imaging system now played a vital role in performing post mortem examinations. The extent to which the expectations of the forensic pathologists were met was reflected by participant 3 who expressed his pleasure in the use of the Lodox system by stating that:

Well the Lodox system far exceeds its usefulness because the time it takes is so much less which makes it a much more efficient process. It certainly allows routine use of radiology to perform post mortems in a busy mortuary which conventional X-rays don't allow.

From the interview extract an inference was made that the Lodox Xmplar-dr system the forensic pathologists' expectations in terms of its functionality as it was deemed an essential part of the post mortem examination process; the system had greatly increased the efficiency with which post mortem examinations could be performed allowing for higher work throughput. Satisfaction in the functionality of the device was also reflected during observations when a forensic pathologist mentioned during use of the system that it was useful in providing information about the body that could be used as evidence in court regarding the cause and time of a death. The forensic pathologist mentioned that it could be useful for constructing the circumstances of a person`s life around the time of their death; the system's utility in assisting in the identification of persons through revealing unique identifiers such as implants and dental work was also alluded to by the participant.

All four forensic pathologists interviewed expressed satisfaction in how easy it was to learn and understand the basic imaging functions that the Lodox Xmplar-dr system could perform. This was a consequence of the simplicity of the system's controls when performing image generation tasks for the purpose of determining the location of injuries, projectiles and other types of pathologies. In the interview, participant four summarised the high likability that came from the ability to use the basic functions of the system effectively by stating that:

If I were to go to a mortuary without the Lodox system I would experience major difficulties when doing my [post-mortems] the way I would like to do them because now it makes it easier for me to know for example the location of bullets, fractures and on natural cases its easy as sometimes it's not necessary to open the person. For example, it's easy to see pneumonia so it saves massive amounts of time and energy when working, and resources too.

In the preceding observations, satisfaction in the ease of use and learnability of the system was also noted as the forensic pathologists mentioned how useful the system was when confirming from the images generated, suspected injuries and pathologies that had been observed and noted in preliminary visual examination of the deceased`s body; this gave them increased confidence in not only the efficacy of the system but also in their own performance, the result being better cause-of-death determination.

5.1.1.2. Features negatively perceived

Forensic pathologists interviewed who had prior experience with other imaging systems mentioned that the Lodox Xmplar-dr to a certain extent met their expectations in terms of the quality of the images generated particularly when compared to previous imaging systems they had used. Participant four's response when asked about their expectations of a PMI system implied that there was a degree of confidence in the output of the system when the participant responded:

There is also the quality of the image the current Xmplar system is fine but the previous [model of the imaging system] produced blurry images and was not as crisp.

The pathologists expressed mild dissatisfaction in the discrepancy between the digital image generated on the HCI screen as a print preview and what was printed by the peripheral printer. Participant two expressed dissatisfaction with the printed images by stating:

And then with image manipulation I would also like if the print preview is the same as the image that is printed, currently … the margins aren't quite right and also the information printed on each corner on the print preview the font is much bigger than … when it is actually printed…

5.1.1.3. Features absent

The absence of some system features deemed as essential was a source of dissatisfaction for the forensic pathologists which resulted in the system falling below expectations in terms of functionality. This was highlighted in the response by participant two when asked about what aspects of the Lodox Xmplar-dr system could be improved. Participant 2 gave the opinion that it would be beneficial if the system`s workstation had other storage media options rather than the printing media to which the users were limited, by stating that:

It would be easier if, for example, we wanted to save an image on to a flash drive if the interface gave you some limited options on how and in what form you can save the image... I think if they took the printer way and printer paper because we do not have any other option besides print to paper … then [it would be] quicker to just find what we want in the [electronic] list...

5.1.2. Comfort

Field notes and interview quotes that mentioned the extent to which the forensic pathologists experienced comfort during operation of the Lodox Xmplar-dr system`s electronic human computer interface (HCI) and physical operation were coded to this theme. Patterns identified from the extracted codes led to the generation of two sub-themes: high perceived comfort and low perceived comfort.

