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# Product Usability Driven System Engineering

Saad Aldoihi

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# Product Usability Driven System Engineering

Thèse de doctorat de l'Institut Polytechnique de Paris préparée à  
l'École Nationale Supérieure de Techniques Avancées

École doctorale n°626 : École Doctorale de l'Institut Polytechnique de  
Paris (ED IP Paris)

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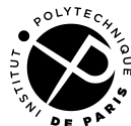
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*To Mona, Mila & Elias*

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# Introduction

## Overview

This chapter introduces the general context of the research. First, it starts with the background and the essentials of usability to an everyday product. Also, it shed light on the Usability definition and why there are so many definitions that contribute to the definition. Basically, usability is defined by its context of use. Therefore, the definition is extremely adjustable to suit the context of use. In particular, usability definition can be classified into two categories. One is the attribution list base, and the other is the sentence base.

## Background

Usability is essential to every product. As systems and products get advanced in technology and capabilities, the need for usability grows dramatically across industries. Usability can give the system and product enduring advantages. Obvious advantages include but not limited to faster adaptability by users, cost-saving, and more user satisfaction (Bias, 2004) (Jokela, 2004). The importance of usability grew as more organizations understand its significance. Low usability generates poor user experience and early user abandonment (Hertzum, 2020). Usability is a critical factor in many industries, but it is more so to aviation and healthcare. The reason is that usability has deviated from the safety attribute. However, ISO/IEC 9126 characterized usability as quality attributes because it serves as non-functional requirements. Usability as an attribute deviate from safety or quality according to its intended use (see Fig 1.1)

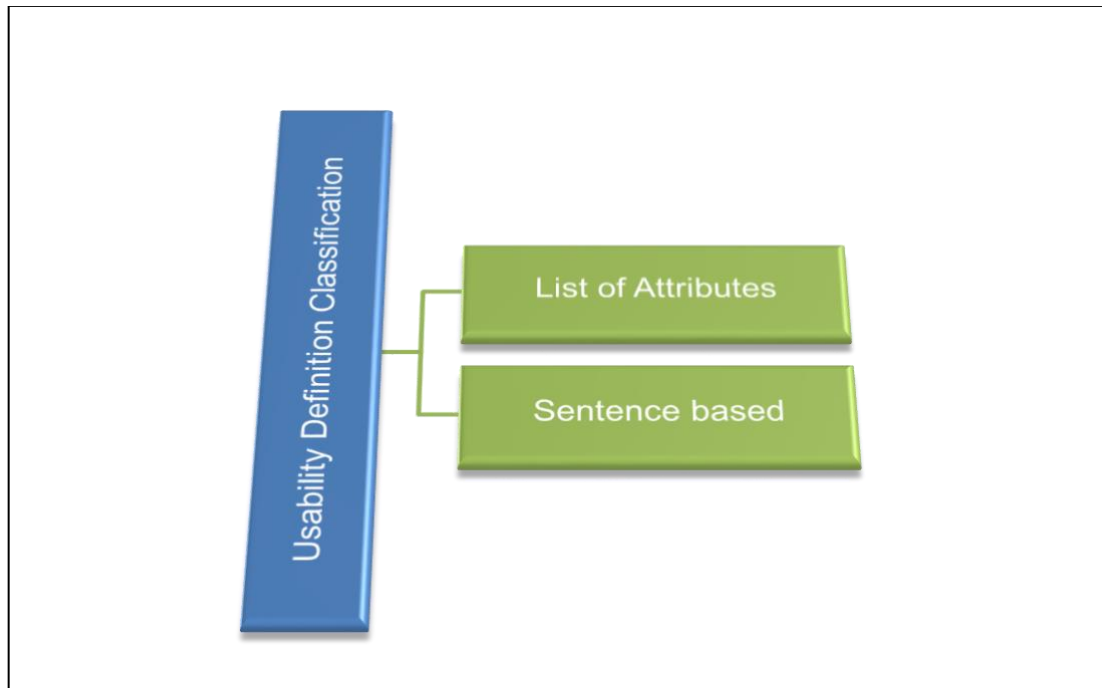


*Fig 1.1: Usability deviation according to the intended use*

Many usability principles have been incorporated into industry best practices (Joyce et al. 2017). Usually, usability is governed by a set of human-machine interaction recommendations used to achieve an appropriate outcome (Ferreira et al. 2020). However, there are many inspection methods that evaluate a specific product or system. Ivory and Hearst (2001) documented 132 different usability evaluation methods. Most notably is heuristic evaluation. Recently, it gained momentum due to its fast execution and deployment. Orlovska et al. (2018) stated that usability evaluators need to extremely master a multidisciplinary approach. This multidisciplinary approach includes neuroscience, computer science, sociology, and psychology.

Generally, usability means the extent to which the user is able to fulfill the product's usefulness. Quiñones & Rusu, (2017) referred to usability as user capability to utilize. Weichbroth, (2018) stated that usability is a deviation of ease of use. Usability definition is classified into two types (see Fig 1.2). The first one is a list of attributes. The second is sentence-based. Even though the usability concept is straightforward and unpretentious, researchers were not able to pinpoint what usability actually means (Karwowski, 2006). The primary reason is that usability is diverged

according to its intended purpose. Determining usability is highly dependable in its context of use. Thus, usability definitions keep expanded to suit specific context of use. In other words, usability is defined by the context of use in which the product or system is going to serve. Usability usually deviates according to the intended use.



*Fig 1.2: Usability definition classification*

### Aims and Objectives:

#### Aim:

The aim of this research is to determine and explore the nature of Product Usability facing Computed Tomography scan (CT scan) technicians and radiologists in Saudi Hospitals. In particular, the research focuses on CT scan cross three dimensions, which are:

- User
- Environment
- Tasks

## Objective

the specific objectives of this research are:

- Identify user experience to CT scan through heuristics evaluation
- Identify the usability of CT scan based on demographic characteristics
- Explore invisible physical exertion while operating CT scan
- Explore invisible mental exertion while operating CT scan
- Explore effecting factors generated by the Context of Use

To justify the rationale for this research, a state of the art of product usability was conducted and presented in the following chapter.

## Research Questions

This research is aimed to answer the following questions

RQ1: What are the usability issues of operating a CT scan?

RQ2: What is the current usability issue based on the technicians' perspective?

RQ3: Does the Usability issue differ based on demographic characteristics?

RQ4: is there invisible physical exertion in operating a CT scan?

RQ5: is there invisible mental exertion in operating a CT scan?

RQ6: What are the factors which contribute to the usability issue?

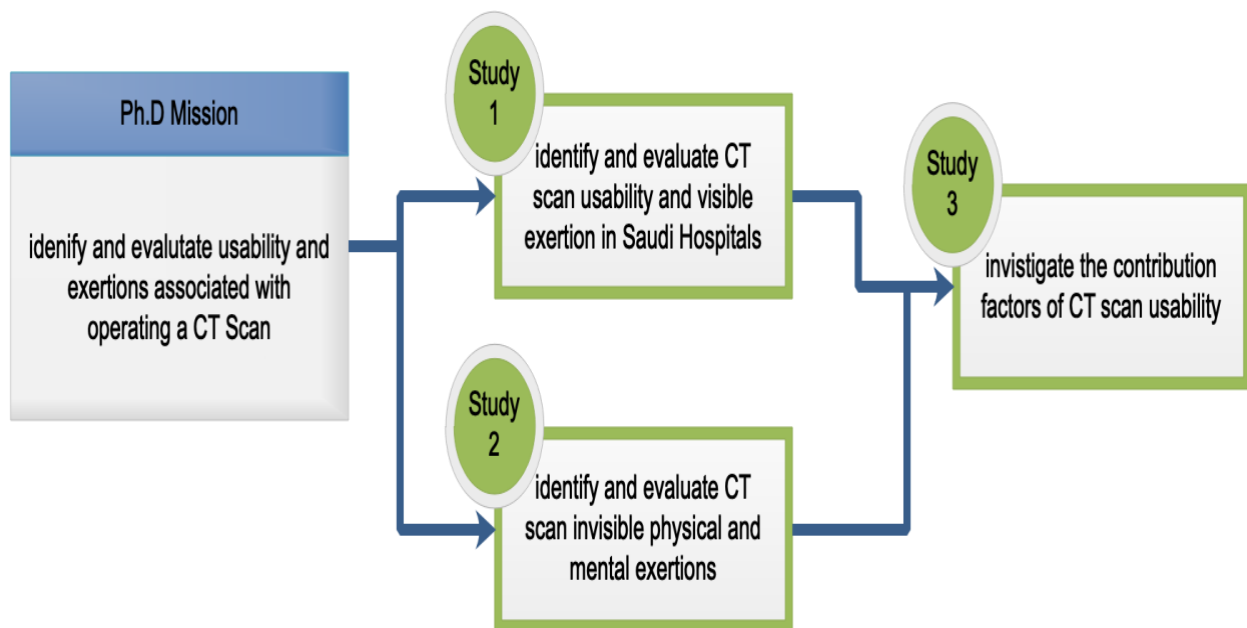
RQ7: What the effect of captured requirement engineering on the context of Use?

## Research Scope:

The purpose of this research is to evaluate CT scan usability in Saudi Arabian Hospitals heuristically. It also explores the invisible exertion associated with operating CT scans. Moreover, it profoundly investigates the factors contributing to usability and how the context of use is



immensely affected by the captured requirement. Primary, it examines the system from three dimensions (Users, Tasks, and Context of use). The population of the studies consists of CT scan technicians and radiologists in Saudi hospitals. As this research was a Ph.D. scholarship from King Abdelaziz City for Science and Technology (KACST), it is bonded by a definitive time limit, which is 36 months. A research scope can be visualized through the research mission and research studies structure. See Fig. 1.3.



*Fig. 1.3: Study mission and structure*

### Contribution:

This research contains studies on usability, cognitive, human-machine interaction. The studies have several contributions:

#### 1. Usability contribution:

- 1.1. it contributed to the product usability definition.

- 1.2. To the best of my knowledge, it was the first study to identify the usability violation in operating CT scan in Saudi Arabian Hospitals (based on 14 usability attributes) (Aldoihi, Hammami June 2018) (Aldoihi, Hammami, November 2018) (Aldoihi, Hammami, January 2020).
- 1.3. It measures CT scan usability in conjunction with demographic characteristics effects in Saudi Arabian Hospitals. This contribution might extend to countries with similar demographics characteristics (Aldoihi, Hammami June 2018).
- 1.4. The studies provide a list of improvement recommendations to CT scan designers and manufacturers within the domain of usability (Aldoihi, Hammami, June 2018) (Aldoihi, Hammami, November 2018) (Aldoihi, Hammami, January 2020).

## 2. Cognitive Contribution:

- 2.1. To the best of my knowledge, it was the first study to identify invisible physical exertion within CT scan context of use (Aldoihi, Hammami, April 2019) (Aldoihi, Hammami, November 2019)
  - 2.1.1. It is the first study to process data to prove that over 50% of technicians transfer a bedridden patient from the hospital bed to the CT scan table.
  - 2.1.2. It is the first study to process data to prove that over 70% of technicians prepare the examination room for receiving the next patient. This preparation includes cleaning and disinfecting the room. Due to the Coronavirus pandemic, currently, the world health system is overloaded. Such activities will be put health system capacity at uncharted risk (whenever the technician prepare, there is an effect on the bandwidth capacity of the hospital).
    - 2.1.2.1. It proposed a new CT scan with confinement capability (Patient enter CT scan room in a confined tube)

- 2.1.3. It is the first study to process data to prove that over 65% of technicians prepare and administrate the contrast media.
  - 2.2. To the best of my knowledge, it was the first study to identify invisible mental exertion within the CT scan context of use (Aldoihi, Hammami, April 2019) (Aldoihi, Hammami, November 2019).
  - 2.3. It proved that there is physical exertion on technicians come in the form of usual every day's activities (Aldoihi, Hammami, November 2019).
  - 2.4. It measures the physical, mental, frustration, and discomfort loads in conjunction with usability attributes based on NASA-TLX measurement (Aldoihi, Hammami, June 2018) (Aldoihi, Hammami, November 2018).
3. System engineering contribution:
    - 3.1. It evaluates the CT scan's system based on the system engineering perspective.
    - 3.2. It contributes to CT scan's system development practice by pinpointing to the current system's flaws, which are:
      - 3.2.1. system failure to upholds overweight patients
      - 3.2.2. system incapability to control CT scan's table from the control room
      - 3.2.3. troubling caused by movement on imaging quality
      - 3.2.4. lack of cross brands standardization
    - 3.3. context of use demand agility with the diversity of language to serve larger and diverse patients.
    - 3.4. It paves the way to intergrade business intelligence with the CT scan ecosystem to observe product data usage and handle parameters where medical error can be prevented.

3.5. It paves the way to system modeling where one ecosystem can handle extended dimensions such as usability, business intelligence, and user experience from the operational ground.

#### Publication:

1. Aldoihi, S., Hammami, O. (2018). Evaluation of CT Scan Usability for Saudi Arabian Users. In Computer, Information and Telecommunication Systems (CITS), 2018 International Conference on (pp. 119-124) Colmar, France. IEEE.
2. Aldoihi, S., Hammami, O. (2018). User Experience of CT Scan: A Reflection of Usability and Exertions. In Computer Systems and Applications (AICCSA), 2018 IEEE/ACS 15th International Conference. Aqaba Jordan.
3. Aldoihi, S., Hammami, O. (2019, April). Evaluation of Invisible Physical and Mental Exertion from CT Scan Operation in Saudi Arabian Hospitals. In 2019 6th International Conference on Control, Decision and Information Technologies (CoDIT). Paris, France.
4. Aldoihi, S., Hammami, O. (2019, May). On the Impact of Product Usability on CT Scan Scheduling: A Case in Saudi Hospitals. In 2nd ICCAIS2019 International Conference on Computer Applications Information Security. Riyadh Saudi Arabia.
5. Aldoihi, S., Hammami, O. (2019, November). Effect of Invisible Exertions on Computed Tomography Radiologists in Saudi Hospitals. In 2019 IEEE/ACS 16th International Conference on Computer Systems and Applications (AICCSA). IEEE. Abu Dhabi, UAE.
6. Aldoihi, S. and Hammami, O. (2020) Usability Evaluation and Assessment of Computed Tomography Scan. Intelligent Information Management, 12, 27-35. doi: 10.4236/iim.2020.121002.

7. Adlohi, S., Hammami, O. (2020, June). Factors contributing to CT scan usability. 2020 IEEE International Conference on Computational Intelligence and Virtual Environments for Measurement Systems and Applications (CIVEMSA), Tunis, Tunis, 2020

# Product Usability: State of The Art

## Introduction:

The evolution of the semiconductors industry is moving rapidly, and it reflects on other industries as a result. Nowadays, many products that used to be a solid mechanic started to be composed of electronic components. Eventually, the control commands of those products are the User Interface. The famous Moore law stated that semiconductors would double in capacities and speed every two years. Consequently, Moore Law has influenced many industries in correlation. Conjecturally speaking, product usability in consumer electronics clearly has been subjected to Moore Law metaphorically. As a result, Usability is doubling in size and capacity in correlation to its future.

We are surrounded by consumer products that demand a certain way of engagement especially in the sense of ‘the right way of use’. Product and system developmental practices indicate that usability is tremendously under pressure (Eijk, et al. 2012). Consequently, advanced knowledge is not accessible and always lacks applicability because of a misunderstanding of usability, abandonment of organizational support, and poor utilization of usability (Bias and Mayhew, 1994; Gould and Lewis, 1985; Nielsen, 2004). Increasingly, Product usability has been at the center of attention for many designers because there are legislation requirements, and market requirements that require products to fulfill desired usability standards, and to enhance customer acceptance in the market (Stewart, 1991; ISO, 1993).

Many of the present development practices do not take into account the user-centered approach. Consequently, it fails to consolidate users' feedback and needs. This was the primary purpose of developing the ISO 13407 standard (Bevan, 1999). Subsequently, when designing a product, it is

vitaly essential to identify the target users. Thus, knowing who will use the product would make it easier to implement the user's requirement and desires' features. Appealing to desire is a crucial factor for product success. Additionally, Ferre et al. (2001) defined four elements that deemed vital to usability process which are:

- Who are the system users?
- What will they tend to achieve?
- What will they require from the system to perform?
- How should fulfill their needs?

lack of usability can occur from both product as a failure in design or from the user as a failure to fulfill its usefulness, and this commonly referred to as Ergonomics. Many perspectives and definitions of usability have been perfected over time (Hertzum, 2010). Despite the important characteristics of usability, it offers immense benefits such as getting customer acceptance in the market, increases user satisfaction, reduce training cost, and increases sales and boost revenue.

Kim and Han (2008) stated Usability inspectors assemble precise measures. These measures cover task completion time, frequency of error, and user preference. These measures should reflect product usability. According to the obtained measures, the inspectors attempt to terminate if a certain alternative is better than the others in terms of one measure prioritize over the other. A designer or a design team can use guidelines, heuristics or rules as aids in the design process to ensure good usability (Welie, et al. 1999). Usability can extent to many of its such branches namely user experience and user-centered design (UCD) approach (Tarkkanen et al. 2013).

Even though there are many standards and guideline which seems to govern the usability, it is very hard in practice. Since ISO merely refers to usability as a definition, it lacks a clear structure that can govern the design process. In general, Usability consists of a set of autonomous attributes

such as learnability, satisfaction, and efficiency, or all put together (Bevan, Azuma, 1997). ISO Usability attributions are extremely hard to stipulate exactly the measurable usability attributes and their elucidations from different perspectives (Seffah, Metzker, 2004). Usability practitioners struggle with budgetary constraints. As a result, usability testing can be limited to only 5 participants. Procuring more test sessions and larger scale of Usability participants call for resources not readily available to usability practitioners who frequently working solely within a development group or company (Faulkner, 2003).

## Overview:

### Brief History of Usability:

In an early appearance of usability, it came as a replacement of the term ‘user friendly’ (Bevan, et al. 1991), ‘user-friendliness’, and ‘ease-of-use’ (Lewis, 2006). The term usability popularized at the start of the 1980s and eventually was embraced by the software industry (Lewis, 2006; Bygstad et al. 2008). For the first time, usability got to be defined is by a researcher called RB Miller (1971), who set usability measure as “ease of use” (Shackel, 1990). However, according to Lewis (2006), the earliest existence of publication which contains ‘usability’ in its title was by Bennett (1979). Extensively, Usability refers to how easy a product is to use (McNamara and Kirakowski 2005) and to handle. To reach one homogenous definition of usability is extremely difficult since there is one unified and formal definition. Still to this day, Usability comes in literature as heterogeneous attributes, aspects, or dimensions to form coherent understand.

Considering the history of usability is evolutionary, which according to Rubin (2002) passed through three waves. Rubin (2002) added that the first wave of usability began during World War II. Where most designs airplane cockpits were poorly designed and causing great confusion among pilots. The main concentration of this phase was on human physiology, performance under stress, and information processing. The second wave referred to usability with small “u” which started



with the coming of the computers. The second wave emphasis was on the product or service rather than the larger issues that disturb user awareness. The third wave started with the coming of the internet, and it referred to as Usability with a capital “U”. Whereas in the context of small ‘u’ and capital ‘U’, Barnum stated that “little u” is the usability testing activity which associated with the learning and the observing coming from users who are using the product to execute tasks in an easy and straightforward way. While the capital “U” is *“the umbrella term that encompasses usability testing and a host of other tools that support your understanding of the user experience and the process of creating usable, useful, and desirable products”*.

Usability Definitions:

*Academic Definitions:*

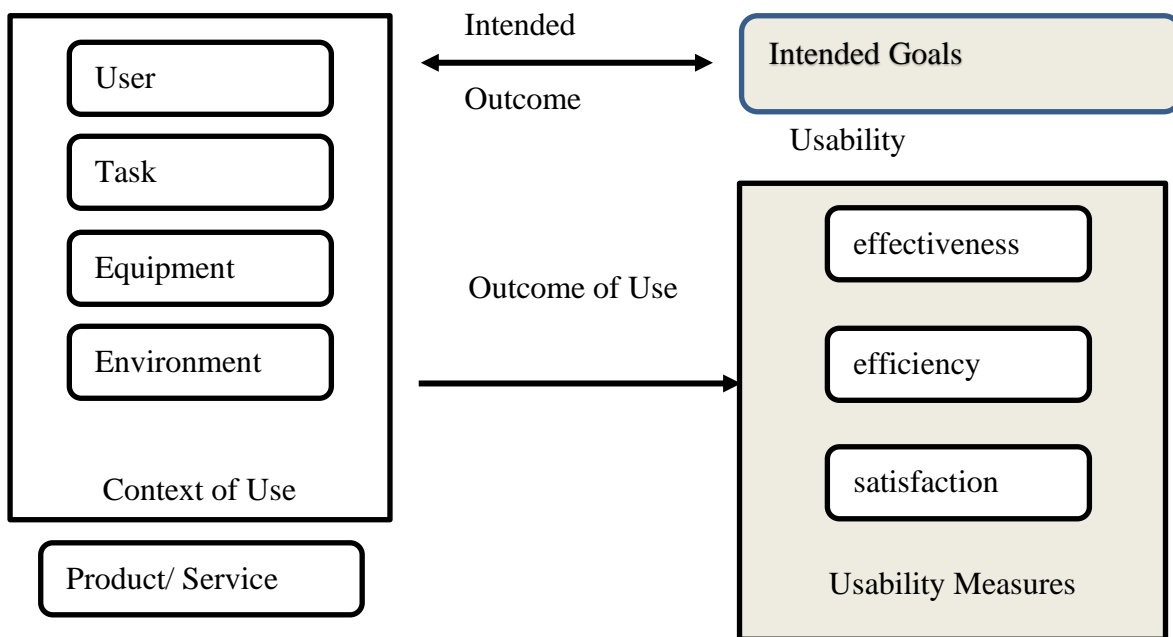
Many Authors have different definitions and attributes to Usability. The excessive amount of definition does not make it easy for an academic and a practitioner to grasp its valued meaning (Weichbroth, 2018). definitely, there is no wide acceptance of one unified homogeneous definition, but rather Usability consist of somehow sets of unified attributes that form a cohesive usability understanding. Folmer and Bosch (2004) argue that although there is a consensus on the term usability, but there are many diverse methods and measurements of usability which resulted that many authors have different definitions of usability. Even though there are many deferent definitions and attributes of Usability from authors and standards, but they all agreed on the vital importance of Usability.

Usability in its simplest definition comes from Dumas and Reddish (1999) and McNamara and Kirakowski (2005). Dumas and Reddish (1999) proposed *“Usability means that the people who use the product can do so quickly and easily to accomplish their own tasks.”* While McNamara and Kirakowski 2005 stated how easy the product to use. However, the first usability definition came in literature is *“the quality of interaction which takes place”* (Bennett, 1979, p. 8).

Shackel (2009) defined usability as “*the capability in human functional terms to be used easily and effectively by the specified range of users, given specified training and user support, to fulfill the specified range of tasks, within the specified range of environmental scenarios.*”. Bevan (1991) defined Usability as “*The usability of a product as a function of the particular user or class of users being studied, the task they perform, and environments in which they work*”.

### *Standards Definitions*

The International Standard ISO 9241-11 defines usability as “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use” See Fig 2.1. ISO 9241-11 attributes are Effectiveness: means that the accurateness and comprehensiveness with which users accomplish specified goals, Efficiency: means that the resources expended in correlation with the accurateness and comprehensiveness with which users accomplish goals, and Satisfaction: means that the Freedom from uneasiness, and optimistic attitudes towards the use of the product. In a similar context, ISO 9241 defines User Experience as a user's perceptions and reactions that outcome from the use or expected use of a product, system or service (ISO 9241, 2008). Therefore, according to Bevan measures of user experience are identical to measures of satisfaction in Usability (Bevan, 2009). Institute of Electrical and Electronics Engineers- defines Usability as “The ease with which a user can learn to operate, prepare inputs for, and interpret outputs of a system or component” (IEEE Std.610.12- 1990). The final definition is from ISO / IEC 9126 where usability defined as “Usability refers to the capability of the product to be understood by, learned, used by and attractive to the user, when used under specified conditions”.



*Fig 2.1: ISO 9241 Usability Framework*

Although ISO / IEC 9126 definition pays particular attention to ease of use, the term “quality in use” used to depict usability more broadly See Figure 2.2 (Abran, et al. 2003; Bevan, 2001). The quality in use described in ISO / IEC 9126 as “the capability of the software product to enable specified users to achieve specified goals with effectiveness, productivity, safety, and satisfaction in specified contexts of use”

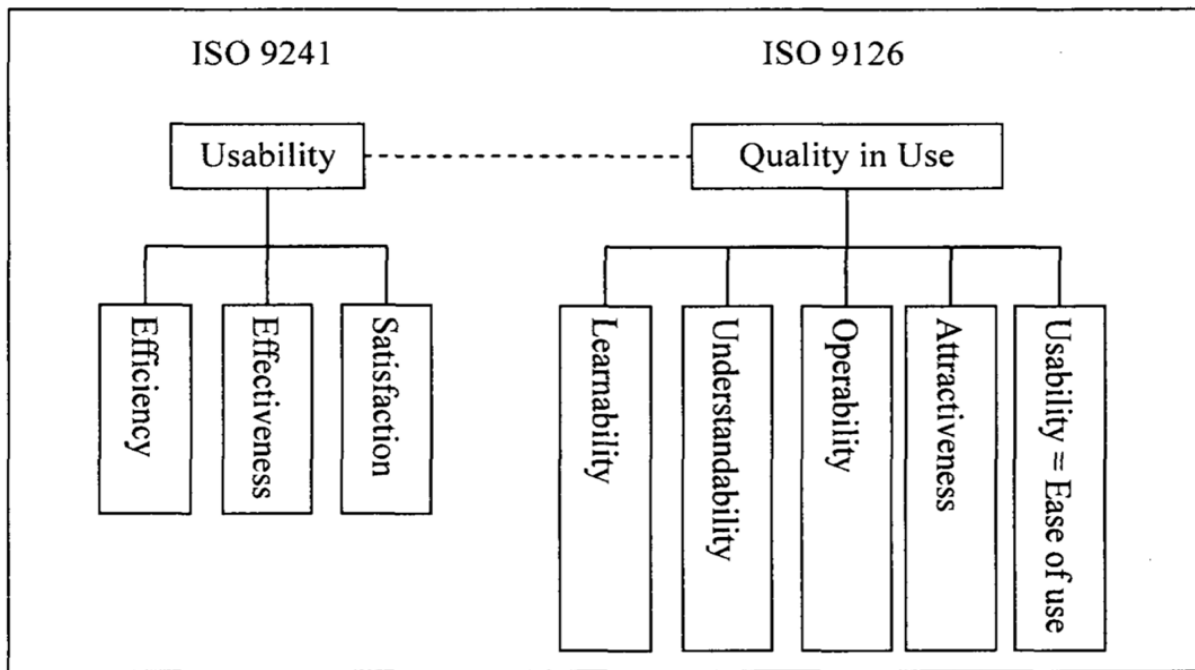


Fig 2.2: ISO 9241 Usability vs ISO 9126

### Usability in industry:

MacKenzie (2012) define the Human factors as “both a science and a field of engineering. It is concerned with human capabilities, limitations, and performance, and with the design of systems that are efficient, safe, comfortable, and even enjoyable for the humans who use them.” When companies had to introduce products that required certain user interaction, the need for usability and user-centered design had been increasingly vital. With more products that have computer capabilities, companies started to venture into the usability aspect of product. Traditionally, when a company sells products, a critical component of the package is the user manual. Needless to say, that some products without it are useless. Therefore, many companies felt the needs for self-explanatory products. Corporate efforts to contribute usability to operate product has been proportional. For instance, in 1963, the invention of the mouse by Douglas Engelbart had led to the emergence of Human-centered

Interaction HCI (MacKenzie, 2012) and started the era of graphical user interfaces GUI. In fact, the first computer to feature GUI was the Xerox Star. Gibson (2017) depicted 3 companies from various industry namely Rent the Runway, Airbnb, and Uber where they completely changed the nature of their industry and gain wide user acceptance through sharing the following characteristics:

- Usefulness: attain the user need.
- Usability: their digital UIs are easy to use.
- Overall user experience: the extension of user experience quality beyond traditional UX.

Wang stated that the user might discover a component of the interface difficult for numerous reasons. The system is problematic to learn, it decreases the performance of the tasks, and it causes errors of use or it is frightful and unfriendly (Wang, 2001). Consequently, the industry has introduced interface guidelines as a recommended style for developers (See Table 2.1).

*Table 2.1: Industry Interface Guideline*

Company	Attributes	Description
Microsoft	Enabling	The application satisfies the needs of its target users, enabling them to perform tasks that they couldn't otherwise do and achieve their goals effectively
	Efficient	The application enables users to perform tasks with a level of productivity and scale that wasn't possible before.
	Versatile	The application enables users to perform a wide range of tasks effectively in a variety of circumstances

	Direct	The application feels like it is directly helping users achieve their goals, instead of getting in the way or requiring unnecessary steps. Features like shortcuts, keyboard access, and macros improve the sense of directness.
	Flexible	The application allows users complete, fine-grained control over their work.
	Integrated	The application is well integrated with Microsoft Windows, allowing it to share data with other applications.
	Advanced	The application has extraordinary, innovative, state-of-the-art features that are not found in competing solutions (Microsoft Corporation)
Apple IOS	Bars	Tell people where they are in your app, provide navigation, and may contain buttons or other elements for initiating actions and communicating information
	Views	Contain the primary content people see in your app, such as text, graphics, animations, and interactive elements. Views can enable behaviors such as scrolling, insertion, deletion, and arrangement
	Controls	Initiate actions and convey information. Buttons, switches, text fields, and progress indicators are examples of controls (Apple Inc.)
Google	Accessibility	Clear, Robust, Specific
Android	Bidirectionality	layout the basic structure for User interface mirroring construction for right to left languages such as Arabic and Hebrew (Google)

### *Attributes, Aspects, Dimensions*

To many authors, usability could not consist of a definition. Rather, a set of defined attributes which constitute a cohesive whole definition of usability. According to Ferre, et al. (2001) usability cannot be defined as a specific attribute because it all depends on the intention of the system under development. For instance, a museum kiosk system must offer learnability since most of its users would only use it once in their lifetime. Ferreira et al. 2020 argue that a cancel button is fundamentally important, and users at any time should be able to cancel and exit from

all windows. Similarly, Jordan (1999) argued that guessability could be neglected on the product or service where training is required before using a product or system because there is no real pressure to finish the task successfully from the first attempt such in the aircraft control or specialized military equipment. Consequently, such equipment is designed for experts with the assumption that users will undergo comprehensive and specialized training to handle such complexity. Shackel (2009) believed that there is an ambiguity to the definition. Therefore, Shackel proposed further four measurements to categorize usability which must be represented in numerical values in order to measure the system's goal:

- Effectiveness: the compulsory level of performance in terms of speed and errors by a percentage of users within usage environments;
- Learnability: the required level of a specified time, amount, relearning needed to accomplish a task;
- Flexibility: level of allowance of adaptation to numerous tasks beyond the pre-specific; and
- Attitude: level of continuation of user satisfaction with the system.

In Shackel's work, there is two part of usability which are the definition and the attributes. In the attribute part, Shackel was clearly trying to follow and expand Miller's work of measuring usability. Hence, Shackel sets a numerical value to his attributes.

Nielsen (1993) definition of usability comes from five quality attributes of the system. Those attributes are learnability, efficiency, memorability, error prevention, and satisfaction. To Nielsen, the usability attributes derive from system acceptability (Figure 2.3). Whereas Krug (2014) called his definition of usability as "One Crucial thing". Krug saw usability as breakable of attributes as follow:

- Useful: is it really what people need
- Learnable: can it be figurable, and assume correctly how to use it.

- Memorable: when used after the first time, do people have to relearn how to use it.
- Effective: does it gets the job done?
- Efficient: does it do the job with a reasonable amount of the time and effort
- Desirable: are people desired to have it?
- Delightful: does it further excitement and enjoyment.

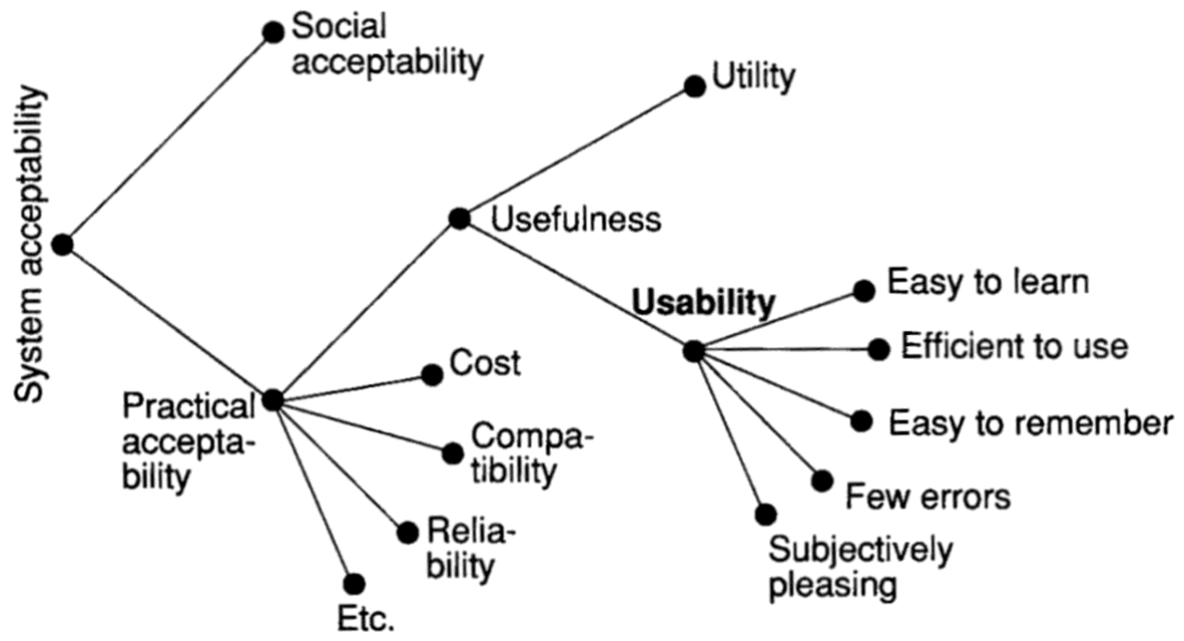


Fig 2.3: Nielsen attributes and its relation to system acceptability

In an attempt to fully enumerate the attributes, Dubey and Rana (2010) surveyed 234 articles that offered Usability definitions and attributes. In total, the 234 Usability definitions and attributes articles had been traced to their 37 original sources (See Table 2.2). As a result, they found 37 formal definitions that produced 152 attributes. The study found that most four frequent attributes are Learnability (20 Frequency), Satisfaction (17 Frequency), Flexibility (14 Frequency), and Efficiency (13 Frequency). In short, different authors saw usability differently through certain attributes. Nonetheless, those attributes show similarities and interlink.



Table 2.2: Usability Attributes (Source: Dubey, Rana, 2010)

Source	Attributes	Source	Attributes
Brinck et al. (2002)	functionally correct, efficient to use, easy to learn, easy to remember, error tolerant, subjectively pleasing	Kim (2002) Delete it	interface effectiveness
Butler (1985)	task, predefined time	Lecerof et al. (1998)	users' needs, efficiency, users' subjective feelings, learnability, system's safety
Campbell et al. (2003)	easy to learn, easy to use, easy to remember, error tolerant, subjectively pleasing	Lewis (1995)	system usefulness, information quality, interface quality
Constantine (1999)	learnability, efficiency in use, rememberability, reliability in use, user satisfaction	Löwgren (1993)	result of relevance, efficiency, learnability, attitude
Dix et al. (1998)	learnability, flexibility, robustness	Makoid et al. (1985)	user satisfaction, type of errors
Donyaee et al. (2001)	effectiveness, efficiency, satisfaction, productivity, safety, internationality, accessibility	McCall's (1977)	operability, training, communicativeness
Dumas et al. (1993)	users, productivity, tasks, ease of use	Nielsen (1993)	learnability, efficiency, memorability, few errors, satisfaction
Gluck (1997)	usableness, usefulness	Oulanov (2002)	affect, efficiency, control, helpfulness, adaptability
Gould (1988)	system performance, system functions, user interface	Porteous et al. (1993)	efficiency, affect, helpfulness, control, learnability
Grady, 1992	human factors, aesthetics, consistency in the user interface, online and context sensitive help, wizards and agents, user documentation, training materials	Preece (1994)	learnability, throughput, attitude, flexibility
Hix et al. (1993)	initial performance, long-term performance, learnability, retainability, advanced feature usage, first impression, long term user satisfaction	Reed (1986)	ease of learn, ease of use
IEEE Std. 1061 (1992)	comprehensibility, ease of learning, communicativeness factors	Sauro et al. (2009)	task times, completion rates, errors, post task satisfaction, post-test satisfaction
ISO 9126-1 (2001)	understandability, learnability, operability, attractiveness, usability-compliance	Shackel (1981, 1986, 1991)	ease of use, effectiveness, learnability, flexibility, user attitude
ISO 9241-11 (1998)	efficiency, effectiveness, and satisfaction	Shneiderman et al. (2005)	time to learn, speed of performance, rate of errors by users, retention over time, subjective satisfaction
Kengeri et al. (1999)	effectiveness, likeability, learnability, usefulness		

### Effectiveness:

Effectiveness is an attribute that specified by ISO which implied the accuracy of successfully completing specified goals. Simply, in dealing with products, the outcome of our use is achieving the intended purpose which has two forms of outcome successful or failure. Thus, Effectiveness deals only with successful aspects. According to Jordan (1998), Effectiveness can be extended to the overall goal achieved. As Jordan explains, if an operator wants to produce 100 components per day, and by the end of the day, the operator only produces 80 components, the overall Effectiveness would be 80%. Fidgeon (2017) postulated that pass/fail measurement could be used to illustrate the successfully completed of the task. As a result, a percentage of successfully executed task becomes an effectiveness measure of overall system. Jordan (1999) argued that effectiveness normally achieved when the final goal or task is determined successfully, but not all effectiveness are created equal. Thus, a special component called quality of output has to be established to measure the output quality.

### Quality of the output:

Jordan (1999) postulated that in some tasks, achieving the final goal is not enough. Consider someone has a dirty clothe with ink stain, when a user places the clothing into the washing machine and set it for an hour. The washing machine will ultimately finish the task successfully. However, the quality of the output for the washing machine will be determined by the degree of removal of the ink stain.

### Efficiency:

ISO refers to Efficiency as the required resource expended to achieve a specified goal with accuracy. Quesenbery (2004) stated that efficiency can be described as the finished tasks achieved with accuracy speed. Jordan (1998), referred to Efficiency as the amount of effort required to

achieve a goal. Thus, Jordan implied that the less effort required is required, the higher efficiency is achieved. Nielsen (1994) proposed that efficiency is the concept that the system efficiency performed to permit a high level of productivities. To quantify efficiency Ferre, et al. (2001) proposed that the number of tasks required by a unit of time and performed by the user using the system. The more user performs with maximum speed, the efficiency the system is. The other measurement proposed by Fidgeon (2017) as calculating the time of users who performed the test and the average task completion become the efficiency measurement

### Satisfaction:

Satisfaction attribute referred to by ISO as the user positive attitude toward the product with comfort. In other words, it is implying the acceptance and approval of the users toward the product. To Jordan (1998), the satisfaction attribute is more subjective than effectiveness or efficiency. Ferre, et al. (2001) implied that satisfaction subjectivity of the user toward the system. Thus, what implies here is satisfaction is subjective to each users' preference and liking attitudes which makes satisfaction extremely hard to objectivity to suit a larger audience. Fidgeon (2017) proposed that satisfaction can be measured in the form of a questionnaire during or after performing the tasks. One way of the questionnaire could be the ranking of user experience through a Likert scale.

### Qualitative:

One of the easiest ways to find out that the users are satisfied with the product is to ask them either by questionnaire or interview. When data is collected, further analysis can be carried out to determine the overall satisfaction score. The main difference between questionnaires and interviews is that in the questionnaire the users can be asked to rate their satisfaction level whereas in the interview the users can be asked which part of the product they do not like in particular.

## Learnability:

Learnability is also called easy to learn. Its primary focus is how easy and quickly are users going to learn the tasks to perform in the first time. Ferre et al. (2001) stated that learnability is the easiness to a user to learn the functionality of the system with completeness and proficiency. Therefore, for novice users, this attribute is extremely vital. They continued to add that in some systems, learnability is critical to system success especially where users encounter the system is very limited such as in museums and so on. Jordan (1998) explained that learnability is the freedom of difficulty to perform a task for the first time. In Jordan terminology, Learnability is very similar to guessability, yet guessability is more for a one-time use concept, such as in an emergency situation where to put down a fire, a user guessability of how the fire extinguisher work should be correctly illustrated and assumed.

## Designing Usability

### What Constitute Less Usable

Assessing what makes product and service less usable can be delivered from many factors such as culture, environment, or deficiency of design or understanding the user's needs. Rubin and Chisnell (2008) proposed five reasons which constitute less usable, and they are:

Machine or system overtakes the primary focus of the development stage: when designing a product development team tend to concentrate on the development of the product solely, and not taking into account Bailey's Human performance model. Bailey (1993) model consists of three dimensions which are the human, the context, and the activity. What has been evidence from practice is that design emphasis on the activity and neglect the human and the context.

The product users are more than ever expanding, and a new segment of the population had adopted: in the past, sophisticated technology users were mainly experts and highly technical where they adopted such technology because of the nature of their work. However, nowadays, sophisticated technology constitutes most of the products, and more than ever new and large segments of the population are adopting and embracing. As a result, demand for designers create professions where designers are coming from the educational tube whereas in the past designers were hobbyist.

Perfect usable design is hard and difficult: designing the usable system is a long, fuzzy, and unpredictable endeavor, yet “many organizations treat it as if it were just ‘common sense.’” (Rubin and Chisnell, 2008). Although many concepts are written about the topic, the usability required intense knowledge and backgrounds in behavioral and social science.

Working in integrated ways is the essence: while developing a product, many organizations do not create the integration substance for the team. Mainly, tasks and activities were to be distributed among employees, and they set it up when each team finishes their part to compromise it as one integrated product (cohesive whole).

Matching the design and implementation: designing the user interface and technical implementation are totally different whole sets. Possessing immense qualifications for technical implementation would not be equally qualify-able to handle the user interface. The challenge of design has increased dramatically due to the market needs to reach broader consumers which have less technical sophistication.

## Raising complexity and the digitalization of surrounding.

Designing and making of useful objects have been the nature of human spirit since the dawn of history. Hence, throughout history, human has been a tool user. Tools have multiplied human capabilities. With the advancement of tools, human progress in civilization meanwhile human relationships with tools get complicated. Historically, what has been used in the past as a tool has been coined to be a product. In today's world, handling tools and machines requires so much effort and learning and normally specialization. However, products that we use in everyday life are seemingly easy to use and eventually figurative to be handled by an average person. On the other hand, there are products that have been challenging to be handled by the average person. More and more people have been confronted with complex products due to the lack of usability. Industry's failure to incorporate the user-centered approach and the lack of considering users' feedbacks led to the development of ISO 13407 (Bevan, Nigel, 1999).

Nielsen (2004) listed two reasons for bad design; absence of incentive and absence of usability culture. When customers buy products, they expect them to function well, to meet their needs, and be easy to use. However, many regularly used products are difficult and perplexing to operate (Babbar, Behara, and White, 2002).

Designing of a complex system is hectic and nearly unmanageable (Jaber et al. 2015). Norman (2013) stated that product raising complexity comes from the fact that product must fulfill human's psychological and behavioral needs, so by human perception standards, the product should execute the user's commands regardless to the illogicality of the command, and in an industrial and commercial environment, when the products operate incorrectly, it could lead to accidents, injuries, and even death. Thus, to Norman, the designing process should not only come from the technical requirement, but also it should come from user requirement namely cognitive and psychological requirements. Norman added that the solution for rising complexity is Human-

Centered Design HCD which put the human needs, capabilities, and behavior at the center of the design, and to be accommodated from the beginning.

### Financial cost of building the Usability Lab

Questions might be raised on ‘how much does usability lab cost?’. There are two parts of what would form a laboratory, and that is expertise or technical-know-how and testing equipment. The first part comes in the form of hiring a professional to apply their knowledge to produce effective information that would affect the design and handling of the product. The second part will be more costly since usability evaluating equipment are costly especially for a start-up company that might not bear the cost. David Travis on his website –[userfocus.co.uk](http://userfocus.co.uk)- stated that ordering the whole sets of ISO 9241 would cost a staggering amount of \$1329. Barnum (2010) reported that when setting a usability lab, normally three rooms are required. One room will be for the participant, and the other will be for the observers which called the control room, and the last room is called the executive viewing room.

The price for setting up the lab has been decreasing dramatically overtime. For instance, Barnum (2010) stated that in 1994 Southern Polytechnic erected its first usability lab with costing of \$100,000. However, at equivalent status post-2000s, it would cost a range of \$25,000. In 2009, Barnum (2010) stated that a usability lab was established with a cost of \$6.600 (see Fig 2.3 for detail).

*Table 2.3: Usability equipment breakdown*

Equipment	Vendor	Cost (US\$)	Quantity	Total (US\$)
Desktop computers	Sun Microsystems	934.72	2	1,869.44
RAM upgrade	Dell	64.90	4	259.60

Equipment	Vendor	Cost (US\$)	Quantity	Total (US\$)
20" Viewsonic VG2030WM	Dell	226.87	4	907.48
Watchport/V camera and TrackerPod	Eagletron	315.98	1	315.98
Four-camera package DM- STAR4i-PK1	DVRMaster.com	999.00	1	999.00
4' 8' privacy glass and installation	Atlanta Glass Experts	710.00	1	710.00
Miscellaneous cables	Computer supply store	200.00	1	200.00
Logging software	Morae	1,400.00	1	1,400.00
<b>Total</b>				<b>\$6,661.50</b>

Despite the financial cost, there are many benefits of setting up a local usability lab. The benefits can range to include the following:

- Show the organization’s strong commitment toward usability
- User experience would be taken into account while designing the product
- Saving the time for designers when they are in a dispute about ergonomics
- User approve in the usability lab means user acceptance in the market

## Evaluation Methods

### Usability testing:

The term usability testing has been comprehensively applied to any procedure tend to evaluate product or system (Rubin and Chisnell, 2008). Ferreira et al. (2020) stated that the main objective of usability testing is to provide conceptual level of how easy is the product going to be. Thus, Rubin and Chisnell, (2008) defined the usability testing as “a process that employs people as



testing participants who are representative of the target audience to evaluate the degree to which a product meets specific usability criteria”. Usability testing is an essential process of usability evaluation because it offers valuable information on the product or system prior to deployment. Spencer (2004) described that usability testing is a crucial method to obtain information and knowledge and whether or not the product constitutes usable.