5.1.2.1. High perceived comfort

During the interviews, all four forensic pathologists as the active users of the system mentioned that the ability to position and take images from different angles without having to move from the human computer interface (workstation) was a great source of satisfaction as it greatly improved comfort in use of the Lodox Xmplar-dr system especially when compared to the manual adjustment of the system that was required for previous X-ray imaging systems that some of the forensic pathologists had used. Most functions on the Lodox Xmplar-dr system no longer required manual configuration and adjustment on the actual system but could be done on the workstation. Interview participant three succinctly expressed:

The Xmplar system is certainly an improvement on the one we had [previous model] so now I find it much more user friendly especially where you need to do laterals and stuff like that, with the [previous model] there wasn't a way to do that.

The ability to perform most imaging functions from the workstation without physical manipulation of the system or body greatly increased comfort in use of the system as it reduced the risk of injury at the operational level.

5.1.2.2. Low perceived comfort

During observations and the subsequent interviews, forensic pathologists expressed their concern about the possible negative health impact which came from the manual placement of bodies on the Lodox Xmplar-dr system's scanning table by the system's passive users, forensic assistants who handled the bodies. As reflected by participant one:

The bodies are transferred from gurney to the table manually and if that could be improved a sling or mechanical system would help to prevent injury to us e.g. for bodies that are heavy and with rigor mortis.

This concern was one also noted by the researcher during observations and a note was taken referring to the manual placement of bodies on the Lodox Xmplar-dr system's scanning table by the assistant forensic pathologists. The reason for the concern was the health risks associated with lifting bodies namely the potential for gradual and cumulative deterioration of the musculoskeletal system. The risk of exposure to infection from the corpse was also a concern for the forensic assistants.

5.1.3. Trust

Field notes from the observations and interview quotes that implied the extent to which the forensic pathologists believed the system would behave as intended were coded to this theme. During coding two sub-themes emerged: system related technological factors, further categorized into reliability, durability, and support services for system-related technological factors; and user related factors, particularly training.

5.1.3.1. System related technological factors

To a certain extent, the forensic pathologists as the active users of the technology had trust in the technology. This was implied from the response by participant 3 who mentioned that the Lodox Xmplar-dr system was a much more efficient modality which was crucial during time and resource deficient circumstances by stating that:

It certainly allows routine use of radiology to perform post mortems in a busy mortuary which conventional X-rays don't allow and you have to be much more selective which cases you are going to X-ray.

The response by participant 3 reflects the extent to which the system was valued in its forensic application. However, there were some aspects of the system that diminished the trust they had in the technology.

Reliability

The concept of reliability is broad but essentially it focuses on the ability of a product to consistently perform its intended function. Blischke and Murthy (2011) have defined reliability as the probability that a product or system will be capable of performing its intended function for a specified period when operating under normal or stated operating conditions. The reliability of the Lodox Xmplar-dr system was a source of dissatisfaction for all four forensic pathologists interviewed. The system failed to meet their expectations in terms of trust in the reliability of the system as the forensic pathologists all mentioned that the system overheated, and required a lengthy rebooting time after having been used intermittently which greatly reduced efficiency and work throughput. This dissatisfaction was illustrated by the response given during the interview with participant 2 who noted that:

The issue of overheating causes problems so we can't scan too many bodies in succession we have to wait for the system to cool. Also because most scanning is done in the morning when we want to take it for rescan it seems like the system needs to reboot … restarting which takes a while and can be annoying because now I will not be able to access the menu which … wastes time as well.

During observations, one of the participants pointed this out by mentioning that the system was a "*workhorse but it could be temperamental which had an adverse effect on work throughput*". This had a negative impact on workflow and was a major source of frustration as it caused bottlenecks in the imaging process due to the wait involved whilst the system cooled down, reducing the number of possible examinations in a given time period.

This was further compounded by Participant 4 when asked about his expectations of a PMI system; the participant stated it was very frustrating if the system malfunctioned when they wanted to perform a post-mortem as it meant they would either have to wait or perform the post-mortem without utilising it. This had a negative impact on the trust the forensic pathologists had in the system, as it fell short of their expectations as they depended on the continued functioning of the system.

Durability

A mild dissatisfaction in the durability and robustness of the system was observed in interview participants' responses when they were asked about the aspects of the Lodox Xmplar-dr system's human computer interface and electromechanical system which needed improvement. Doubt was cast on the system`s ability to withstand the adverse conditions in a forensic examination lab, compounded by the consequences of human error. Interview participant three best elucidated this view by stating that:

I suppose the biggest challenge in a busy mortuary is the robustness of the actual mechanics and the system's ability to survive the abuses of the forensic pathology officers who sometimes don't exercise the care that they should. Also, anything that would improve waterproofing of the system, its robustness in handling bumps and crashes.