Dumas and Redish (1999) defined sets of characteristics which shared by every technique, those are articulate test plans and goals, participants epitomize real users, the participant does real tasks, documentation of what participant do and say, and analyzing of the data to diagnose and fix the problem. Ferre et al. (2001) implied some considerations that may affect the testing result either positively or negatively. The considerations are whether or not participants permitted to reach to the evaluator for help, and prior to the test, to what extend do the participant has information about the system. With the aim of removing complexity prejudice, some methods do not require participants. Rather, they rely on expert opinion to identify, restructure, and require changes, and that form of testing called non-empirical method.

### Heuristics evaluation

Heuristics evaluation is a form of discount usability engineering method (Nielsen, 1994), and it is widely practiced and accepted as an evaluation tool. It was originally proposed by Nielsen and Molich (1990). Therefore, Nielsen and Molich argued that heuristic evaluation is a way of examining the interface and forming an opinion of determining what is good and problematic about the interface. In principle, evaluator measures set of predefined guidelines which has been developed by a usability expert. Barnum (2010) defined Heuristic evaluation as basically an inspection done by an expert. In general terms, it means that usability experts turn into ‘the rule of thumb’ or principles that had been set by other experts such as Nielsen’s 10 heuristics or Shneiderman’s the eight Golden Rules (see table 2.4). Nielsen argued that Heuristic evaluation

proposed a simpler method. Heuristic evaluation popularity derives from the fact that it is extremely easy to implement and follow, and it associates with low cost. Therefore, heuristic evaluation is ideal when resources are scarce due to the fact that non-expert can carry out the evaluation process. Prior to Heuristics evaluation, Nielsen and Molich implied that most people applied their intuition and common sense to evaluate usability which is heuristic. Originally, Nielsen and Molich enlisted 9 usability heuristics which are:

- Simple and natural dialogue
- Speak the user's language
- Minimize user memory load
- Be consistent
- Provide feedback
- Provide clearly marked exits
- Provide shortcuts
- Good error messages
- Prevent errors

However, Nielsen (1994) later on modified them to 10 usability heuristics (see table 2.5).

To show the strengths and weaknesses of various Usability Engineering Methods, Jeffries, Miller, Wharton, and Uyda (1991) conducted a study of testing different methods and they found when resources are limited, heuristics evaluation can work surprisingly well in comparison to other techniques.

*Table 2.4: Shneiderman's (1987) Eight Golden Rules*

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The Eight Golden Rules of Interface Design
Strive for consistency.
Cater to universal usability.
Offer informative feedback.
Design dialogs to yield closure.
Prevent errors.
Permit easy reversal of actions.
Support internal locus of control.
Reduce short-term memory load.

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*Table 2.5: Nielsen's (1994) 10 Usability Heuristics for User Interface Design*

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10 Usability Heuristics for User Interface Design
Visibility of system status:
Match between system and the real world.
User control and freedom.
Consistency and standards.
Error prevention.
Recognition rather than recall.
Flexibility and Efficiency of use.
Aesthetic and minimalist design.
Help users recognize, diagnose and recover from errors.
Help and documentation.

---

## Assessment

### Why are There Many Definitions

Usability has many definitions and attributes, aspects, and components to it. Why is there no one unified definition that everyone will follow and recognize as complete measures and factors of usability? Such an effort will be easier for practitioners to perfection their work, more understand

the usability. However, it seems that practitioners in desperate need of ‘usabilitizing the usability’. Nielsen advocated that usability immensely depends on acceptability where user requirement has to be met, and if it did not meet, that is mean the system is not useful.

Usability diverse definitions, attributes, and standards are the contribution of five main factors:

- Fast usability evolvement over short time,
- the multidisciplinary natural of Usability,
- usability has high sensitivity to preferences
- New technology can immensely influence the core of usability
- Raising complexity and the interconnectivity of modern devices

Is the Topic Dead?

*Assessment method:*

Subject evaluation method has been conducted to test whether the Usability is a dead topic (at least in Academia). McNamara and Kirakowski (2005) indicated that in referring to Usability ISO 9241 and Nielsen’s usability are the most widely used references. To construct the assessment method, ISO 9241 definition has been adopted, and a literature review has been conducted in a multiplatform search agent namely GoogleScholr. The research funding is presented on a yearly base starting from 2015 to 2019.

*Assessment:*

As mentioned earlier, Rubin (2002) propose that Usability passed through waves which are:

- The first phase was during World War II when was the motivation to improve airplane cockpits, and the main focus was on performance under pressure, human physiology, and information dispensation.

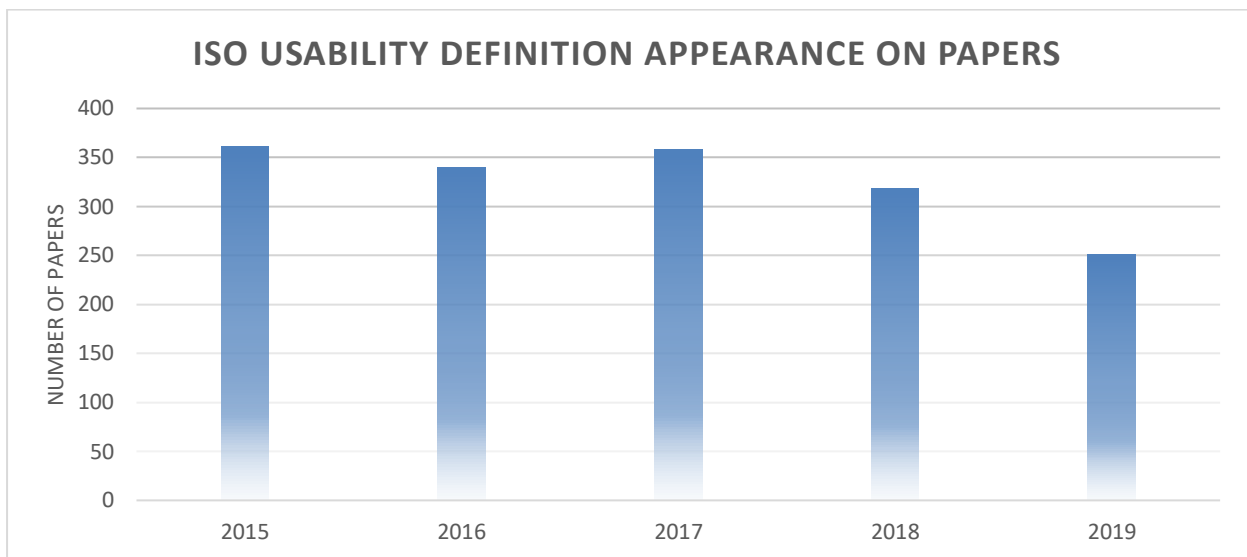
- The second wave which called usability with small “u” started with the coming of computers, and the second wave stress was on the product or service rather than the wider issues that affect user awareness.
- The third wave started with the coming of the internet, and it referred to as Usability with a capital “U”.

Considering Rubin (2002) prospective on the evolution of usability, it worth to mention that Rubin (2002) wrote his assessment of the Usability evolution pre-2002, so at that time, the launch of the interactive touch screen to the phone and tablet industry had not taken place yet. Therefore, a significant phase has started when the mobile industry embraces the touch the interactive screen because a new and higher set of rules has been defined for usability and the user-centered design. Thanks to the advancement of sensors and telecommunication technology, users are able to interact with their phones/ tablets according to the pressure they apply to the screen (3D touch). Touch screen feature to the product offers tremendous advantages such as the ability to be customizable, adjutancy of size and colors, feel like an extension of the user’s body (Wigdor and Wixon, 2011), and most importantly gain the user acceptance.

Usability is increasingly achieving significant popularity because it is being considered a vital success of the system (Bygstad et al. 2008)(Stary and Eberle, 2008)(Baglin, 2015) and product. Significant usability research topics include the following: usability evaluation methods and metrics, usability factors, user interface design principles and guidelines, usability problem classifications, and user-centered design methodologies (Te’eni, et al. 2007). Comparatively, recent research interest in human emotions has expanded the customary focus of researchers from usability to user experience (Joshi, Sarda, 2011).

### *Evaluation:*

As an evaluating gesture, ISO-9241 Usability definition appearance's frequency in literature was taken into account. The literature time variance is from 2015 to 2019 (see figure 2.1). In addition, there is a healthy contribution to the topic through databased dedicated to fields such as the Journal of Usability Study, International Journal of Human-computer interaction, Journal interaction with computers, CHI Conference Proceedings, and so on.



*Fig. 2.1. ISO Usability Definition appearance on papers per year*

### Who Cares?

#### *Requirement:*

A customary way of building the business case for usability is cost justification and return-on-investment (ROI) (Bias and Mayhew, 1994). Consequently, organizations will not apply usability unless there are tangible benefits from it. Obvious benefits are cost saving on training and material resources. It leads to reduced training, enhanced user productivity, and documentation (Juristo, et al. 2007). A field study by Allwood (1984), reported that the

absence of usability causes hardship in using a computer which costs between 5 and 10% of total working time. Thus, principally, any product with the difficulty of usage would cause around 10% reduction of total working time. Despite the requirement for usability, Krug (2014) mentions that there are a billion websites and other billion apps for the iPhone alone, and there are only about 10,000 usability consultants around the world. the Requirement for usability comes from many directions, but there are two main requirements.

### *Legal Requirement :*

Since Product usability has been a Non-functional Requirement, it has gained popularity within the manufacturing establishment. Many legislations have been introduced to meet specific usability requirements in a variance Industry. Demand to cope with the user and legal requirements made usability a business priority (Rubin, 1994) or even a part of the industry's responsibility to its customers (Jordan, 1998). Wegge and Zimmermann stated that a company has to consider usability during the product design ideally from the very early beginning because of the existent laws and regulations, an example of which are:

- the Americans with Disabilities Act,
- the US Telecomm. Act Section 255,
- the US Rehabilitation Act Section 508, the EU Mandate 376 (M376, 2006),
- the EU Anti Discrimination Directives, - the EU telecomm. Directives,
- and - "Behinderten Gleichstellungs-Gesetz" in Germany ( Wegge, Zimmermann, 2007)

the laws and regulations were introduced to prevent ergonomics and industry non-technical mistakes. In 2011, for instance, a patient went to severe diabetic coma during a visit to Medstar Health Hospital because the medical team gave the patient insulin due to a “confusingly” pop-up message in the digital blood-sugar reader (Modern Healthcare, 2014). One attribute which comes in a form of the legal requirement is safety. Considering human nature, when a product's safety

feature is hard to operate, users tend to neglect it. As for safety features, the modern car's information system is not reachable with the driver unless the driver is pulled over. On the other hand, to take an X-Ray picture, the operator usually had to move to a different room which is a violation of the usability principle. However, the X-ray machine designed in such a way in accordance with the safety attribute which in this case has given more emphasis. As a similar circumstance, in the banking industry, we can see more emphasis on security attributes at the expense of usability.

### *Market Requirement:*

Usability is very essential for industry and consumers alike. To manufacturers, it can cause serious revenue damage and customer disloyalty (Kim, Christiaans, 2016). Customers tend to return a product that does not meet their expectations (Ouden, et al. 2006). Even though, it functioned properly. Norman (2013) argues that when the product got to be designed well, the result will be brilliant and pleasurable. Whereas, when done badly, it simply becomes unusable and leads to user disapproval and frustration. Accenture Consultancy puts the figure at 68% of consumer product return has nothing to do with a technical problem but rather with usability issues, and it is costing U.S market 16.7 billion (Douthit, et al. 2011). In approximately 50% of products that were returned by consumers no technical fault could be detected (Ouden, 2006). In a recent study by Anderson, Lin, Simester, and Tucker, on 8,809 new products, they found that 40% (3,508) of products are still being sold three years later (Anderson, et al. 2015). It is very hard for the manufacturer to allocate the problem and knowledge since the returned product has a non-technical problem (Kim, Christiaans, 2016).

### *How Do I Know?*

Through observation of recent products, one cannot help but notice that products which used to be solid mechanic functionality have started to feature User Interface, and demand interaction from the user in order to do what they designed to do. The computing power has been increased,



and it became more powerful and sophisticated. As a result, more capable software is becoming part of a single device component. Undoubtedly, the internet of things has influenced recent product development in just recent years. Internet of things has connected the home appliance with the user through a website or an app. One of the challenges of designing a product is to balance the complexity of the system against the usability of the system (Robles, Kim, 2010). Many new-generation products started to feature the internet of things as functionality. Usability has to be considered during the development process.

Suppose there is statistical data collection on product usability where certain aspects of specified measures are collected and stored on a large scale. As a result, Product usability is a direct measure of a person's own cognitive process, and it can be largely exploited to unintended applications e.g. job interviews, insurance, politics, etc.

Right now, unless usability is largely popularized by newspapers, news, video blogging, etc., it would be hard to know.

# RESEARCH METHODOLOGY

## Introduction:

Usability testing involves many techniques that have been borrowed from the psychology field especially cognitive and applied psychology (Lewis, 2006 and Jordan 1991). Thus, research in the field of human-computer interaction poses challenges and complexities due to the fact that research methods had been adopted from different disciplines and modified to suit the complexity nature of HCI. As a result, in-depth knowledge and understanding of research methodologies are of vital importance to the success of the study (Lazar, Feng, and Hochheiser, 2017). Research is not only gathering facts, assembling bibliography, and referencing statements, but also drawing conclusions and expressing thought and interpretation (Supino, Borer, 2012). Research is a search for knowledge by investigating scientific and social problems objectively and systematically (Rajasekar, Philominathan, and Chinnathambi, 2006). Grinnell (1993) explained that “research is a structured inquiry that utilizes acceptable scientific methodology to solve problems and creates new knowledge that is generally applicable”. According to Neuman (2013) research is optimized to reduce the common five error decisions which are:

- Overgeneralization: which is indiscriminately over-generalization reinforced by our beliefs and assumptions. This status also includes social and environmental stereotypical assumptions.
- Selective observation: which is to seek decision and result that would lead and support our predetermined founding

- Premature closure: it is when the researcher decides to close the data collection process because he/she feels that research questions had been answered, and rush to analyze the information based of a small amount of evidence or participants.
- Halo effect: it is when the reputation of an institution or person predetermined our decision on the perceived subject. For instance, picking a study which was written by one of the top prestigious universities and thinks that the study's findings would hold true unconditionally.
- False consensus: it is when the researcher reflects his/her view on the observation thinking that other people are not different from him/her self.

According to Nayak and Singh (2015) research has to follow one of the three objectives. The first is a theoretical objective where the researcher formulates novel theories, principles, or laws. The second is a factual objective where the researcher detects novel facts. The third is the application objective where the researcher advocates for novel applications. In contrary to the two previous objectives, this objective does not contribute to knowledge, but rather introduces application in the form of improvement or modification for practical problems.

The following chapter illustrates the methodology and the theoretical framework that was utilized in the making of this research project. Thus, the chapter primary purpose is to serve the justification and rationale behind choosing the methodological framework for the study. Declaration of the similarity of project management and this research was presented to show how the researcher as experience project manager utilized project management tools and techniques to overcome difficulties and constraints posed by the reality of everyday life. Moreover, the chapter presents the research paradigm and its differences and where the paradigm is best serves its strengths. Then, it presents the Computed tomography – CT scan as product usability pick of choice, rationale, and research participant. The following section, it presents the method and

research tool instruments that have been utilized within the research framework. Then, it presents data analysis methods and procedures. The last section presents ethical consideration, and the ethical approval process during which this study underwent. In addition, the overseen of funding and management organization.

### Project management as a Tools:

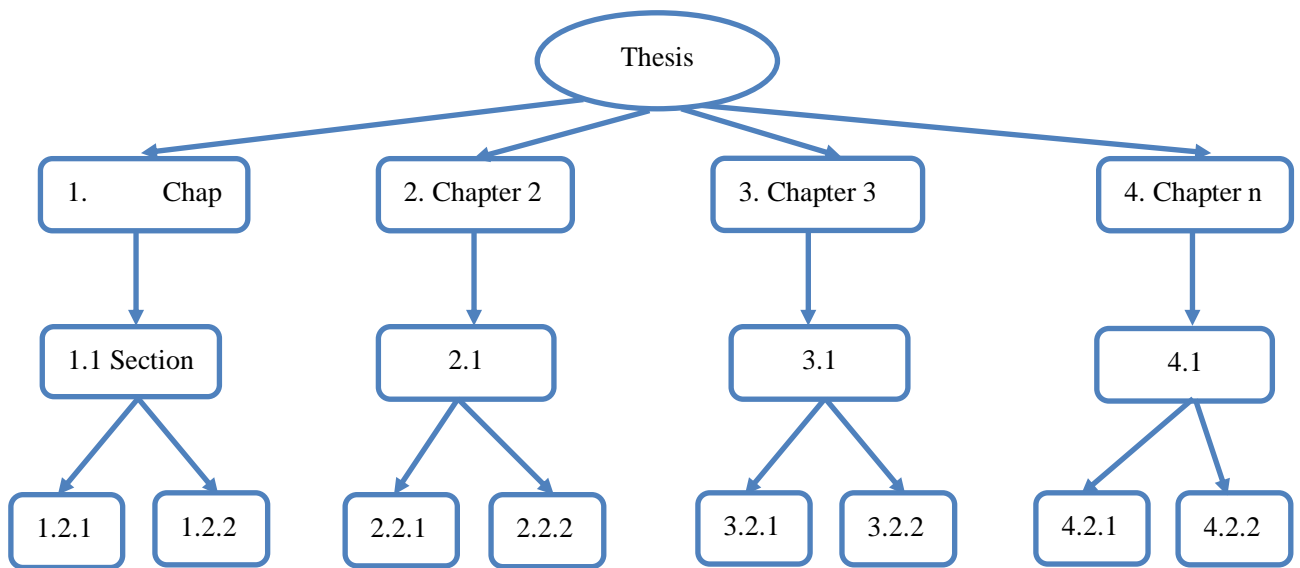
Due to the researcher's solid project management experience and expertise, the research has been treated as a project. The researcher has 6 years of project management experience ranging from projects in higher education and research organizations to an international engineering consulting firm. Consequently, as a prerequisite to lead projects, the researcher is a certified Project Management Professional- PMP (Appendix 11) from Project Management Institutes. To be recognized as a project, three conditions have to be satisfied which are:

- Limited to time
- Limited to cost
- Limited to Scope/Quality

As a result, all the predeterminations of a project are met. Particularly, this Ph.D. has a definite start, definite finish, definite cost, and definite scope and quality. Most importantly, project final achievement and success is when all stakeholders declare their satisfaction and acceptance of the final outcome which in this case it would be the final Ph.D. thesis. Therefore, the thesis' stakeholders are any person or object which can influence the project positively or negatively. According to Pickard (2013), Qualitative design does not tolerate a meticulous plan prior to the research launch which makes it very similar to incremental or agile methodology in project management. A detailed plan usually referred to as waterfall methodology which usually associated with the construction industry and civil engineering environment

In principle, projects have to be decomposed into more manageable pieces. The project management book of knowledge defines work breakdown structure as “a hierarchical decomposition of the total scope of work to be carried out by the project team to accomplish the project objectives and create the required deliverables.”(PMBOK, 5th e). Therefore, the thesis has been decomposed into chapters and sections. (see figure 3.1 for more detail). The lowest level of work breakdown structure consists of a work package which in this thesis frame is the activities that required the researcher to work-on to accomplish the sub-section activities.

Another critical principle of project management is crashing and fast-tracking. The project management book of knowledge defines crashing is “A technique used to shorten the schedule duration for the least incremental cost by adding resources” (PMBOK, 5th e, p.181). An example of crashing is implementing overtime to the resources working on the project, outsource work to external entities, or paying extra to expedite delivery and handling. Fast-tracking, on the other hand, is a technique where it used to compress schedule by working on tasks in contemporaneous instead of sequences (PMBOK, 5th e, p.181). For obvious reason, crashing and fast-tracking only work on the activities or tasks which a lined to the critical path. For the nature of this research, the human resource committed to the project is only the researcher, so fast-tracking and crashing have to be carefully evaluated to suit the nature of the research. Activities that deemed to fast-tracking and crashing are subject to thesis’ supervisor approval.



*Figure 3.1: Thesis Work Break-down Structure*

Another equally critical principle of project management is configuration management. configuration management restricts and controls changes by subjecting every change into the documentation to review and approve by predefined authorized committee. The concept of configuration management is to minimize the deviation of the original plan and ensure that the changes are documented and reflected to everyone on the project and everyone has the same version of the amended changes (Menendez, 1988, p 3; PMBOK, 5th e.). As a result, a key component of configuration management is the Change Control Board which has the authority to approve change requests that may influence the cost, time, or scope dimensions of the project. In principle, the approved change request initiated by the Change Control Board is the only permissible change that can influence and affect the plan's baselines. Therefore, the Change Control Board of this research is the supervisor, embodied as a higher authority, and the researcher, embodied as a project manager.

## Research Paradigm:

Creswell (2009) divided the research design into three elements. The first element is the philosophical worldviews in which the researcher makes claim to knowledge. The second element is the research design in which the researcher presents the strategies inquiry. The third element is the research method in which the researcher constructs specific methods that will determine the specific tools and instruments to be used during the research.

Philosophical Worldviews which also called paradigm, epistemologies, and ontologies refers to the prior knowledge that the researcher holds within the study field frame. Creswell (2013) stated that there are four categories of worldviews which are postpositivism, Constructivism, The Transformative Worldview, and Pragmatism. The postpositivism is deterministic philosophy where the quantitative or probability is the base of the outcome. Thus, this philosophy is usually associated with a Quantitative approach especially when the knowledge of the research developed by careful observation and measurement of the objective reality. The Social Constructivist Worldview is when the researcher heavily relies on the participants' views regarding the investigating phenomenon, and it is seen as a qualitative approach. The Transformative Worldview was introduced by individuals who want to bring better change to society and overcome postpositivism limitations that were imposed by laws and theories. The primary focus of the Transformative Worldview is to highlight the needs of society's group who might be excluded or disenfranchised. The Pragmatic Worldview is a philosophy that focuses on what really works to solve the research problem instead of sticking with a predefined approach. This philosophy tends to use both qualitative and quantitative as a combination to overcome the limitation which imposed by each specific approach alone. Pragmatism does not associate with a specific philosophy. Rather, it enables the researcher to tailor the methodology approach in accordance with needs and purposes.

The second element is strategies of inquiry which is the process of the researcher's determination of choosing the approach and determining the research design. Generally, the research design listed three methodological categories, and these qualitative, quantitative, and mixed method. Qualitative is the tendency of exploring the phenomenon through quantitative techniques to explain behavior or attitudes (Kothari, 2004). Qualitative techniques involve Narrative research, Phenomenological research, Grounded theory, Ethnography, and Case studies. Quantitative is a phenomenon that can be measured by the means of quantity or amount (Kothari, 2004). Quantitative techniques involve survey research and experimental research. The most attractive feature of quantitative is linearity. Consequently, new researchers are drawn by this method because it provides a solid framework (Pickard, 2013). The mixed method is capable to combine both methods in a single process. Mixed methods approach techniques involve Convergent parallel mixed methods, Explanatory sequential mixed methods, Exploratory sequential mixed methods, and Transformative mixed methods (Creswell, 2013). Table 3.1 illustrates an overview of the methods.

The third element is tools and techniques which motivate the researcher to use in finding the answers to the research questions. Those include the tools and instruments used in data collection, data analysis, and interpretation throughout the study.