Support services

Whilst forensic pathologists understood that technical problems could occur, the speed of the response from the Lodox Systems support services was a cause of frustration when forensic pathologists experienced technical problems, and the main cause of distrust and dissatisfaction. This was inferred from the response given by interview participant two when asked about their overall experience in their use of the Lodox Xmplar-dr system:

When it has a technical issue I find it frustrating, it's not like dissatisfaction with the machine itself but its dissatisfaction with the process as in how long it takes for someone to come down and find out what the problem is with the system and then to solve the problem which may mean a replacement part coming from ...

The security of using the Lodox Xmplar-dr system that forensic pathologists derived from knowing that the system could be utilised and depended upon when needed was diminished due to support services not reacting promptly to technical problems.

5.1.3.2. Training for user related factors

Dissatisfaction and low levels of trust came from the system not meeting expectations as a result of the gap between what the forensic pathologists could achieve when using the Lodox Xmplar-dr system and what they perceived the system is fully capable of, the consequence of this being under-utilisation of the system. The more complex functions that the device could perform were not explored and the forensic pathologists cited a lack of adequate and consistent training that reduced the confidence they had when using the system and to fully realise the system's full potential.

From the observations and interview responses it was deduced that there was frustration, and therefore dissatisfaction, due to the forensic pathologists spending a substantial amount of time seeking assistance on how to perform imaging tasks or when they performed the imaging tasks based on their own understanding, which could be detrimental to the quality and interpretation of the images generated. Participants expected the system to assist them in cause of death determination but did not know how to utilise the system to its full potential and mostly relied on its most basic imaging functions. This was reflected in the response by participant one when asked if they were fully utilising the Lodox Xmplar-dr system and its capabilities and the participant stated that:

….so only when something is obvious are we able to make a certain diagnosis but if it is not then it becomes difficult. But it's just a function of our training it's not necessarily the Lodox device.

Participant two elaborated on this further by stating:

They don't regularly come to train us only once or so a year and due to the high turnover of doctors the older doctors frequently have to train the new doctors and it becomes a bit of a monkey see monkey do.

An incident reflecting the words of participant two was noted during observations as there were some body positions that they wanted to scan but were not able to, due to lack of training on how to manipulate the system both manually and from the HCI. As a result, there was potential for certain injuries to go unnoticed reducing the confidence the forensic pathologists had in making a diagnosis based on images generated by the Lodox Xmplar-dr system.

Inadequate training had a negative impact on the forensic pathologists' satisfaction when using the system. In such cases, dissectional autopsies would be performed, which reduced efficiency in work through-put and diminished the system's utility in its forensic application. This was exacerbated by the lack of information regarding software updates on the system which resulted in changes in the layout and look of the human-computer interface. This created a learning curve resulting in frustration and potential delays during the period the forensic pathologists took to understand the changes. This was illustrated by participant two when discussing their overall experience with the Lodox Xmplar-dr system.

I think the only real frustrations have been for example if there was a software upgrade having to look carefully again to determine where things are, or if someone changes the way it looks on the screen there's a little bit of a learning curve about where certain features are.

Another source of dissatisfaction could be traced to the mismatch between the disciplinary training of the forensic pathologists and the requirement that they interpret images in the manner of radiologists, whose disciplinary training is specifically targeted at the interpretation of medical images. This was reflected in the response from participant two when asked if they were fully utilising the system and its capabilities:

Probably not because I think we do not get enough training in radiology, so I find I have to go and look for information myself about how to interpret different things so as a result, I think that we are probably missing quite a few things.

5.2. Psycho-pleasure

5.2.1. Positive psycho-pleasure

The four forensic pathologists interviewed expressed high levels psycho-pleasure stemming from the Lodox Xmplar-dr system meeting and in some cases exceeding their expectations. The forensic pathologists' positive feelings of psycho-pleasure could be attributed to how the system met and to a certain extent exceeded their expectations in terms of functionality when compared to previous imaging modalities some of them had used during a post mortem examination.

The Lodox Xmplar-dr system exceeded the forensic pathologists' expectations due to the system's improved functionality. The functional attributes of the system, when used in forensic pathology, elicited positive emotions of psycho-pleasure as the system met or exceeded their expectations in terms of the antecedent emotion of physio-pleasure. Positive feelings of psycho-pleasure were the result of the system`s ability to meet or exceed expectations by satisfying the physio-pleasure subcategory of likability due to the confidence the forensic pathologists had in the system`s ease of use and the enhanced feature list. Positive feelings of psycho-pleasure as a result of comfort were attributed to the manipulation of the system with minimal physical interference due to the system being capable of generating most imaging tasks autonomously without human intervention.

5.2.2. Negative psycho-pleasure

Negative psycho-pleasure emotions were the result of the system failing to satisfy certain aspects of the antecedent emotion of physio-pleasure. Areas of frustration in likability were due to some system features not fully meeting expectations in terms of the functional attributes of the system when used in forensic pathology. The forensic pathologists expressed annoyance with the limited options for saving generated images and the discrepancy between electronic and printed images.

The psycho-pleasure sub-category of comfort was a source of dissatisfaction for the forensic pathologists. The negative psycho-pleasure emotion of anxiety arose from the potential health risks both short term and long term that the forensic assistants were exposed to during manual placement and manipulation of the bodies on the system`s scanning table.

Technological and user factors were a source of dissatisfaction in the trust sub-category of psycho-pleasure. Reliability of the Lodox Xmplar-dr system was a technological factor that the forensic pathologists cited as a source of frustration as it impeded work throughput and caused bottlenecks in the forensic examination process. Trust in the durability of the components of the system cast doubt on the system's ability to withstand the operating conditions in a forensic laboratory for sustained periods.

A source of dissatisfaction for both technological and user factors was the lack of support services for both the system and its users. Trust in the technology was diminished as a result of the apprehension that the system might malfunction or break down and the Lodox support services might not respond promptly to any technical problems. This would have the negative result of causing workflow bottlenecks and necessitating post mortems without utilising the system, thus causing inefficiencies in caseload management. Trust was also a negative source of psycho-pleasure due to inadequate training which had adverse effects on full utilization of the system.

Table 4 summarises the satisfaction or dissatisfaction characteristics that influence psycho-pleasure.

Table 4: Summary of satisfaction/disatisfaction characteristics influencing psycho-pleasure.

Positive influences	**Negative influences**
- System`s perceived ease of use. - Enhanced feature list in comparison to previous Lodox Statscan imaging system. - Easy manipulation of the system when performing imaging tasks. - Minimal physical interference due to the system`s autonomous functioning capability.	- Potential health risks due to manual placement and manipulation of bodies on scanning table. - Reliability of the system impeded work throughput. - System`s ability to withstand the operating conditions in a forensic laboratory for sustained periods. - Lack of support services for the system. - Inadequate training of users.

6. Discussion and conclusion

The purpose of this study was to evaluate the usability of the Lodox Xmplar-dr imaging system in post-mortem imaging by qualitatively evaluating the level of satisfaction of its active users - forensic pathologists - in their use of the system. From the literature review it was deduced that research on usability in medical devices had a focus mainly on the comparison of the usability of different devices or was aimed at finding flaws in the design of medical devices based on quantitative evidence. The focus has been on efficiency and effectiveness with satisfaction being a by-product of the former two dimensions of usability, owing to the concept`s subjective nature. This study, in contrast, focused on the satisfaction aspect of usability, and developed a conceptual framework within which to assess user satisfaction in the use of a medical device.

Characteristics that explore the satisfaction aspect of usability were first determined based on the expectancy disconfirmation theory of satisfaction and the cognitive and consumption emotions experienced by the user during use of the product. Emotional satisfaction characteristics based on those identified by Bevan (2008) that allow for the incorporation of user experience into usability evaluations were adapted, namely pleasure, likability, comfort and trust. These satisfaction characteristics were modified by categorizing them into two pleasure characteristics. The first, physio-pleasure which is system related and task-oriented, was conveyed by the efficiency and effectiveness of the system in performing tasks and encompassed likability, comfort and trust. The second characteristic, psycho-pleasure, stemming from the hedonistic and subjective aspects of the user's experience, was derived from the imaging system`s ability to meet or exceed the users' expectations by satisfying the system-related satisfaction characteristic of psycho-pleasure.