Table 3.1: overview of *Qualitative, Quantitative, and Mixed method* (Creswell, 2013)

	Qualitative Methods	Quantitative Methods	Mixed Methods
Paradigms	Constructivism or transformative knowledge claims	Postpositivist knowledge claims	Pragmatic knowledge claims
Strategies Inquiry	Narrative research Phenomenology Grounded theory Ethnographies Case study	Experimental Surveys	Convergent Explanatory sequential Exploratory sequential Transformative, embedded, or multiphase
Data Collection	Emerging methods Open-ended questions Interview data, observation data, document data, and audiovisual data Text and image analysis Themes, patterns interpretation	Pre-determined Instrument based questions Performance data, attitude data, observational data, and census data Statistical analysis Statistical interpretation	Both predetermined and emerging methods Both open- and closed-ended questions Multiple forms of data drawing on all possibilities Statistical and text analysis Across databases interpretation
Practices	<ul style="list-style-type: none"> <li>Discovered the experiences and perspectives of participants</li> <li>Focuses on a single concept or phenomenon</li> <li>Studies the context or setting of participants</li> <li>Validates the accuracy of findings interprets the data</li> </ul>	<ul style="list-style-type: none"> <li>Tests or verifies theories or explanations</li> <li>Identifies variables of interest</li> <li>Related variables in questions or hypothesis</li> <li>Uses standards of reliability and validity</li> <li>Employs statistical procedures</li> </ul>	<ul style="list-style-type: none"> <li>collects both quantitative and qualitative data</li> <li>Develops a rational for mixing</li> <li>integrates the data at different stages of inquiry</li> <li>Employs the practices of both quantitative and qualitative</li> </ul>

One of the primary objectives of this study is to evaluate the user experience of the CT-Scan and investigate the contributing factors associated with usability issues. Principally, the theses can be divided into three spectrums. First a study entitled “CT scan user experience: A reflection on Usability and exertion” tends to examine the existence of usability issues and exertion during operating a CT. In general, this stage explores the “what”. The second study entitled “the invisible physical and mental exertion” examines any association with invisibility factors that can contribute into the general productivity and usability of operators. The third study entitled “CT scan contributing factor” examines the usability factors in closer look through conducting one to one interview with technicians across Saudi Arabia. A combination of qualitative and quantitative approach was utilized to achieve the main aim of this study. The philosophical worldview used to construct the overall frame of this study is the pragmatism worldview. As stated earlier, pragmatism is not committed to any particular system or method, but rather it subscribes to the freedom of choice that allows the researcher to use and utilize tools and methods across the qualitative and quantitative spectrum which deems to overcome the difficulties (Creswell, 2013).

### Research contributions:

Kothari (2004) argued that research by definition is the contribution of unique information through the tools and instruments of observation, experiment, and comparison to add to the advancement of current knowledge. In fact, the emergence of new technology has been the primary outcome of scientific research (Bagnulo, Eardley, Eggert, and Winter, 2011). Wobbrock and Kientz (2016) stated that knowledge is usually associated with three groups of contribution which are theoretical, methodological, and empirical.

Wobbrock and Kientz (2016) identified seven research contribution types, and they listed as:

- Empirical contributions- data and knowledge collected qualitatively or quantitatively by the means strategies of inquiry (explain in the research paradigm section).
- Artifact contributions- it normally associated with the design-driven activities that often accompany empirical contribution. Artifact activities include prototypes, interfaces, tools, sketches, and “envisionment”.
- Methodological contributions- it is normally associated with the development of new knowledge and techniques that help researchers to improve research and practice. Methodological contributions come in the form of introducing a new methodology, modification of existing methodology, improvement of measurement and analyzing of a phenomenon.
- Theoretical contributions- it is the direct measurement of phenomenon in a form of framework, conceptual model, improved concept, definition, or principle.
- Dataset Contributions- it provides a new corpus aimed to advantage and assist the research community. Dataset includes benchmark tasks, repositories, and actual data.
- Survey contribution- it is a contribution which consists of meta-data analysis and synthesizes of work. It helps to identify trends and gaps.
- Opinion Contributions- opinionated research in a form of essays or argument seeks to persuade the readers or alter the thinking of their minds.

### Methodological Justification:

When surveying the usability evaluation methods, one will not fall into a lack of shortage of such. Mainstream methods include Heuristics, thinking-Aloud, Contextual Interview, Eye Tracking, Competitive Usability Testing. To meet the objective of this research, the researcher evaluated 11 usability tools and techniques to apply it to the investigated phenomenon. Then, the researcher concluded that mix method approach is the most suitable. Heuristic methods will constitute the first phase and an in-depth interview to constitute the second phase. Methods such as thinking-

Aloud and cognitive walkthrough were eliminated as they will not do justice to evaluate a CT scan. CT scan system is a very complex and advanced system with many layers of capabilities. Therefore, choosing the right method is a critical factor for the success of evaluation. These methods are primarily suitable for different applications such as website evaluation, designing a new app, or early product design.

### Product description:

Hofer (2007) explained that CT scan is considered a superior type of x-ray that emitted concentrated x-ray beam around the patient that being investigated at the various position. Even though computed tomography was known as a theory, CT Scan became feasible as a practical solution when English engineer G.N Hounsfield, EMI's employer, conducted the first successful clinical CT examination (Kalender, 2011). As a result, EMI monopolized the manufacturing of the CT scan for 2 years. The earliest CT models were known as conventional x-ray tomography which consists mainly of the x-ray tube, an x-ray film, and hardware to connect between the movable tube and the film (Hsieh, 2003). The modern CT component consists of an x-ray source, a rotary table, an x-ray detector, and a data processing element capable of computation, analyzing, visualization (Cantatore, Muller, 2011). Seeram (2015) considered the CT work process consists mainly of three phases which are data acquisition, image reconstruction, and image display. The Data acquisition, the first phase, comprised of the hardware process cycle where the emitted x-ray passes through the patient and gets reflected through the detector. In other words, data acquisition is the recorded electrical signals acquired from detectors that pass to the computer for further processing. The image reconstruction, a second phase, comprised of the computerized image reconstruction algorithm which includes fan-beam filtered back projection algorithms, cone-beam image reconstruction algorithms. Finally, the data display is where the image is developed and stored for future analysis and retrieves.

## Rationale:

Over the course of technological advancement, healthcare products have been at the forefront to deploy the newest and most sophisticated to overcome challenges. No device in the healthcare sector would hold the most advanced and technological sophisticated more than the CT scan. Such an expensive tool designed to diagnose patients in a variety of exams, which according to Pietrangelo (2017), it used to identify a variety of issues such as abnormalities of the bones of your skull, arteriovenous malformation, abnormal blood vessels, tumors, stroke, body injuries including the head, birth defects, atrophy of brain tissue, and brain bleeding. Such variety of use made CT scan a vital valuable tool for hospitals and healthcare centers to have.

The primary users of such device are hospital's physicians and technicians where they have to deal with the device in accordance with safety and operational guideline. Most importantly, not only physicians and technicians have to deal with the sophisticated device in controlled environmental content, but also patients have to be looped in the process. Therefore, such circumstances have motivated the researcher to consider CT-scan as product tool for usability evaluation. In addition, due to CT scan impotence, hospitals dedicated department, called Radiology, to be in charge of managing and operating such complicated technology. Another important aspect of improving CT scan's usability would tremendously benefit patient from extended exposing of radiation.

In addition, the researcher has identified that there is a research gap where there is no prior study that measures CT scan user experience heuristically in Saudi Arabia. With such importance, the researcher felt the need to considered CT scan usability evaluation and identify the usability issues facing radiology stuff.

## Participant:

When the researcher includes every one of the population, it is called census which is prohibitively costly and subject to vast timescale and a group of interviewers. Therefore, researchers bypass this dilemma by sampling a small and manageable group of people as representative of the cohesive whole (Dawson, 2002). However, there are cases where the entire population represents a small or a handful of people such as all administrators who work for one college district (Plano, Creswell, 2015). Carefully selected sampling and determining the size of sampling is a crucial element for the success of the study (Cooper, Schindler, 2014). For example, Cairns and Cox (2008) implied that if the study is designed to measure air traffic control system is vitally important to recruit people who's familiar with the matter rather than recruiting student from the same department. Similarly, carefully setting prequalification procedure to eliminate unwanted participation is a critical success factor for the overall study.

The research target population is radiology staff whose primary work is handling and operating CT scans within the Saudi healthcare system. In order to be a qualified participant, there are three criteria have to be fulfilled which are:

1. The participant primary work is handling and operating CT scan
2. The participant has to hold a radiologist job title
3. The participant is currently working within the Saudi healthcare system.

In the Saudi healthcare system, radiologist consists of two classifications (see table 3.2). The first is called technologist, and the second is called physicians. The number of participants for each phase was varied because each phase had its own aims, objectives, and methodology. The first study was targeting CT scan radiologists to measure and evaluate user experience heuristically. Hence, the study was considered to include all radiologists who work on CT scans which at the

time of conducting the study were 400, and the total CT scans were 190 devices (According to the Radiology Department in the Ministry of Health Nov-2017). During the second phase, an online Surveying questionnaire was deployed to all sampling populations through a ministry email encouraging CT scan radiologists to participate. The first participation encouragement email was sent through an official ministry email from the Radiology department collaborator. A second reminder was sent two weeks after the first reminder, and finally, a third encouragement email was sent a week after. In total, the response was 44 participants. During the third phase, the one-to-one interview technique was deployed to 12 CT scan radiologist participants who hold different demographic characteristics.

*Table 3.2: detailed description of Category Job Title*

Category	Job Title
Technicians	Technician
	Technician Specialist
	Senior Technician Specialist
	Consultant Technician
Physicians	Registrar
	Senior Registrar
	Consultant

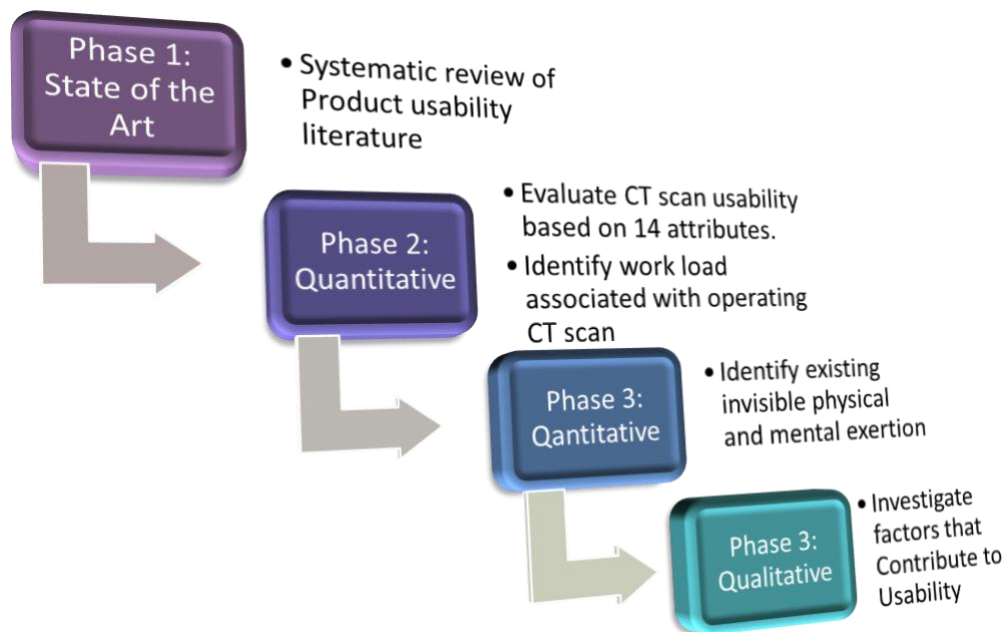
### Research Design:

Research design is a crucial frame of research project success. Consequently, many of the failed research projects are contributed to the fact that they lacked the rigorous research design which makes it feasible from distance (Dawson, 2002, p3; Bordens, Abbott, 2010, p102). Research design by definition is “an action plan for getting from here to there, where here may be defined

as the initial set of questions to be answered, and there as some set of conclusions (answers) about these questions” (Yin, 1984, p.19). in essence, the research design should be thought of as blueprint of how the research is directed in term of data collection and research map (Yin, 1983, p.20; Kothari, 2004, p.31).

Dividing the research into small manageable pieces is critical steps of research design and project management best practices. Hence, the research structured into four phases (Figure 3.2). Phase 1 comprised of product usability state of the art which survey existing preliminary studies and identification of major themes and thoughts on the topic. Phase 2 explores the CT scans’ user experience. This phase deployed a quantitative survey to measure major flows of design based on heuristic evaluations. Phase 3 explores and measures invisible physical and mental exertion associated with CT scan context of use. this phase deployed the use of a quantitative survey to collect primary data. Phase 4 investigates the contributing factor. This phase deployed a self-administered qualitative questionnaire to collect specific detailed of usability issues associated with the context of use.



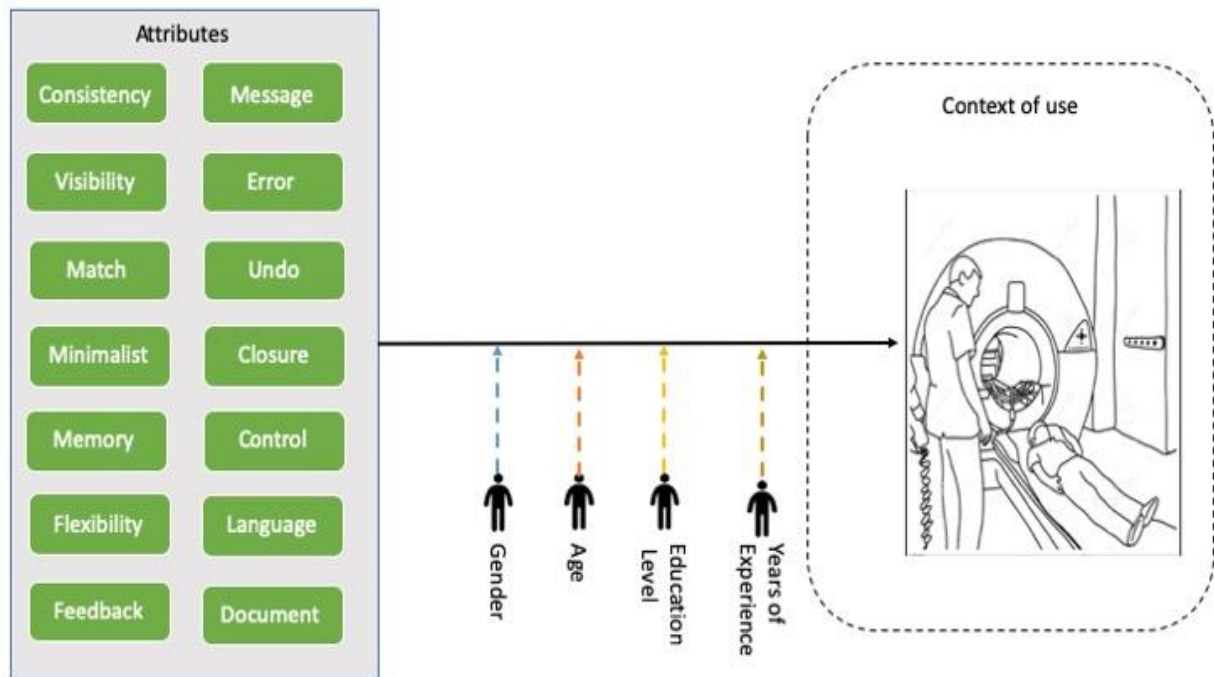


*Figure 3.2: Research Design Diagram*

### Measurement:

A variable is “an indicator of a characteristic or attribute of individuals or organizations that researchers measure and that varies among the individuals or organizations studied.” (Plano and Creswell, 2015). Field (2012) stated that when we need to test hypotheses, we need to identify and measure variables. Therefore, Variables are the things that the researchers want to measure or evaluate. In literature, measuring variables is referred to as Level of Measurements which consist of two main classifications categorical and continuous. Variables that generate a change to the phenomenon is called an independent variable. Variables that respond to the changes in the independent variable is called a dependent variable (Kumar, 2014). 14 heuristic variables are measured in this research: Consistency, Visibility, Match, Minimalist, Memory, Feedback,

Flexibility, Message, Error, Closure, Undo, Language, Control, and Document, reported in chapter 4 (see Figure 3.3).



*Figure 3.3: Usability attributes Measurement*

Similarly, along with the heuristic evaluation, four non-heuristic variables were measured, and they are physical, mental, frustration, and discomfort, reported in chapter 4 (See Figure 3.4).

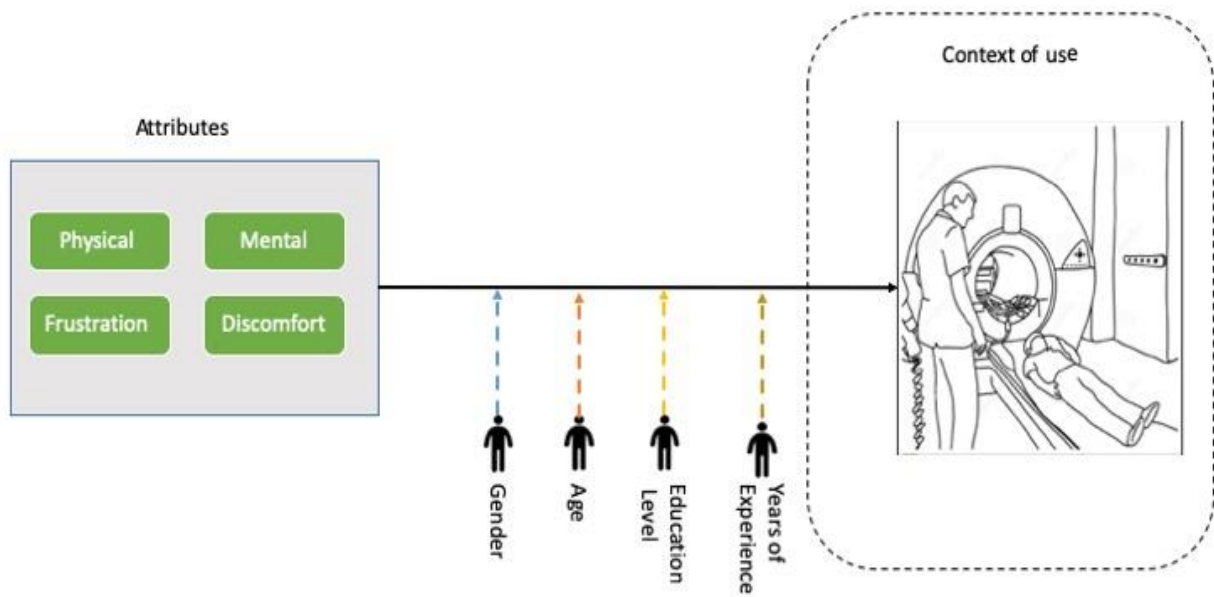


Figure 3.4: Physical and Mental Load Evaluation

### Data Collection Instruments:

As stated earlier, the data collected through two phases where one was utilized through the quantitative approach and the other was utilized through the qualitative approach. Mainly, three major instruments were utilized to gather data for the research reported in this thesis. Namely, data was collected through questionnaires, interviews, and observations.

### Questionnaires:

Questionnaires are usually referred to as a set of questions normalized by items intended to capture responses in a standardized approach. Consequently, Questionnaires are an effective tool to collect and record information concerning a specific subject of interest (Nayak, Singh, 2015). Questionnaires are an essential part of most HCI experiments where they serve the purposes of capture knowledge on demographics (gender, education, etc.) and experience with related

technology. Another purpose is to solicit opinions in regard to the tested devices or interacted tasks (Mackenzie, 2012, p173).

During the course of research design, many usability evaluation questionnaires were studied and examined extensively. A list of the most common usability evaluations was analyzed to provide which evaluation questionnaire would be ideal and practical to measure CT scan Usability. Lazar, et al. (2017) stated that in the field of HCI there are already many existing surveys that have rigorously been tested and validated. Therefore, for most research purposes, there is no need to create a new survey or tool from scratch (see table 3.3). Zhang, Johnson, Patel, Paige, and Kubose (2003) proposed a modified heuristic evaluation questionnaire for medical devices. Zhang et al. questionnaires were adopted to measure CT scan usability to radiologist users in Saudi Arabia (Appendix 8). Along with the heuristic evaluation, NASA-TLX questionnaires (Task Load Index) were adopted to measure physical and mental load to CT scan users (Appendix 8). The post-study questionnaires structured on a five-point Likert scale. For the heuristic evaluation, the measurement scale goes from 0, not a usability problem at all, to 4, usability catastrophe. For the NASA-TLX, the measurement scale goes from 1, Low, to 5, high.

*Table 3.3: Survey Tools in Usability*

Tool	Citation
Questionnaire for User Interface Satisfaction (QUIS)	Chin et al. 1988
Perceived Usefulness and Ease of Use (PUEU) Nielsen's Attributes of Usability (NAU)	Davis, 1989
Nielsen's Heuristic Evaluation (NHE)	Nielsen, 1993
Computer System Usability Questionnaire (CSUQ)	Nielsen, 1993
Purdue Usability Testing Questionnaire (PUTQ)	Lewis, 1995
Software Usability Measurement Inventory (SUMI)	Lin et al. 1997
Heuristic Evaluation Questionnaire for Medical Devices	<a href="http://sumi.uxp.ie/en/index.php">http://sumi.uxp.ie/en/index.php</a>
	Zhang et al. 2003

## Interview:

The interview can be considered as “conversation with a purpose” (Kahn and Cannell, 1957). Ultimately, the use of interview is the most common approach to collect data in the qualitative methodology (Plano, Clark, 2015). For some research purposes, direct participants’ answers are highly optimal through face-to-face or telephone than on questionnaires (Leary, 2016, p93). According to Shneiderman and Plaisant (2005) interviews with users are an effective and highly productive method of data collection because the interviewer can pursue more details as needed and specifically go after the issues of concern.

During the construction of this Ph.D. thesis, the interview was used as a methodological technique to collect comprehensive data from Radiologists to investigate the usability issues contributing factors. One-to-one semi-structured interviews were conducted with nine representative radiologist samples who have different radiologists age, years of experience, and education level. Shneiderman and Plaisant (2005) stated that “interviewing can be costly and time-consuming, so usually an only small fraction of the users are involved”. Conducting interviews permits the researcher to gain an in-depth opinion from the participants concerning attitudes, behavior, and experience which is critical to tasks natural (Dawson, 2012, p 14). Moreover, Lauesen (2007) stated interviewing is a vital way of obtaining knowledge about present tasks and data. As stated earlier, the interview style used and reported in this thesis was a semi-structured interview which according to Dawson 2012 is the most common type of interview. In this type of interview, the same questions are asked to each participant independently because the researcher’s interest is to compare and contrast the information gained from the participants. As a result, an open questionnaire was developed and constructed carefully to measure and identify usability flaws in CT scan users (Appendix 9).

## Observations and Fields notes

Field observations and notes taking were conducted at King Saud Medical City (KSMC). During the site visit, two types of CT scan operational environment was observed. The first, CT scan operating in the Emergency Room. The other was a CT scan operating within the Radiology department. Observation is one of the primary methods of collecting data. Kumar (2014) stated that observation is “a purposeful, systematic and selective way of watching and listening to an interaction or phenomenon as it takes place”. There are two types of observation. Covert observation is when the participants do not know that they are being observed. Normally, the researcher observed participants through a one-way mirror or through mounted cameras. Overt observation is when participants aware of the observer present and aware of being observed (Dawson, 2002). During the observation, Overt observation was used due to the nature of the research.

In HCI, Shneiderman and Plaisant (2005) stated that the purposes of observations are to gain critical data to influence interface redesign. Kumar (2014) implied that observations are the best data collection method when the researcher is more interested in behavior than in perception. In particular, observations are more likely to elaborate note-taking, photographs, videos, or audio recordings rather than measurement (Mackenzie, 2012, p130). Norman (2013) recommended observation should be done while the costumers in their natural environment and in their normal lives. According to Sharp, Preece, and Rogers (2016), observation is essential during all stages of product development, and in early stage, observation assists designers to apprehend users’ context, tasks, and goals.

## Ethical Consideration:

Ethics delivered from the Greek word ethos, which means characters that can be guided by a system of belief, ideas, or dogma. Cooper and Schindler (2014) explained ethics as “norms or

standards of behavior that guide moral choices about our behavior and our relationships with others”. Ethics is a fundamental component of every research. In fact, Ethics is a vital consideration of whether the research would proceed or not. Without ethics, the research is baseless and worthless regardless of its discovery and value (Walliman, 2011, p 42). The primary objective of ethics in research is to prevent harm or suffers of individuals resulted from research activities. Even though there is no general approach to ethics that adhere to sets of laws (Cooper, Schindler, 2014, p 28), Plano and Creswell (2015) stated four ethical requirements which have been followed consensually by the research community. Those four ethical requirements are:

- The researchers obtained approval to conduct their study from their local campus
- The researchers obtained permission to collect data within an organization
- The researchers obtained consent from individuals who participated in their study
- The researchers used procedures that did not harm the participants in their study

Therefore, in accordance with the ethical best practice, the researcher ensured that the previous list constitutes the baseline for a research project. In addition, the researcher ensured that each participant understands that his/her participation is fully voluntary, and each participant has no obligatory commitment to finish the research. Participants could withdraw from the study at any time if they wish. Also, a clear explanation of the study was presented to participants and allowing the participants to ask questions and pose their concerns. Consent form (see Appendix 7) was handed and read to each participant and collected back from them signed and fully understood. The consent form assures the participant about the privacy and confidentiality of the collected data, and where the researcher intends to store the data. Personal data were taken with security in mind and were reported anonymously. The following section will list the ethical and legal approvals needed for the research project

### Ethical Approval:

The Ethical Approval required to make this research was obtained from the Ministry of Health – Research and Study Department (Appendix 1,2, 3) and from King Fahad Medical City Research Ethics Committee (Appendix 4). As a prerequisite, King Fahad Medical City Research Ethics Committee (Appendix 5) requested current and valid certification from U.S National Institutes of Health NIH on protecting human research subjects which can be obtained through online training and passing of a testing exam. Also, an exam from the Saudi National Committee of Bio Ethic-NCBE is the acceptable equivalence to U.S NIH. The researcher enrolled in online training and passed the required exam (Appendix 6).

### Funding:

This Research was overseen by the University of Paris Saclay and then by Institut Polytechnique de Paris under the organization and management of ENSTA-ParisTech. The Research was fully funded by King Abdulaziz City for Science and Technology – KACST through the Ministry of Education’s Scholarship Program.



# Usability Evaluation and Assessment of Computed Tomography Scan

## Introduction

Within the context in which radiologists operate CT scans, much effort and interaction ought to be established between the radiologist and the CT scan device itself - and to some extent, the patient. In the CT scan case, the impeded speech command which directs the patient to take, hold, and release breathe, is available in many languages. This interaction between the operator and machine, has many fields of science, which tends to make it a primary focus of their existence. Most notable of these, are, human-computer interaction, interaction design, and usability. When much of the accuracy of the job is placed on how fluently the operator can deal with the machine, it creates pressure on designers to make the machine extend its capabilities by usability means. According to the FDA database, in the years of 2017 and 2016, there were 437 incidents reported as “User used incorrect product for intended use”, and 11 cases of which resulted in death. Therefore, the pressure on the designers is tremendous as Johnson (2014) depicted that designing for Usability is not as straightforward as following cooking recipes, but rather - it is all about rules that build crucial emphasis on reaching goals rather than following sets of actions. In most of the tasks, the interactions between the operator and the device is goal-oriented. Once users achieve the desired tasks successfully and efficiently, they can declare that his/her goal has been met (MacKenzie, 2012). Similarly, in a CT scan, when the radiologist effectively achieves and completes testing the patient successfully, the radiologist goal is ultimately achieved.

Another important associate concept with usability is the notion of safety. It is deemed as critically vital regarding the operations of a CT scan. An article by Consumer Reports magazine (2015) showed that CT emits radiation on patients as much as 200 chest X-rays. Such amounts of

radiation would take over seven years on the average person to get exposed in a natural setting. Also, the same article showed that most frequently, children received adult-sized doses of radiation. In a Testimony of Rebecca Smith-Bindman (2012), before The Subcommittee on Health Committee on Energy and Commerce United States House of Representatives stated that most common type of CT scan emits radiation that is equivalent to getting 1,500 dental x-rays, and in some CT scan models, the radiation is equivalent to getting 5,000 dental x-rays. In most cases, when getting a CT scan, patients come with concern of the CT scan on their health. Their knowledge either comes from reasonable facts or exaggerated speculations. The safety notion is elevated to constitute the medical device's usability baseline attribute.

The usefulness of medical devices is marked by the extent to which they can execute tasks effectively, effortlessly, and easily. Advances in science and technology have made executing tasks increasingly complex. It requires years of learning and practice to efficiently operate modern medical devices, such as computed tomography (CT) scans or magnetic resonance imaging (MRI) (Aldoihi, Hammami, 2018). A key contribution to such complexity is the fact that contemporary systems consist of multiple layers with extreme compatibility and intractability. When constituting a multi-layer system based on safety and security only, it becomes negative goals. Rather, it should constitute more layers to achieve overall functionality (Samaras & Samaras, 2016). Moreover, (Parlangeli, 2018) showed that the overall expectation of CT scan technological evolutions is to make the CT scan a more usable with a better user-friendly interface; however, the study showed that more technological evolution introduces increased complexity.

The general assumption for medical devices is that they ought to be usable and suited for their purpose (Zhang, 2003). To efficiently operate a CT scan requires adaptability with other systems, such as radiology information systems (RIS) or picture archiving and communication systems

(PACSs). These systems integrate with a superior ecosystem called the hospital information system (HIS). The purpose of the HIS is to collect all patient records and make them retrievable by many of the hospital's applications (Côrtes & Côrtes, 2011). Therefore, a CT scan operation is one component of an ecosystem. This isolated component has a tremendous effect on the overall ecosystem, and most importantly, it has a great effect on the indirect user (patient).

As it is difficult to determine or evaluate current usability practices within the medical device industry, medical device usability issues need to be publicized, analyzed, and explained (Campoe, 2013). Other industries such as air traffic control and nuclear energy have benefited immensely from human factors and usability practices to eliminate errors and improve safety (Alper & Karsh, 2009) (Scanlon & Karsh, 2010) (Lewis et al. 2011). Ultimately, whatever the industry, human factors and usability analyses are safety-driven (Miller, 2013). To the best of our knowledge, no existing study has applied heuristic evaluation specifically to CT scans. Any related studies have not measured CT scans as a direct product but rather as part of a picture archiving and communication system (PACS) or medical imaging software. To the best of our knowledge, this is the first paper to specifically apply heuristic evaluation to CT scans in Saudi Arabian Hospitals.

## CONSOLIDATED USABILITY ATTRIBUTES

Baseline attributes:

Nielsen and Molich (1990) proposed a new method for evaluating usability which they called "heuristics". Ever since, heuristic evaluation as an evaluation tool has taken popularity. This is due to the high effectiveness and low cost. Due to heuristics evaluation success in the user interface, it has been adopted in other domains (Hermawati & Lawson, 2016) such as software and product development. Nielsen (1995) introduced ten heuristics that serve as an evaluation guide to practitioners. The ten heuristics are: 1) visibility of system status, 2) match between

system and the real world, 3) user control and freedom, 4) consistency and standards, 5) error prevention, 6) recognition rather than recall, 7) flexibility and efficiency of use, 8) aesthetic and minimalist design, 9) help users recognize, diagnose, and recover from error, and 10) help and documentation. Many authors from the usability field tried to give a holistic approach and definitions regarding usability. Therefore, it is observed that usability cannot be consolidated as a single attribute. Rather, over the course of time, many authors attempted to consolidate usability as list of attributes. Makoid (1985) noted that there is not a unification approach to the definition of usability, but rather, different definitions and attributes may include different parameters. Even though there are many different attributes, consensus on the importance of usability is the unification factor of all the differences. Consequently, international organizations such as ISO, have introduced usability attributes as standardization. Shneiderman and Plaisant (2004) implied that standardization accelerates industry adoption.

#### Improved Attributes:

Shneiderman and Plaisant (2004) postulated that it is extremely difficult for designers to accomplish the final design without being forced into trade-offs between attributes. In other words, increasing the effectiveness of one attribute, comes at the expense of others. In order to achieve a better yield for discovering the usability problem, traditional heuristic evaluation has been modified, extended, and improved, to suit a specific domain or task (Ling and Salvendy ,2005). To Ling and Salvendy (2005), heuristics evaluation can be categorized into three approaches:

1. alteration of the evaluation procedure.
2. Expansion of the heuristics evaluation procedure, and
3. extending the HE method with a conformance rating scale.

In the medical equipment domain, Zhang et al. (2003) developed a heuristics evaluation which is an extended and modified version of Nielsen (1994) and Shneiderman (1998). Zhang et al. (2003)

combined Nielsen (1994) and Shneiderman (1998) to constitute an extended and more fitted heuristics to medical devices.

### Usability in medical devices

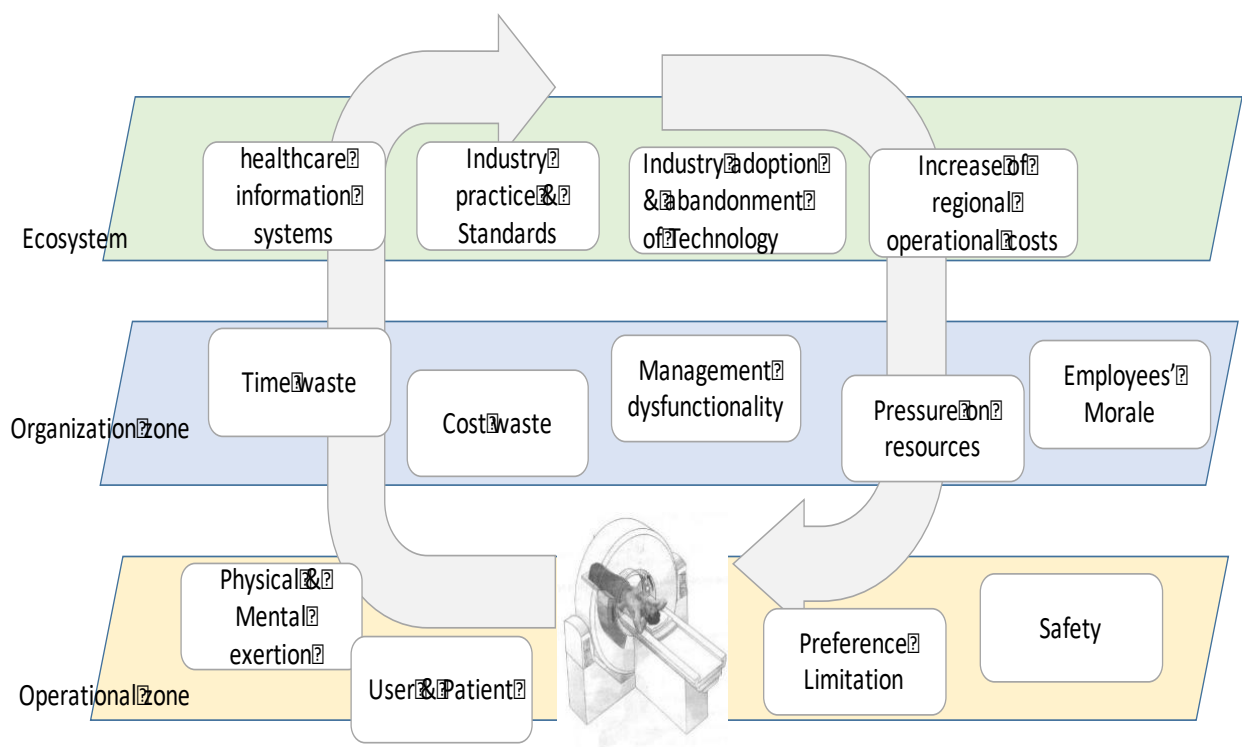
Incorporated usability to medical devices is starting to gain momentum in today's healthcare-lucrative environment. Manufacturers understand the power of usability in gaining a competitive advantage and to stay compliant with a highly rigid regulations system. In recent years, ergonomics of physical exertion has been gradually alleviated since most devices shrink in size and gain more computing power. Subsequently, Matern and Büchel (2011) put forward that medical device manufacturers shifted their attention from reducing physical exertion to reducing mental exertion. It is fair to say that medical devices do not require a physical load to operate them. However, the mental load will always be present since operators (physicians) have different levels of complexity tolerance attitudes. Traditionally, medical errors associated with these devices, are attributed to users or operators.

However, after many years of reviewing and tracking errors, an excessive emphasis has been placed on design, which contributed to usage error (Wiklund & Wilcox, 2005). When introducing medical devices to the market, manufacturers pressure designers and engineers to generate features that give the devices a marketing competitive advantage. However, such strategies contribute to the general added complexity and pose more mental, frustration, and discomfort exertion threat (but not necessarily physical exertion). Medical devices usability attributes must go hand-in-hand with physical, mental, and discomfort attributes. In other words, evaluating medical device's usability must take into account with exertion as a contributing factor, incorporated with targeted attributes

Medical devices usability is of vital importance in contrast to devices from the different field for the following reasons:

- Its direct impact on patient
- Its direct impact to diagnoser
- It can alter a decision
- Its potential serious effect (death, chronic harm)

Usability of CT is fundamental to the hospital and healthcare provider because CT is extremely interconnected to other functioning domains. Fig. 4.1 shows the interconnectivity and effect of CT usability on other systems and functioning zone.



*Fig. 3.1. Interconnectivity and effects of CT scan usability*

#### Context of Use:

In general, usability is extremely essential to buyers because it brings certain benefits and, above all, contributes to maximizing safety. Furthermore, in the healthcare environment, usability is

crucial because it contributes to safety and the prevention of errors. To (Tullis & Albert, 2013) usability revolves only around the user, where the user should be involved, engaged, and doing something within the context of the product or system. Working in the healthcare environment makes one susceptible to extreme physical and mental loads as well as industry guidelines and requirements. Furthermore, (Miller, 2013) noted that usability is an essential attribute of safety. Thus, many industries tend to share this attribute (Hegde, 2013) (Lang et al. 2013) (Vincent et al. 2014).

Eventually, the context of use can be measured by calculating influential factors that affect (positively or negatively) the functionality of the product or users. The context of use covers a wide context of an organization's geopolitical atmospheres, such as requirement components and fitness for use see Fig 4.2. The workload can also negatively pressure the context of use. In addition, Aldoïhi, Hammami, (2019, Apr.) has shown that the invisible workload can tremendously affect the working process of the CT scan operation. It was evident that radiologists seek minimal effort to divert invisible physical exertion after a certain operational time. Thus, radiologists maneuver the CT scan testing process so that they can avoid roving back and forth between the CT scan and the control room (Aldoïhi, Hammami, 2019, Nov.).

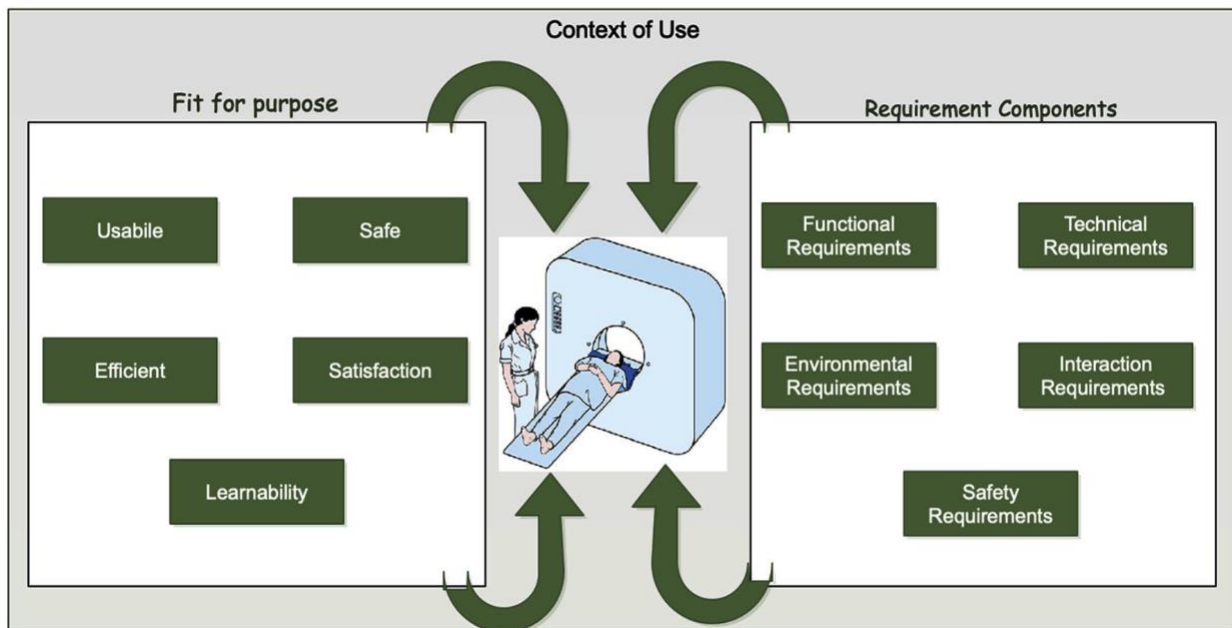


Fig. 4.2. Context of use within the CT scan operation.

## Study Objectives

Most usability evaluations that targeted healthcare in Saudi hospitals tend to discuss the obstacles of introducing new technologies. Nonetheless, literature progress that offers a sense of solution has been extremely limited. One fundamental reason is that many researchers have adopted their methods and evaluated attributes from a pure software perspective. It is fundamentally essential to examine and evaluate healthcare products based on the context of use and, in particular, involving the direct user (technician) and indirect user (patient) together. This study closely examines 14 usability attributes of the CT scan in Saudi hospitals. It also classifies the usability attributes based on severity. Understanding such severity is expected to help CT scan designers and manufacturers to improve future products to suit a specific market. In addition, the fundamental aim of this study is to explain the user's demographic differences where gender, age, education, and experience pose a threat in handling and operating the CT scan.



## METHOD

To answer the research questions, a survey questionnaire was adopted. The research questions are

1. What usability attribute is deemed important to CT scan technicians?
2. What usability attribute do technicians have the most trouble with?
3. How usability attributes correspond between users' demographic characteristics?
4. What kind of exertions exist while operating a CT scan?

### Participants

Careful sampling is a crucial element of successful research. In user research studies, recruiting participants who meet precisely determined criteria can prove very challenging (Albert & Tullis, 2019). Cairns and Cox (2008) insisted that recruiting people with specialist knowledge is essential to user study success. Even though radiology technicians are able to operate many radiology machines interchangeably, such as CT scans or MRIs, the study only focused on technicians who were using the CT scan on a daily basis at the time of the study. To ensure scientific integrity, the authors carefully specified a rigorous pre-qualification procedure to eliminate unwanted participants. To qualify as a participant, candidates had to meet three criteria: 1) their primary work involved handling and operating CT scans; 2) their job category was radiology (Radiologist or Technician); and 3) they were currently working in the Saudi public healthcare system. At the time of this study, there were 400 CT scan technicians working in the public sector, and there were about 191 CT scan devices (according to the Radiology Department in the Ministry of Health, November 2017). The total number of participants was 44 CT scan technicians (Table 4.1 shows demographic characteristics). The technicians were geographically from hospitals in all 13 Saudi regions.

TABLE 4.1. Participant Demographic

Variable	Frequency	N %	Variable	Frequency	N %
<b>Age</b>			<b>Gender</b>		
20-29	14	31.80%	Male	26	59.10%
30-39	23	52.30%	Female	18	40.90%
40-49	7	15.90%	Total	44	100%
Total	44	100%	<b>Radiology Job Title</b>		
<b>Level of Education</b>			Consultant Technician	1	2.30%
Diploma	11	25.00%	Registrar	3	6.80%
Bachelor	25	56.80%	Senior Technician Specialist	9	20.50%
Master	8	18.20%	Technician	15	34.10%
Total	44	100%	Technician Specialist	16	36.40%
<b>Nationality</b>			Total	44	100%
Filipino	7	15.90%	<b>Years of Experience</b>		
Indian	1	2.30%	0-3 years	16	36.40%
Pakistani	2	4.50%	4-7 years	11	25.00%
Saudi	33	75.00%	8-11 years	9	20.50%
Sudanese	1	2.30%	12+	8	18.20%
Total	44	100%	Total	44	100%

## Instrument

The study instrument comprised two elements, the first of which was a two-part questionnaire. The first part gathered information about participant characteristics including gender, age, educational level, years of experience, job title, and nationality. The six measured variables included the following options: (1) Gender (Male, Female); (2) Age (20–29, 30–39, 40–49); (3) Level of Education (Diploma, Bachelor, Master); (4) Years of Experience (0–3 years, 4–7 years, 8–11 years, 12+ years); (5) Radiology Job Title (Technician, Technician Specialist, Senior Technician Specialist, Consultant Technician, Registrar); (5) Nationality (Open).

As shown in Fig. 4.3, the second element comprised two adapted questionnaires. The first section adapted the standard heuristic evaluation approach to identify major usability issues vis-à-vis CT scan, based on Zhang et al.'s (2003) approach to heuristic evaluation. As shown in Table 4.2,

heuristic evaluation tends to measure CT scan usability in terms of 14 attributes: (1) Consistency; (2) Visibility; (3) Match; (4) Minimalism; (5) Memory; (6) Feedback; (7) Flexibility; (8) Message; (9) Error; (10) Closure; (11) Undo; (12) Language; (13) Control; (14) Document. Each attribute was measured by items ranked on a five-point Likert scale (0 = No Problem, 1 = Cosmetic, 2 = Minor, 3 = Major, 4 = Usability Catastrophe).