The physio-pleasure subcategory of likability revealed areas of dissatisfaction in the functionality of the device, on which improvements could be based. A disparity between the system's capabilities and that of the peripherals was noted, particularly with regard to storage and printing of images. It would be beneficial to include peripherals that match the capabilities of the system. A forensics-orientated user interface that is specifically moulded to forensic pathology requirements, and complements and integrates more naturally into a forensic facility and the daily needs of pathology staff, would also be beneficial. The user interface of the system had been adapted from the trauma application of the system, which limited its functionality in forensics.

Comfort in use was a source of mild dissatisfaction particularly for the system's passive users, the forensic assistants. Components of the system could be automated or a mechanical system that allows for easier placement of the body could be added or retrofitted to reduce chances of exposure or injury.

Reliability and durability of the system and some of its components were cited by the forensic pathologists as a major source of dissatisfaction. A comprehensive update of the system and its components, focussed on increasing reliability and durability, particularly for the forensic setting, would be beneficial.

The level of support provided by the Lodox Xmplar-dr imaging system's producers was a source of dissatisfaction for the forensic pathologists. Prompt technical support when the system malfunctioned or when assistance was required to troubleshoot a problem were cited as a major concern.

Concerns were expressed about training related to the relatively high turnover of forensic pathologists in the forensic laboratory and limitations in the specialist training of forensic pathologists with regard to image interpretation, and a need was expressed for more training by the producer. Both concerns represent user-level constraints. While both could be addressed by the forensic pathology service in collaboration with the producer of the system, the specialist training of forensic pathologists might require a shift to reflect changes in the nature of forensic pathology examination.

Lodox Systems Pty Ltd has developed an improved iteration of its forensic imaging technology in the form of the Lodox eXero-dr system (Lodox, 2017), which became available during the execution of this study **Figure 4.** The improved system has addressed some of the concerns that caused dissatisfaction for the forensic pathologists in their use of the Lodox Xmplar-dr version. These innovations include, as stated by the company on their website:

- A more forensic-orientated user interface which provides more comprehensive functionality in the form of forensic-specific X-ray procedures has been developed for the Lodox eXero-dr system. This may improve the satisfaction characteristic of likability of the imaging system, by making it easier to operate the human computer interface.
- Comprehensive waterproofing and drainage has been added to the physical system to prevent accumulation of fluids and particles. To a certain extent this addresses system-related technological factors that had an impact on the trust characteristic of satisfaction in use of the system, by addressing concerns over the durability of the previous imaging system. This is expected to increase the comfort in use satisfaction characteristic particularly for the system`s passive users as it would facilitate cleaning and disinfection.
- An automated gurney system allows better positioning and imaging of bodies. This addresses the comfort in use satisfaction characteristic, as it would reduce the concerns related to manual manipulation of the bodies. An additional expected benefit of the automated gurney system is that it would allow for better positioning and imaging of bodies, enhancing ease of use.

Although the study setting was limited to one location and the sample size was small, the observations and forensic pathologist`s responses reinforced each other, and some overlap was found across the responses of the latter.

Despite the small sample size and single study setting, an advantage of the study is that the usability evaluation was conducted in a practical setting, with the forensic pathologists using the system for actual forensic examinations in a forensic laboratory. The results may therefore be useful to guide usability evaluations on similar imaging systems being used in the forensic context.

The focus of the study was the experience of the users of the imaging system. Interviews with the producers of the system might reveal additional user-level factors that constrain the utilisation of the imaging system, and which may be addressed by the user and the producer cooperatively.

Figure 4*:* Lodox Exero-dr imaging system (Lodox, 2017*)*.

6.1. Conclusion

This study has gathered and analysed qualitative information pertaining to users' consumption experiences in the use of a medical device. The focus on the satisfaction aspect of usability has produced a qualitative evaluation of usability based on the experience of the user, rather than a quantitative focus on the efficiency and effectiveness of a product. Evaluating the satisfaction aspect of the imaging system based on the user experience in a forensic setting has revealed both product design and service issues. The conceptual framework applied in this study may be useful for satisfaction studies of other medical devices. The results may guide imaging installations in the forensic context.

Future work building on this study could be aimed at increasing sample size and expanding to other study settings. Further insights about the satisfaction of forensic imaging system users could be garnered through the refinement of questions in the interview protocol through a better alignment of the interview questions for a better understanding of the users' experiences, how they describe them, and the meaning they make of these experiences. Finally, further exploration towards the integration of satisfaction into usability evaluations would benefit the development of new metrics on which to evaluate forensic imaging systems and other medical devices.

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