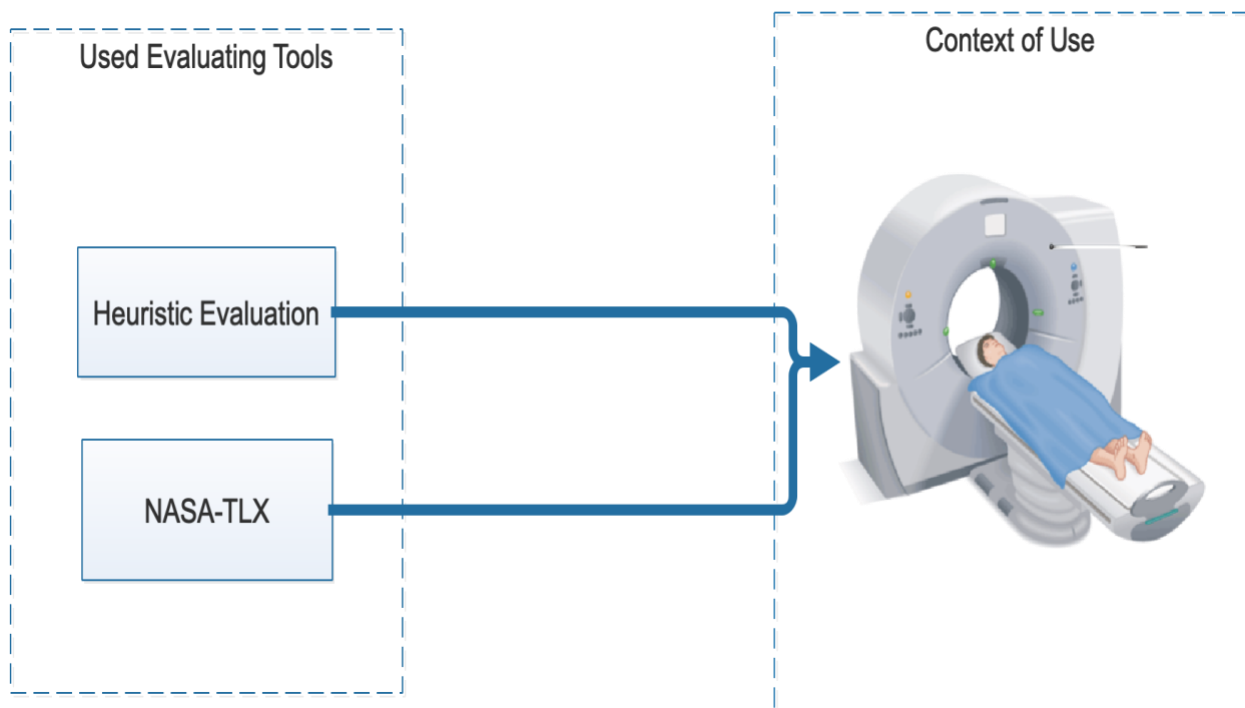
In a third step, NASA-TLX was used to assess the physical and mental loads associated with operating a CT scan. The questionnaire measured the following variables: (1) Physical, (2) Mental, (3) Frustration, (4) Discomfort. Responses were again based on a five-point Likert scale (1 = Low, 2 = Fairly Low, 3 = Medium, 4 = Fairly High, 5 = High).

*TABLE 4.2. Usability Attributes as Defined By Zhang (2003)*

Attribute	Explanation
Consistency	Consistency and standards: Users should not have to wonder whether different words, situations, or actions mean the same thing. Standards and conventions in product design should be followed.
Visibility	Visibility of system state: Users should be informed about what is going on with the system through appropriate feedback and display of information.
Match	Match between system and world: The image of the system perceived by users should match the model the users have about the system.
Minimalist	Minimalist: Any extraneous information is a distraction and a slow-down.
Memory	Minimize memory load: Users should not be required to memorize a lot of information to carry out tasks. Memory load reduces users' capacity to carry out the main tasks.
Feedback	Informative feedback: Users should be given prompt and informative feedback about their actions.
Flexibility	Flexibility and efficiency: Users always learn and users are always different. Give users the flexibility of creating customization and shortcuts to accelerate their performance.
Message	Good error messages: The messages should be informative enough such that users can understand the nature of errors, learn from errors, and recover from errors.
Error	Prevent errors: It is always better to design interfaces that prevent errors from happening in the first place.
Closure	Clear closure: Every task has a beginning and an end. Users should be clearly notified about the completion of a task.
Undo	Reversible actions: Users should be allowed to recover from errors. Reversible actions also encourage exploratory learning.
Language	Use users' language: The language should be always presented in a form understandable by the intended users.
Control	Users in control: Do not give users that impression that they are controlled by the systems.
Document	Help and documentation: Always provide help when needed, ideally context-sensitive help.

The second set was field observation. The first author conducted two days of on-site observations at King Saud Medical City (KSMC) to investigate technicians' use of the CT scan in terms of usability and physical and mental loads. During that time, 8 hours were dedicated to CT scan operation in the Emergency Room (ER), and the other 8 hours were dedicated to CT scan operation in the Radiology Department. KSMC was chosen as the observation site after careful evaluation of several Riyadh hospitals in terms of throughput and diversity of patients.

The observed technicians were made aware of the study's purpose, and a consent form was distributed and obtained from each participant.



*Fig. 4.3: Model Framework*

## Procedure

Two volunteers were recruited during the making of this study. One volunteer was responsible for the communication with the Ministry of Health. The other volunteer was responsible for recruitment from inside hospitals. An official email was sent from volunteer 1 to invite all CT scan technicians to participate in the study. The email contained a web link to the questionnaire.

Volunteer 2 were visited all mega-hospital cities in Riyadh and offer paper-based questionnaires. All participants were given the choice to fill up the questionnaire either by web- link or paper-based. The research surveyed usability questionnaires that measured the lack of usability from different angles. The authors chose to adopt Zhang et al. (2003) because it was unambiguously intended for medical device use. The results were analyzed using SPSS 24.

## QUESTIONNAIRES RELIABILITY

The reliability of the heuristic questionnaire and NASA- TLX was measured using Cronbach’s alpha. For the heuristic questionnaire, alpha was .98; for NASA-TLX, alpha was .79. As a rule of thumb, Leary (2016) suggested that a Cronbach alpha in excess of .70 is generally adequate for newly developed questionnaires.

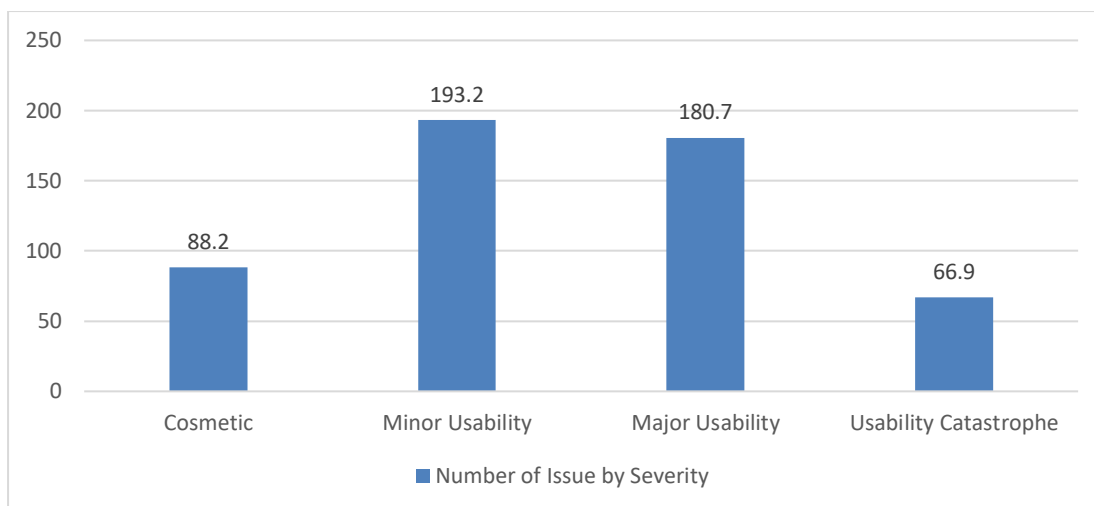
*Table: 4.3 Usability Cronbach’s alpha.*

Usability attribute	No. of items	Cronbach's Alpha
Consistency	6	0.947
Visibility	4	0.903
Match	3	0.901
Minimalist	4	0.919
Memory	5	0.934
Feedback	4	0.907
Flexibility	3	0.877
Message	4	0.909
Error	5	0.902
Closure	3	0.913
Undo	4	0.864
Language	4	0.84
Control	2	0.843
Document	2	0.869

## RESULTS

### Usability attributes

Each participant scored the CT scan based on his/her user experience on multiple dimensions. In total, 529 issues were found ranging from cosmetic to catastrophic. These issues can be split down into 88.2 for cosmetic, 193.2 minor usability, 180.7 major usability, and 66.9 usability catastrophe see Fig. 4.4. On a catastrophic scale, technicians found Memory (27.30%), Visibility (20.50%), Consistency (18.20%), Flexibility (18.20%), Minimalist (13.6%), Closure (13.6%), and Document (13.6%) most troubling see Fig. 4.5. On major usability problem scale, technicians reported Message (45.9%), Minimalist (40.9%), Document (40.9%), Visibility (34.1%), and Match (34.1%) as the highest among other attributes.



*Fig. 4.4. Number of issues categorized by severity*

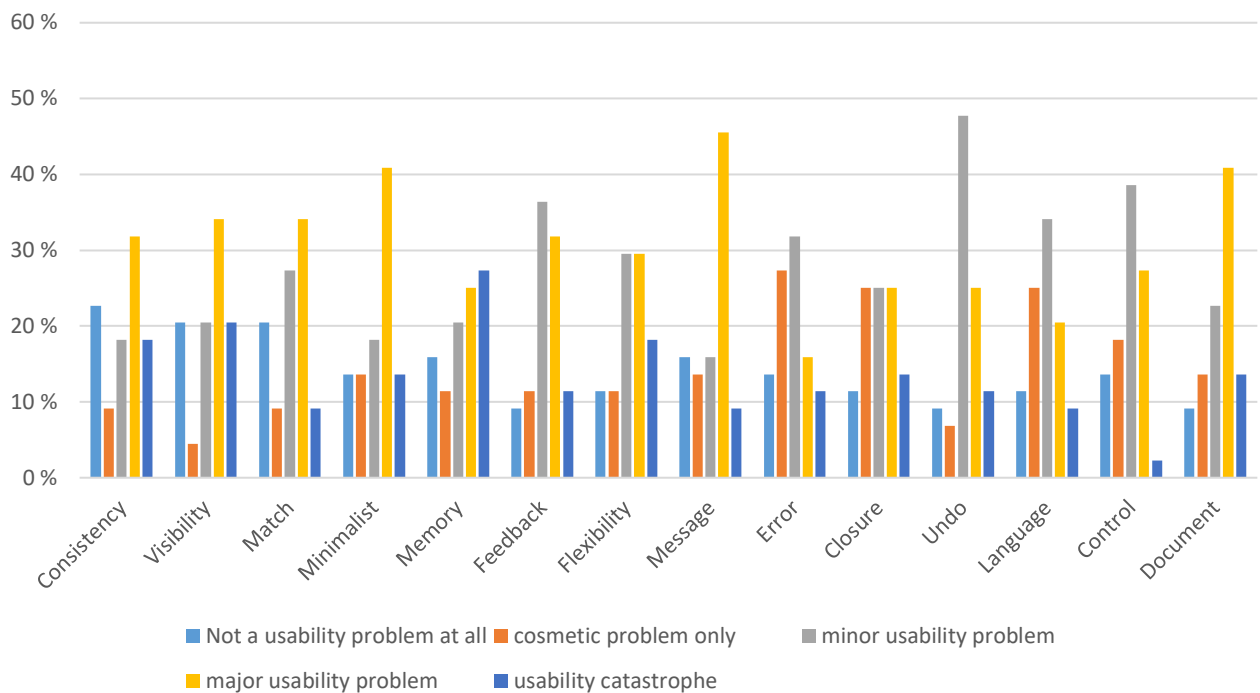


Fig. 4.5 Usability attributes categorized by severity

User experience characteristics are different according to the demographic group. For instance, 33.30% of female technicians reported Consistency as usability catastrophe in contrast to 7.70% of male. Also, 33.30 % of female technicians reported catastrophic on Memory whereas 23.10% of male sees it as catastrophic see Fig. 4.6. In general, female technicians catastrophic rating surpassed male counterpart (except for Control attribute). Age is another crucial factor in the demographic group. As shown in Fig 4.7, as the age group increase, the less usability catastrophe is reported. This finding supports the fact that increase in age is corresponding to an increase in the working experience. As a result, the older the user is, the more working experience the person has. 20-29 age group reported that Memory (35.7%), and Flexibility (28.6%) are most troubling according to usability catastrophe scale whereas 30-39 age group reported Memory (26.1%) and Visibility (26.1%). On the other hand, 40-49 age group is the lowest group in encountering usability catastrophe issues. Education level is essential factor in the demographic group see Fig.

4.8. For education group, Diploma category registered the highest group in encountering usability catastrophe issues.

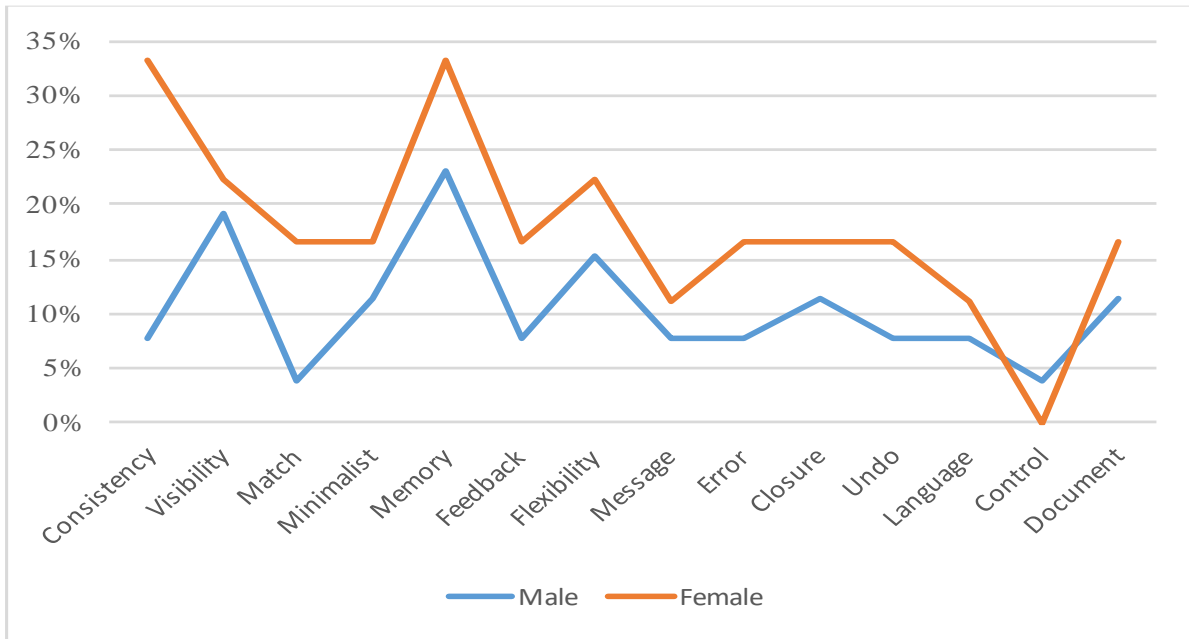


Fig. 4.6. Usability catastrophe corresponding with gender

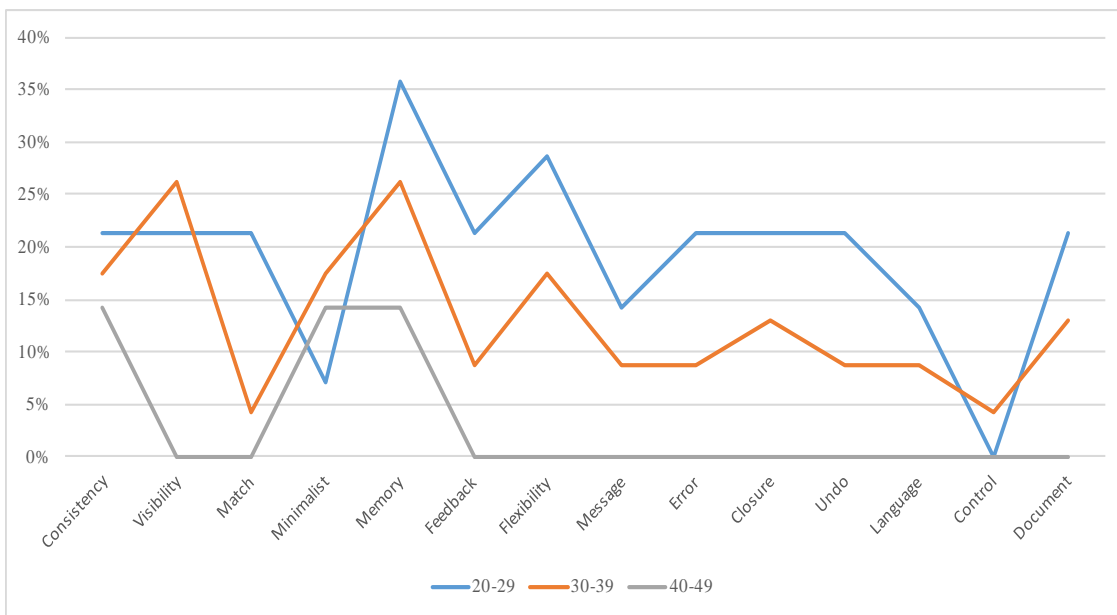
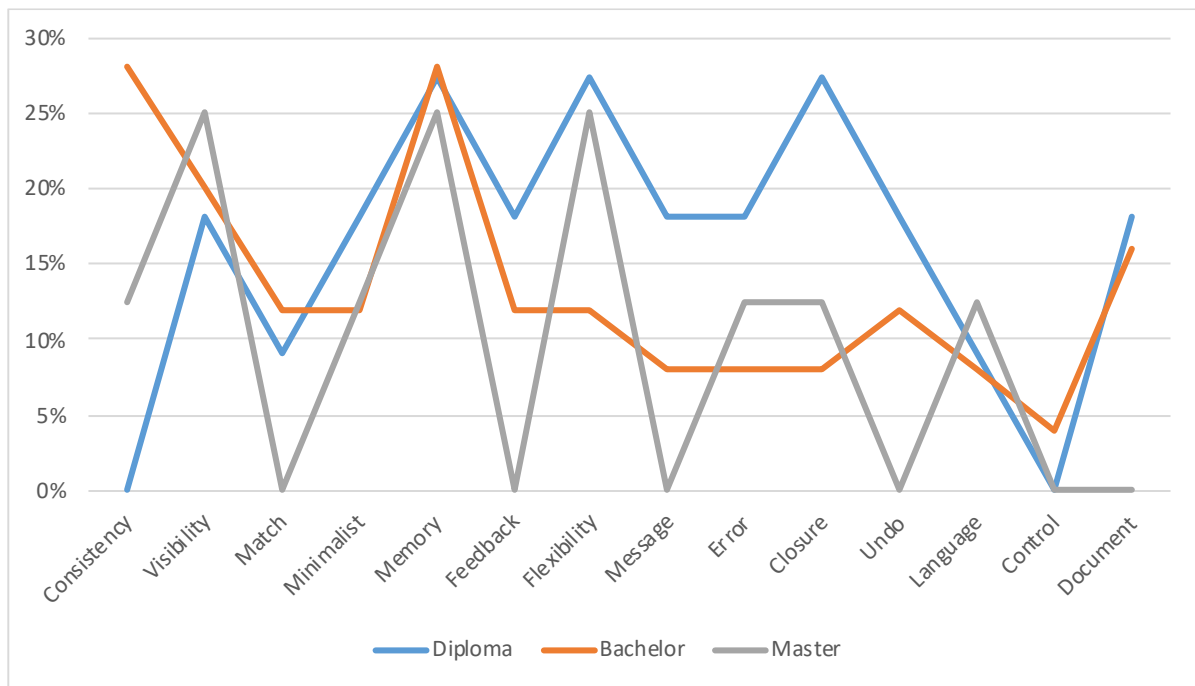


Fig. 4.7 Usability catastrophe corresponding with age





*Fig. 4.8 Usability catastrophe corresponding with education*

## NASA-TLX

Evidently, exertions exist while operating CT. Technicians reported that exertions are maximum (very high) on the mental (22.7%), discomfort (11.4%), physical (6.8%), and frustration (4.5%). As shown in Fig. 4.9, mental exertion constituted 61.3% in the high category. The largest category is medium physical exertion as reported by 59.1%. For fairly high category, technicians reported mental (38.6%), frustration (27.3%), discomfort (18.2%), and physical (15.9%). As illustrated in Fig. 4.10, exertion is different according to user demographic characteristics. For mental exertion, 38.9% of female reported High as opposed to 11.5% of male. Age is a captivating factor in the socio-demographic element. Fig. 4.11 shows the rate of exertion in correspondence with age. It is unblemished to say that the mental exertion is high across all age group. The 20-29 age group shows high present of all exertions compared to any other group.

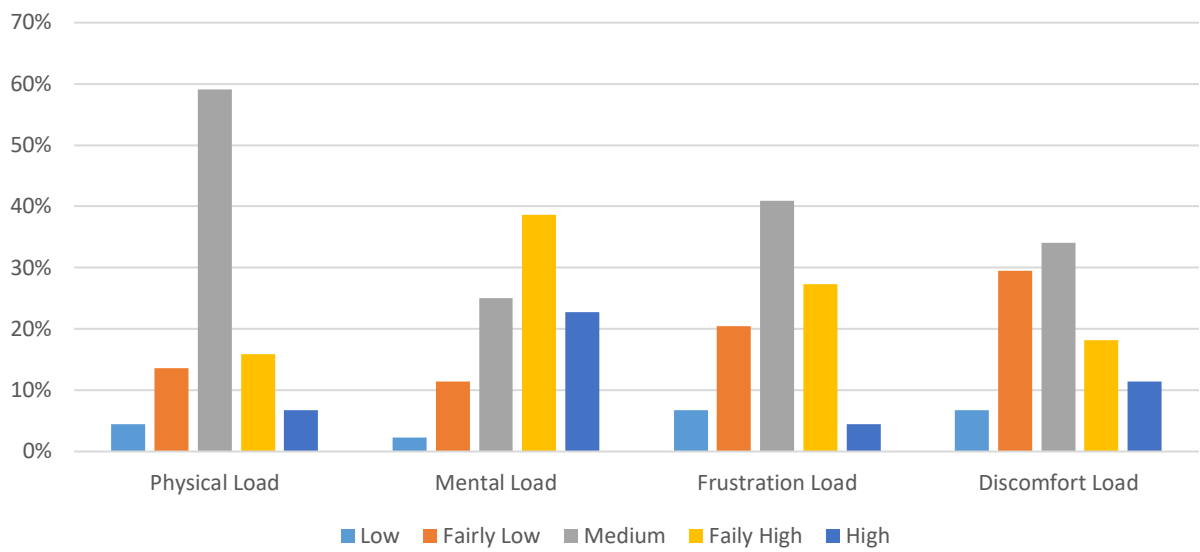


Fig. 4.9. Exertions by severity

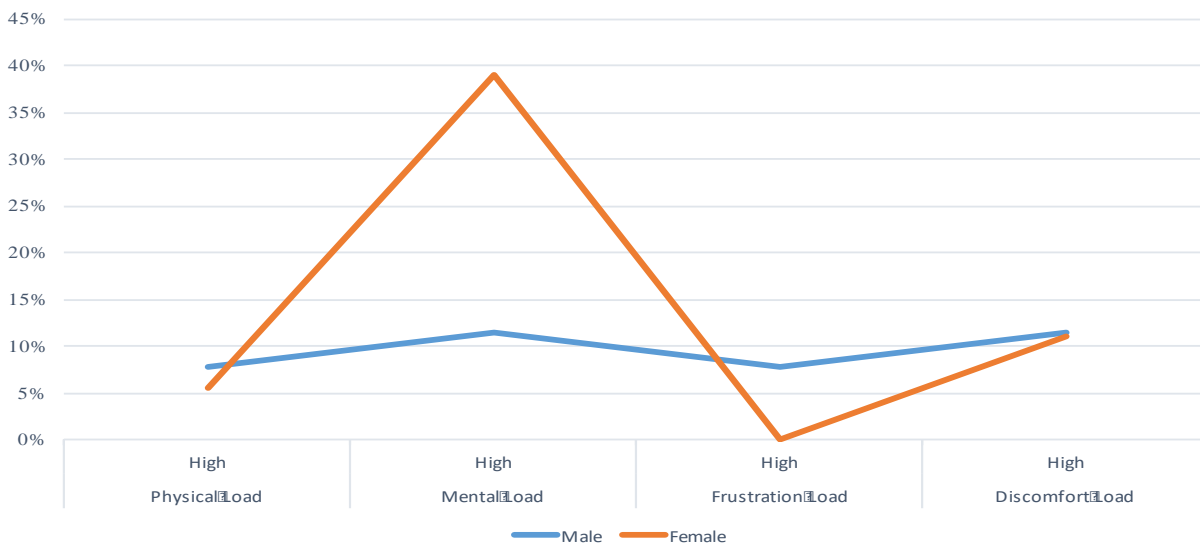


Fig. 4.10. High exertion corresponding with gender

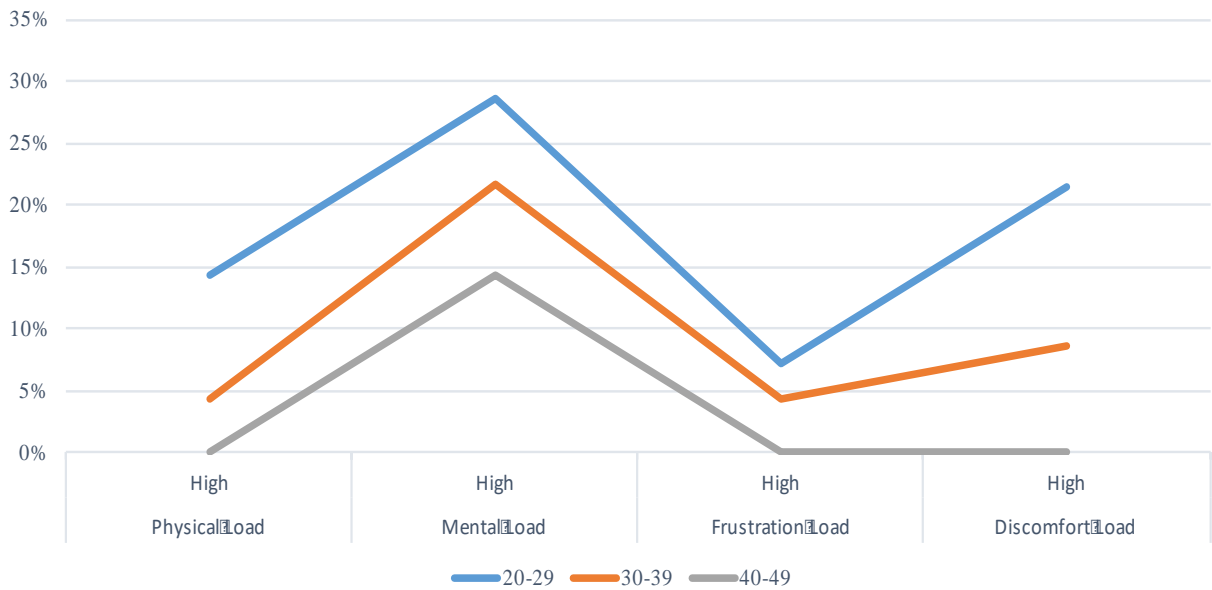


Fig. 4.11. High exertion corresponding with age

## Demographic Characteristics

### Usability attributes

### Gender

Of 14 attributes, Mann Whitney tests showed a difference between Male and Female on Consistency ( $z = 2.21$ ,  $p = .027$ , 2-sided); Flexibility ( $z = 1.99$ ,  $p = .046$ , 2-sided); and Document ( $z = 2.09$ ,  $p = .036$ , 2-sided) (See Fig. 4.12, Fig. 4.13, and Fig. 4.14).

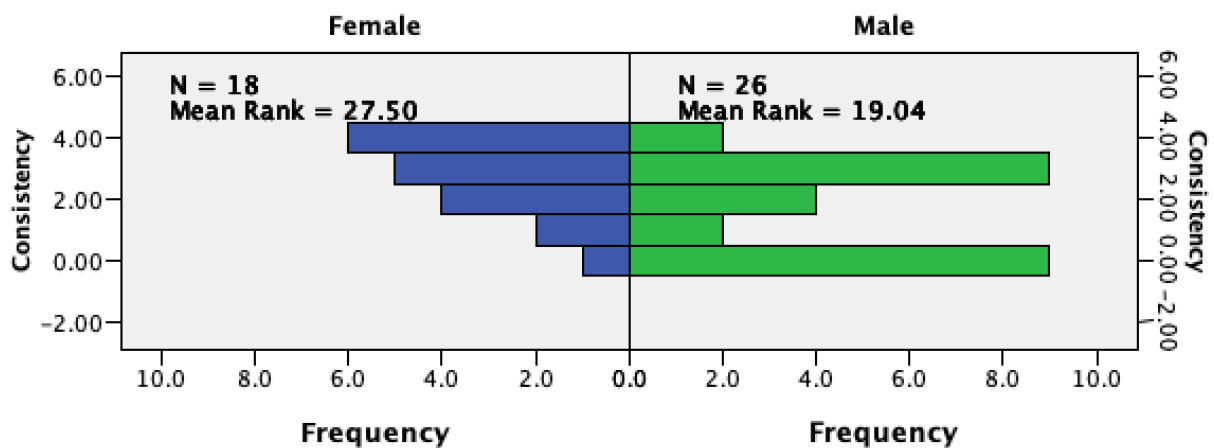


Fig. 4.12. Consistency attribute base on gender

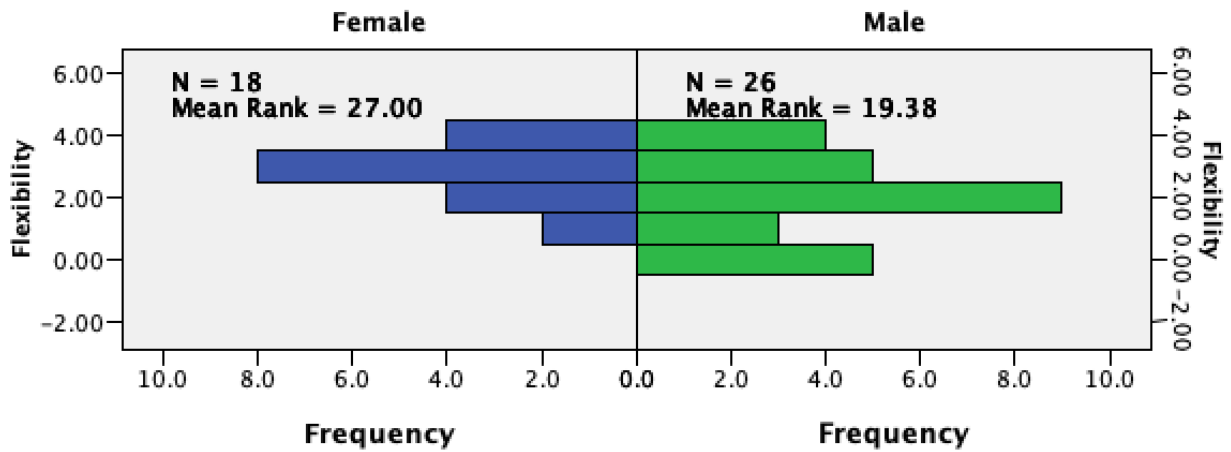


Fig. 4.13. Flexibility attribute base on gender

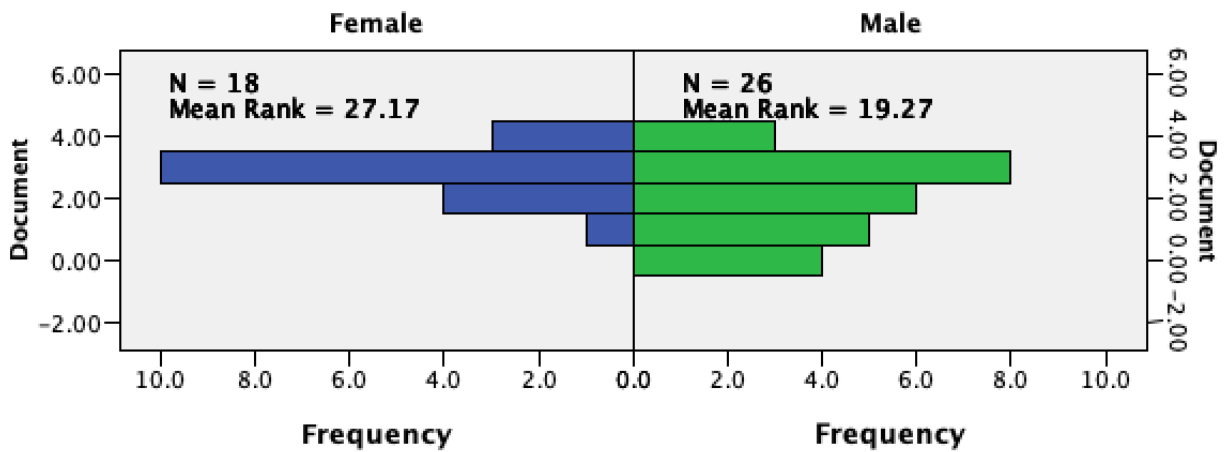


Fig. 4.14. Document attribute base on gender

### Age, Level of Education, and Years of Experience

The nonparametric Kruskal-Wallis test showed no differences between category groups.

## NASA-TLX

### Gender

A Mann Whitney test showed a difference between Male and Female on mental load ( $z = 3.23$ ,  $p = .001$ , 2-sided) See Fig. 4.15.

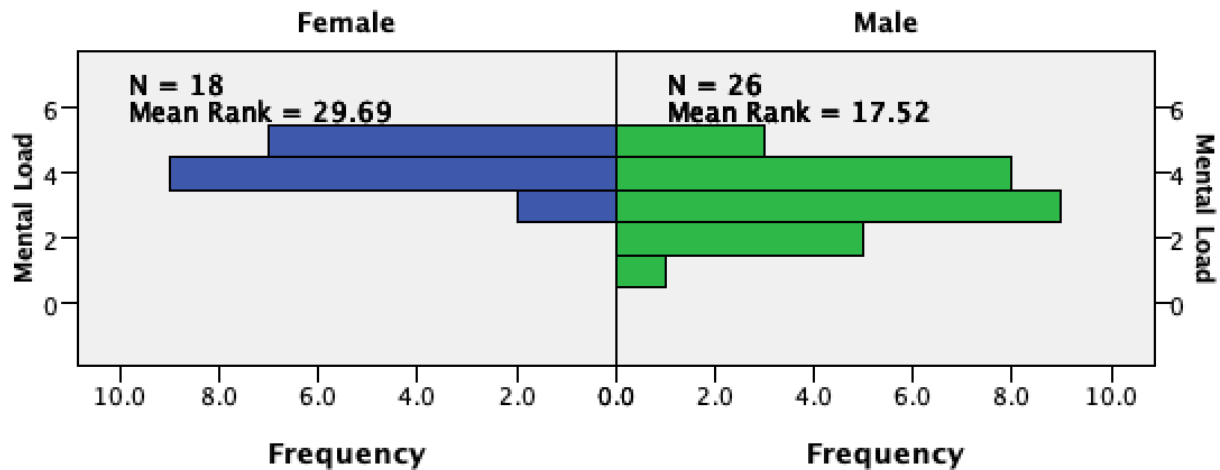


Fig. 4.15. Mental load base on gender

### Age and Level of Education

The nonparametric Kruskal-Wallis test showed no difference between category groups.

### Years of Experience

A Kruskal-Wallis test showed a statistically significant difference by years of experience for at least one group on Frustration ( $\chi^2 = 10.9$ ,  $p = .012$ ) and Discomfort ( $\chi^2 = 9.2$ ,  $p = .026$ ) See Fig. 4.16 and Fig. 4.17. Dunn's pairwise test was performed for the six pairs of groups. There was strong evidence ( $p = .006$ , adjusted using the Bonferroni correction) of a difference in Frustration between 0–3 years and 8–11 years See Table 4.4. The same pair also differed significantly ( $p = .036$ , adjusted using the Bonferroni correction) on Discomfort see Table 4.5.

### Independent-Samples Kruskal-Wallis Test

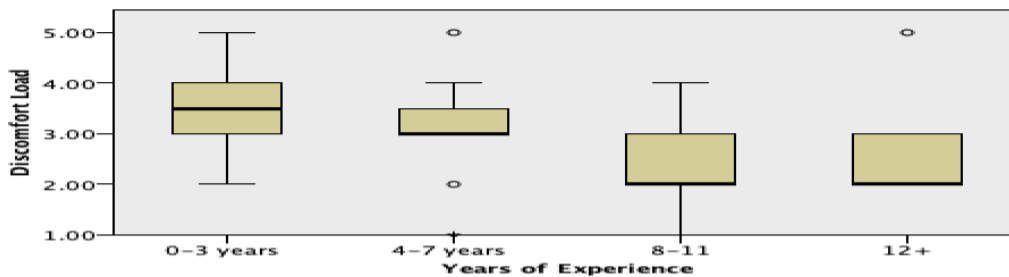


<b>Total N</b>	44
<b>Test Statistic</b>	10.934
<b>Degrees of Freedom</b>	3
<b>Asymptotic Sig. (2-sided test)</b>	.012

1. The test statistic is adjusted for ties.

Fig. 4.16 Frustration differences base on Years of experience

### Independent-Samples Kruskal-Wallis Test



<b>Total N</b>	44
<b>Test Statistic</b>	9.238
<b>Degrees of Freedom</b>	3
<b>Asymptotic Sig. (2-sided test)</b>	.026

1. The test statistic is adjusted for ties.

Fig. 4.17 Discomfort differences base on Years of experience

Table 4.4: Dunn's pairwise test within group

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
8-11-4-7 years	11.970	5.486	2.182	.029	.175
8-11-12+	-12.521	5.930	-2.111	.035	.208
8-11-0-3 years	16.677	5.085	3.279	.001	.006
4-7 years-12+	-.551	5.671	-.097	.923	1.000
4-7 years-0-3 years	4.707	4.780	.985	.325	1.000
12+-0-3 years	4.156	5.285	.786	.432	1.000

Table 4.4: Dunn's pairwise test within group

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
8-11-12+	-3.333	6.010	-.555	.579	1.000
8-11-4-7 years	10.288	5.560	1.850	.064	.385
8-11-0-3 years	14.177	5.154	2.751	.006	.036
12+-4-7 years	6.955	5.748	1.210	.226	1.000
12+-0-3 years	10.844	5.356	2.025	.043	.257
4-7 years-0-3 years	3.889	4.845	.803	.422	1.000

## CONCLUSION

Advancement in technology comes in correlation with advancement in systems, increasing the pressure on users to manage complexity safely and efficiently. These findings support the mounting evidence of physical loads (high = 6.8%, fairly high = 15.9%, medium = 59.1%) where users see themselves as contributing physically to operate a CT. As 86.3% of users believed that operating CT scans involved medium to high mental load, manufacturers should pursue designs that reduce both physical and mental loads. Evidently, the results show that mental load, in particular, is high, regardless of differences in demographic characteristics such as gender, age, level of education, and years of experience. Therefore, the CT scan manufacturers should update

their usability expectation, to include mental loads minimizing procedures and techniques. Acknowledging mental load peaks from the industry would encourage academics and professionals to propose solutions and generally tackle the problem. As of now, there is no manufacturer who points to this problem specifically. A prominent question which comes to mind immediately, concerns industry awareness of high mental loads in the CT. On the other hand, across the fourteen usability attributes, 66.9 cases of Catastrophic usability were recorded. These should be fixed immediately before allowing the product to go to market. To ensure that users are willing and able to operate within the confines of rigid safety and regulatory guidelines, manufacturers should devote more effort to CT scan usability

Despite the heavily regulated practices in radiology, CT scan technicians are overwhelmingly concentrated on delivering images that can be read easily by doctors and interpreters. Undeniably, usability has a profound effect on both technicians and patients. It empowers the technician's ability to execute more tasks within a defined time and reflects on the patient's overall safety. With pressure for resources, technicians tend to maneuver physical exertion by minimizing movement after a certain time. A technician was observed after 4 hours of CT scan operation trying to divert physical movement (going to the exam room to center the patient) by telling the patient to lay down on the table. Then, the technician examined the patient using the repeat series feature without the necessity to go physically into the room to center the patient on the CT scan table. This attitude agrees with the study finding that 27% of technicians rated CT scans as catastrophic in shortcuts for frequently used operations. Considering that going to the exam room to center the patients is the most frequently used operation while operating a CT scan, one important principle of this study is that CT scan designers should consider enforcing more flexibility in the machine, especially enabling users to easily conduct an exam from the control room without the necessity to summon the technician into the exam room to center and re-center



patients. Executing tasks with efficiency might be enough in a particular device, but in a CT scan, it must also come with minimizing physical and mental exertion. Future work will examine the usability for system engineering. A system engineering model will be introduced to handle business intelligence reporting with an emphasis on practical usability principles.

The result indicates a vitally important trend. That is the higher the age is the less usability catastrophe user encounter. That hints at the possibility that users' working experience is fundamentally essential in reducing catastrophic usability problems. In the long term, users learn how to minimize usability catastrophe as they progress at work. It also suggests that there is a positive correlation between the age and usability catastrophe category. To minimize usability catastrophe, manufacturers are encouraged to embedded helping features to CT scan's operating systems. One important concept is to make the machine learn about its users by introducing machine learning capabilities. Another equally essential concept is to make use of business intelligence capabilities within the operating context of the CT scan. For instance, if one user is known for making one type of operating error, CT can self-generate a report and send to human resource department to elevate user's priority to gain a training on that type of error. Since 27.3 % of technicians reported memory attribute as usability catastrophe, manufacturers should elaborate more effort to memory dimensions (Perceptual procedures, hierarchical structure, default values, concrete examples, and generic rules and actions).

These findings add to mounting evidence that users differ according to gender and years of experience. In the context of CT scan operation, males and females different on the Consistency attribute (Sequence of action, Color, Layout, Font, Terminology, and Standards). For that reason, it is recommended that designers should provide customizable options to suit end-user needs and requirements. In addition, as males and females differed significantly on mental load, designers

should take account of these differences in the design process and should actively iterate to the end of the process, testing and comparing in order to accommodate the usability needs of both genders.

In daily CT operations, the study observation finds that examining patients rigidly, requires technicians to go to the exam room and center the patient accurately on the CT's table. Obviously, this procedure contributes to the physical and mental load. Evidently, there are non-machine related activities that contribute to general physical and mental load. For instance, in emergency rooms, technicians are expected to help the nursing team transfer the patient from the bed to the CT table. The non-machine related loads could come in many forms such as management targets, assigned departmental duties and status of exam room, for example. Knowing what contributes to physical and mental loads is essential to CT manufacturers, even if it is not machine-related because such knowledge could be a gate to future developmental growth, in terms of techniques or integrations

# Evaluation and Effect of Invisible Physical and Mental Exertion from CT Scan Operation in Saudi Arabian Hospitals

## INTRODUCTION

Heuristics is a popular method to evaluate system and product usability, and it proposes improvements during and after the development. A key component of the success and rising popularity of heuristics is its low cost and effectiveness. In academia, there are 152 usability attributes (Duby and Rana, 2010). As a customary practice in industry and academia, usability is constructed from a list of attributes to constitute the dimensions of the cohesive whole. Geisen and Bergstrom (2017) referred to these dimensions as metrics for evaluation. It is clear from the literature that usability lacks uniformity and unity of dimensions, which has caused some ambiguity among new researchers.

However, it is vitally important to state why usability diverges in dimensions. An important reason is that usability is used to evaluate various products and systems that hold different execution goals and purposes. According to Ferre et al. (2001), usability can only be defined in accordance with the intended system and the intended users. They illustrated their argument regarding a museum kiosk where the dimensions must emphasize minimum training since kiosk users are most likely to use it only once in their lifetime.

Similarly, usability attributes should be representative of the overall environment where the larger scope must be counted as an attribute. For instance, the incorporated usability considers the local environment of the work, including the managerial target and departmental duty that measures the

invisible exertion, which can contribute to and affect usability. The obvious objective is to use the usability evaluation to consider human factors that are associated with the work and managerial environments. When evaluating usability attributes, there is a clear indication that they lack an exertion evaluation, such as for physical and mental exertion. Consequently, many authors (Longo and Kane, (2011), (Ramkumar et al. 2016), and (Aldoihi, Hammami, 2018) have included NASA-LTX for a usability evaluation as a substitute for physical and mental exertion, which is lacking in popular heuristic methods.

One of the ISO 9241 usability evaluation settings is “context of use.” In essence, it implies that evaluation usability must consider the work atmosphere in which the device or system would operate. For instance, when evaluating a newly developed CT scan, the natural everyday busy setting of an over-crowded and understaffed hospital must be considered, including the management target and duty expected from the operators. In other words, exertion delivered from any source should be included in an operator’s human factor and usability evaluations. Dimensional attributes such as safety, operator satisfaction, and productivity are the essence that constitutes the overall usability (Helander, 2005). Furthermore, impeding attributes that consider the organizational context would add more accuracy and validity of the overall usability.

The effects of physical and mental exertion on technicians working in radiology are overwhelming. Current radiology practice suffers from declining salaries, increasing workload, and workflow complexity (Forman et al. 2012). Although a radiology work environment is categorized as shift work, disturbances in daily sleeping cycles are associated with physiological and behavioral effects as well as a loss of the rhythm entrainment (Krupinski & Berbaum, 2009). Considerable fatigue and human error affect radiology practices with recent literature covering how diagnostic accuracy is compromised after long working hours (Krupinski, 2010), (Krupinski,

2012), (Krupinski et al. 2017), and (Taylor-Phillips et al. 2015). Under financial pressure, radiologists' practices are adopting a faster and more agile productivity style to accommodate larger workloads. Radiologists are now more likely to increase their interpretation error by 26.6% as opposed to 10% under average working speeds (Sokolovskaya et al. 2015).

Radiology technicians today experience extreme pressure from many invisible exertion constraints, such as safety requirements, ethical practices, productivity and optimization requirements, system and technology requirements, and industry best practice adaptations. Regardless of the industry, most new requirements are driven by increasing safety (Miller, 2013). Technicians are expected to facilitate all requirements while retaining the integrity of daily tasks. CT scan working conditions are categorized into the following themes:

- Dim lighting
- Small and confined control rooms
- Safety standards and practices
- Facilitating Technology

## STUDY OBJECTIVE

The overall objective of this study is to identify invisible exertion existence while operating CT and to identify whether the Radiology Department duty and management targets can be transformed into invisible physical and mental exertion. Furthermore, it identifies demographic differences among the study participants, such as gender, age, years of experience, and working sector. Primary, the study explores the type of invisible exertion as physical or mental. To the best of our knowledge, no previous research explored and evaluated these invisible exertion effects for CT technicians. As other researchers have not exploited the theme of this study, we expect this work can open a new arena of research for evaluating a variety of invisible exertions and their effects on working environments.

## BACKGROUND

### Usability as a factor in medical devices

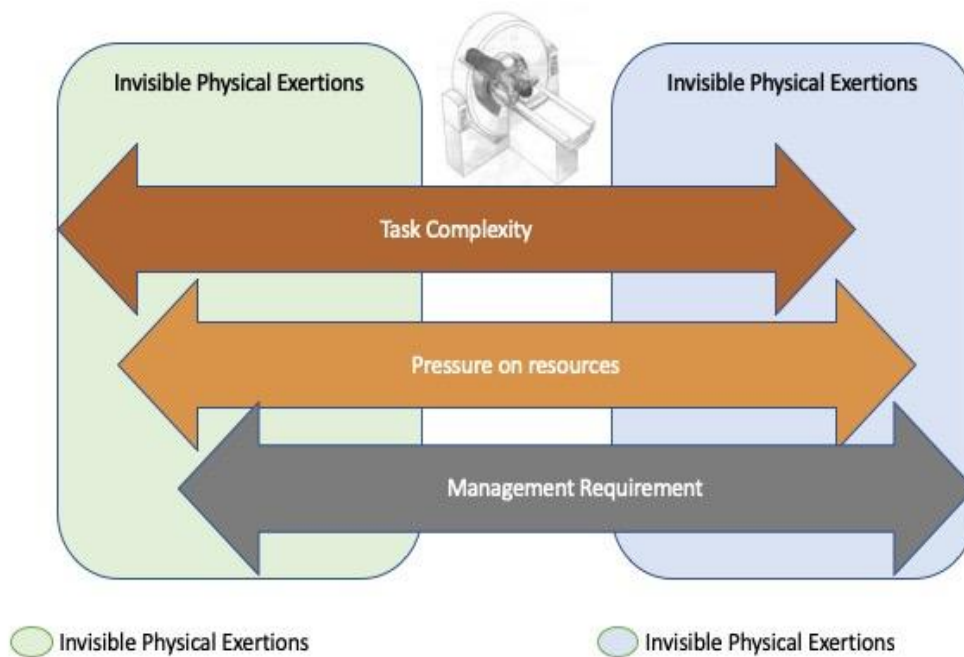
From the beginning, medical devices have been implemented on the premise of assisting the examiner by providing vital information that could alter the examiner's decisions regarding the patients. As the devices gain more computing power and advanced sensing technology, more functionalities and connectivity with other devices present more challenges to the novice user. Consequently, evaluation methods have been suggested from different fields. In recent years, usability evaluations have dramatically shifted focus to medical devices.

Designing usability for medical devices is not like other electronic devices for the following reasons. Medical devices provide data on decisions regarding the actions of doctors. Medical device usability has a limit, where user characteristics and preferences count for the overall outcome. Aldoihi and Hammami (2018, July) showed that CT scan operators indeed differ in perceiving the usability attributes according to gender and years of experience.

### Cognitive and Physical Exertion

Cognitive load is deeply involved in psychology. An obvious sign of such involvement is that cognitive load is only clarified through psychology or behavioral lenses (Moreno & Park, 2010). Eventually, cognitive biases appeared to influence people's behaviors inadvertently (Dimara et al. 2018). Key components of cognitive load are the nature of the work and how memory can correspond with it (Sweller et al. 2011). Mental load has been perceived by early psychological theorists as a multi-dimensional phenomenon where the interpretation of phenomena comes as a result of the outcomes of the interaction between subjective individual characteristics and objective task characteristics (Campbell, 1988) (Wood, 1986). Subsequently, mental load resulting from indirect (invisible) work has not been properly studied.

Mental load studies have heavily concentrated on the direct aspects and have somehow neglected indirect aspects. It is essential to include invisible elements to understand the overall characteristics of the mental load since the mental load is multi-dimensional by nature. Mental load exists whenever there are intractable tasks that demand a great deal of control. There are three main aspects of invisible physical and mental loads, which are task complexity, management requirements, and pressure of resources (see Fig. 5.1).



*Fig. 5.1 Conceptual framework*

Another extremely important load is the physical load. For CT scan technicians, there is a considerable amount of physical load during the operation of the machine. Nonetheless, there are many tasks performed by the technicians where the physical load is unavoidable. Such tasks are the framework of this study. For instance, it is a customary practice in Saudi Arabia that CT technicians help the bedridden patient transfer to the CT table. Literature has demonstrated the effect of overload on radiologists on many fronts. Various studies have explored the risk factors

associated with excessive loads (Hanna et al. 2018), (Krupinski et al. 2012), and (Krupinski et al. 2010). Bruni et al. (2012) noted that considerable discrepancies in interpretation are demonstrated in the late shift for radiologists as opposed to the starting shift. It is critically important to explore and identify the effect of the invisible load on radiologists so that researchers and practitioners can propose reduction procedures.

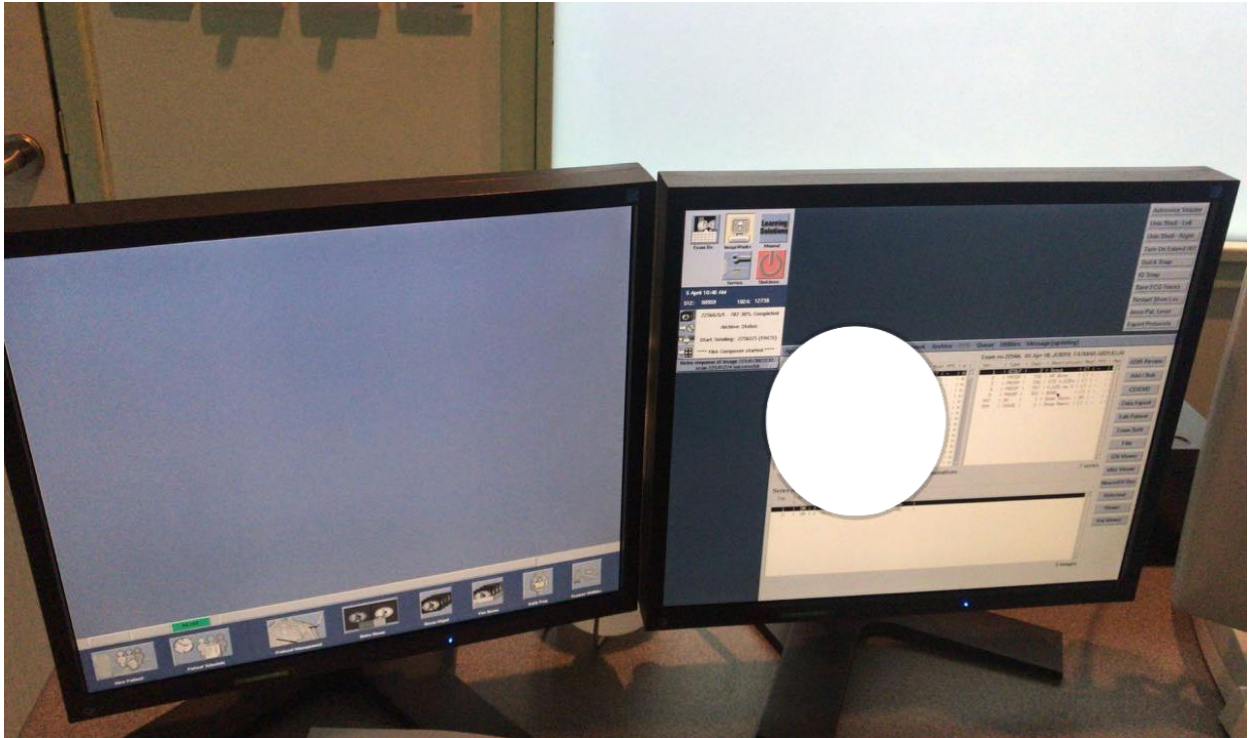
## DESCRIPTION OF THE PROBLEM

The current state of hospitals demands a substantial amount of efficiency provided from a minimal amount of resources. So, radiologists today are working with multi-objective aims, such as safety and optimization of space and other resources, and exertions from various directions provide added pressure to radiologists. However, considerable pressure results from invisible sources. The working practice of CT scan radiologists demands proactivity and efficiency with daily operating routines that include helping bedridden patients move to the CT scan table, administrate the contrast media, and re-centering the position of the patient. Therefore, numerous such activities result as invisible exertions, which can be categorized as non-machine-related exertion. As hospital management teams strive to maximize productivity and optimize the intake of resources, identifying primary sources of invisible exertion is imperative to maximize productivity while minimizing human error.

In field observation, radiologists overcome invisible exertion through a variety of techniques and maneuvers. During a CT exam, extensive effort positioning the patient correctly on the CT table is required before the exam. Technicians are required to direct the patient to lay down on the CT table and ensure the patient is precisely centered. Often, after a technician has spent many hours of extensive operating exams, they may try to prevent invisible exertion by maneuvering the CT scanner instead of directly re-centering of each patient. So, without the need to configure a new



exam for each patient, the technician modifies the previous exam for the new patient to avoid entering the exam room and re-centering the patient. Figure 5.2 and Figure 5.3 show this repeated series functionality. Figure 5.4 summarizes the various exertions required during a CT scan, and this study highlights the impact of these actions on the operating technicians.



*Fig. 5.2: Repeat Series*



Fig. 5.3: Repeat Series

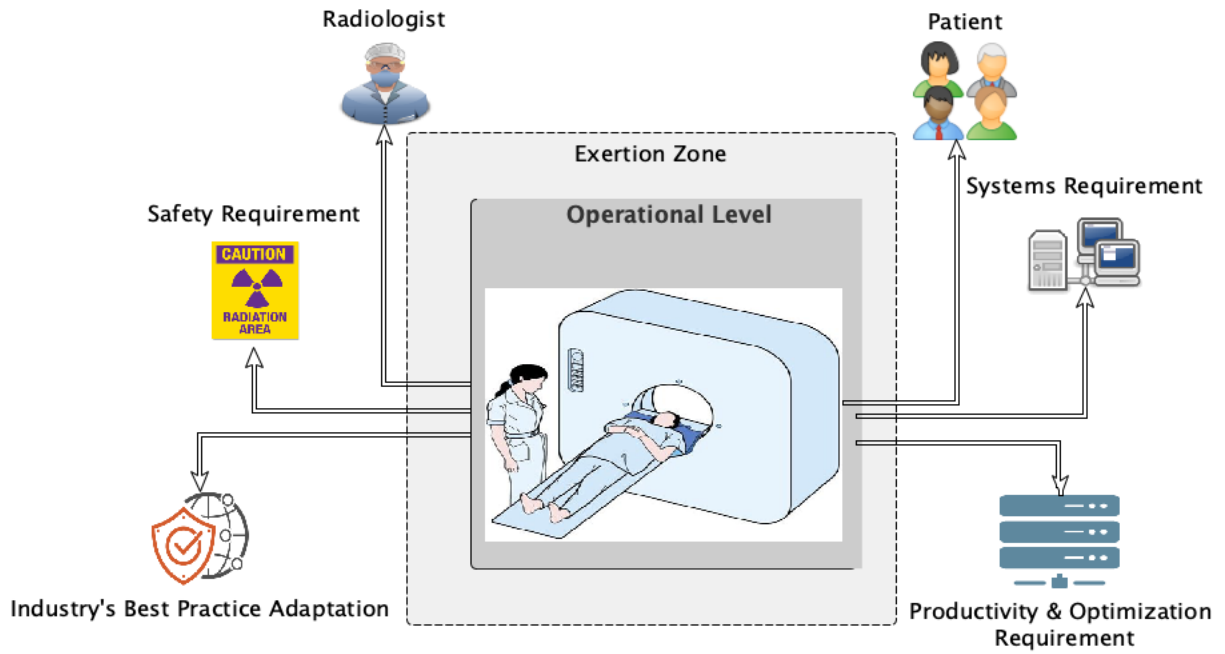


Fig. 5.4: Overview of the range of invisible exertions required by a CT technician.

## METHOD

Eighteen hours of observational field visits were conducted at the Radiology Department in King Saud Medical City. This stage worked as a preliminary phase to collect and observe variables requirements. The purpose of the visits was to pinpoint the various sources of invisible physical and mental exertions. A questionnaire was also developed to measure invisible exertions in terms of the physical and mental aspects while operating a CT scanner.

Ethical approval was sought and approved by the Ministry of Health in Saudi Arabia after satisfying the legal requirements of the Ministry's Institutional Review Board. Also, ethical principles were maintained and preserved for confidentiality, anonymity, and the right to withdraw.

### Participants

The population of the study comprises CT scan technicians who operate the machine on a daily basis and who are geographically located in Saudi Arabia. One vital variable dimension that must be distinguished is the work sector. In Saudi Arabia, the healthcare sector is divided into two categories. That is a public and private sector. It is essential to distinguish these two groups within the demographic characteristics. In total, 57 technicians participated in this study. The participants are all CT scan technicians who, at the time of the study, were working in Saudi Arabia in either the public or private sector. Participants were invited to the study by either online questionnaire link or by a telephone call.

The genders comprised 50.9% male and 49.1% female with an age range from 20 to over 50 years. This range spread included 77.2% from 20 to 29 years, 15.8% from 30 to 39 years, 3.5% from 40 to 49 years old, and 3.5% over 50 years. Education comprises 3.5% as having earned a diploma, 86% with a bachelor's degree, and 10.5% with a master's degree. Years of experience consisted

of 68.4% with 0 to 3 years, 8.8% with 4 to 7 years, 10.5% with 8 to 11 years, and 12.3% with more than 12 years. The working sectors included 87.7% in the public sector and 12.3% in the private sector. See Table 5.1 for more details of the demographic characteristics.

*TABLE 5.1: Participant Demographic Characteristics*

Variable		Total Percentage
Gender	Male	50.90%
	Female	49.10%
Total		100%
Age	20-29	77.20%
	30-39	15.80%
	40-49	3.50%
	50+	3.50%
Total		100%
Educational level	Diploma	3.50%
	Bachelor	86.00%
	Master	10.50%
Total		100%
Radiology Years of Experience	0-3 years	68.40%
	4-7 years	8.80%
	8-11 years	10.50%
	12+	12.30%
Total		100%
Working Sector	Public Sector (Government Hospitals)	87.70%
	Private Sector (Private Hospitals)	12.30%
Total		100%

## Procedure

After evaluating the causes of invisible physical and mental exertion, a field visit was conducted to King Saudi Medical City (KSMC) to gather and observe technician exertion. Due to the excessive particularity of the measured variables, a questionnaire was developed to suit the special particularity. The questionnaire was sent to technicians across Saudi Arabia, asking them to respond to six statements regarding their views on physical and mental activities while operating

a CT. The first part collected participant demographic characteristics, as reported in the previous section, and the second included participant responses for two invisible exertion measurements. A volunteer was recruited to visit the hospitals and offer a paper-based questionnaire. In addition, an electronic version of the questionnaire was developed and sent to the participants.

## Measurement

The objective is to measure the physical and mental dimensions of invisible exertion. Table 5.2 describes these two dimensions each with three associated measurement attributes. Three statements represent physical exertion, and the other three represent mental exertion. In addition, open-ended questions were added after each statement as optional commentary feedback. A self-rating questionnaire was created based on a five-point Likert scale.

*TABLE 5.2: DIMENSION MEASUREMENT*

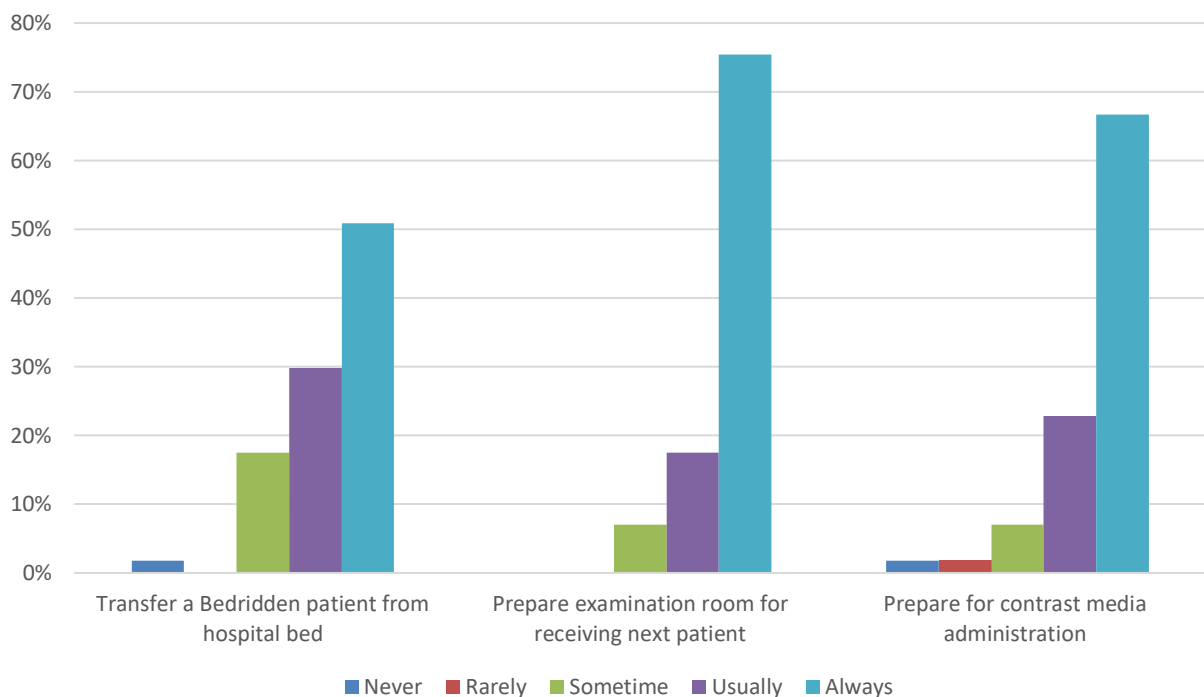
ID	Exertion Dimension	Measurement
PRQ1	Physical	Transferring a Bedridden patient from hospital bed into CT table
PRQ2		Preparing examination room for receiving next patient
PRQ3		Preparing and administrating for contrast media
MRQ1	Mental	working in understaffed environment
MRQ2		the department needs more CT Scan machines
MRQ3		the management targets are unreasonable

## RESULTS

### Invisible Physical Exertions

Invisible physical exertion is presented clearly in Fig. 5.4. The research statements demonstrate the invisible physical exertion through the activities that are required to operate a CT from three dimensions, which are PRQ1- PRQ3, as stated above. For transferring the bedridden patient to the CT table, 29 (50.9%) technicians responded with “always.” “Usually” constituted 17 (29.8%)

responses. “Sometimes” constituted 10 (17.5%) responses, whereas “never” constituted only 1 (1.8%) response. For preparing the examination room for the next patient, 43 (75.4%) responded with “always.” “Usually” constituted 10 (17.5%) responses. “Sometimes” constituted 4 (7%) responses. For preparing and administrating the contrast media, 38 (66.7%) responded with “always.” “Usually” constituted 13 (22.8%) responses. “Sometimes” constituted 4 (7%) responses. “Rarely” and “never” constituted 1 (1.8%) response.

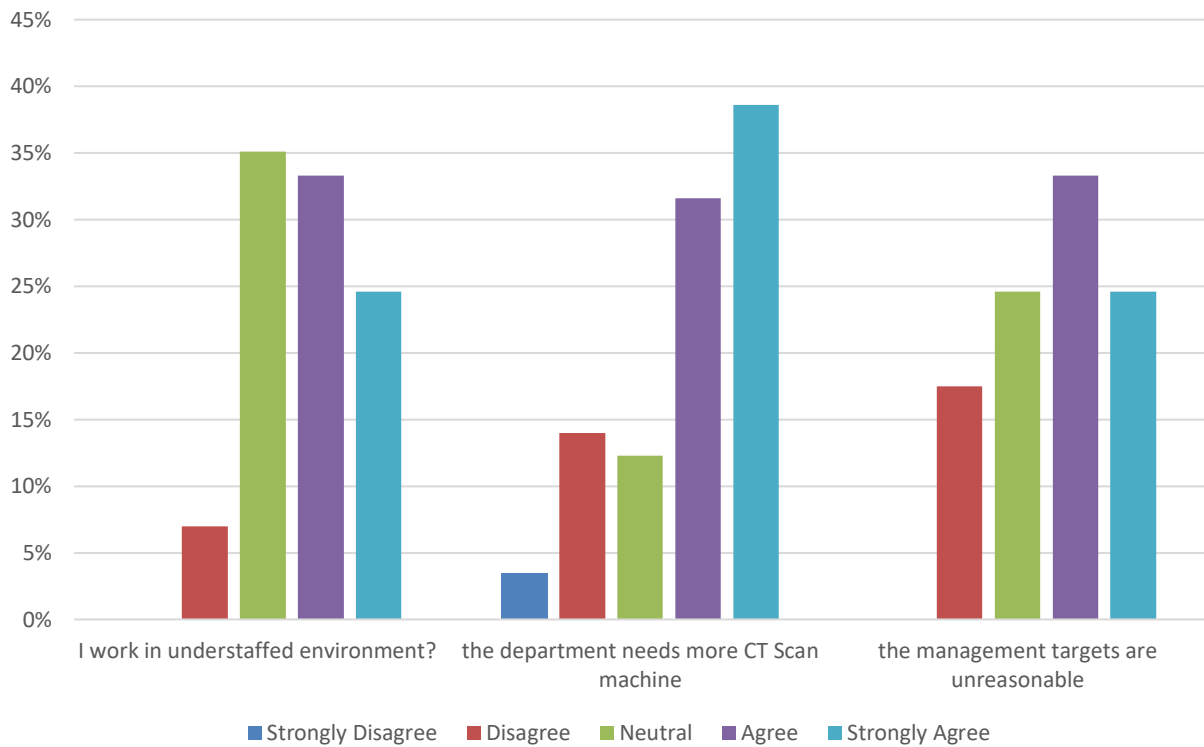


*Fig. 5.4: Physical exertion responses*

### Invisible Mental Exertions

Invisible mental exertion is presented clearly in Fig. 5.5. The research questions demonstrate the invisible mental exertion through activities required to operate a CT from three dimensions, which are MRQ1-MRQ3, as stated above. For working in an understaffed environment, 14 (24.6%) technicians responded with “strongly agree.” “Agree” constituted 19 (33.3%) responses. “Neutral”

constituted 20 (35.1%) responses. “Disagree” constituted 4 (7%) responses. For suitability of the number of CT machines, 22 (38.6%) technicians responded with “strongly agree.” “Agree” constituted 18 (31.6%) responses. “Neutral” constituted 7 (12.3%) responses. “Disagree” constituted 8 (14%) responses. “Strongly disagree” constituted 2 (3.5%) responses. For management alignment with existing resources, 14 (24.6%) technicians responded with “strongly agree.” “Agree” constituted 19 (33.3%) responses. “Neutral” constituted 14 (24.6%) responses. “Disagree” constituted 10 (17.5%) responses.



*Fig. 5.5: Mental exertion responses*

## Demographic Characteristics: Physical and Mental

### *Gender:*

Figure 5.6 shows the proportion of difference between male and female respondents. For the physical exertion statement in PRQ1, 62.1% of male technicians indicated that they always contribute physically by transferring the bedridden patient to the CT table, in contrast to only 39.3% of female technicians. Interestingly, 3.6% of female technicians stated that they never helped or contributed to transferring the bedridden patients to the CT table. In response to PRQ2, 89.7% of male technicians indicated that they have always prepared the exam room for the next patient, as opposed to 60.7% of female technicians. In response to PRQ3, 79.3% of male technicians indicated that they always prepared the contrast media for the next patient, in contrast to 53.6% of female technicians. Interestingly, 7.2% of female technicians responded with “never” or “rarely.”

In response to mental exertion statements, in MRQ1, 34.5% of male technicians indicated that they work in an understaffed environment, as opposed to only 14.3% of female technicians. In response to MRQ2, 48.3% of male technicians indicated that the department needs more CT scanners to accommodate the patient overload, compared to 28.6% of female technicians. In response to MRQ3, 27.6% of male technicians indicated that management targets are not aligned with existing resources, compared with 21.4% of female technicians.



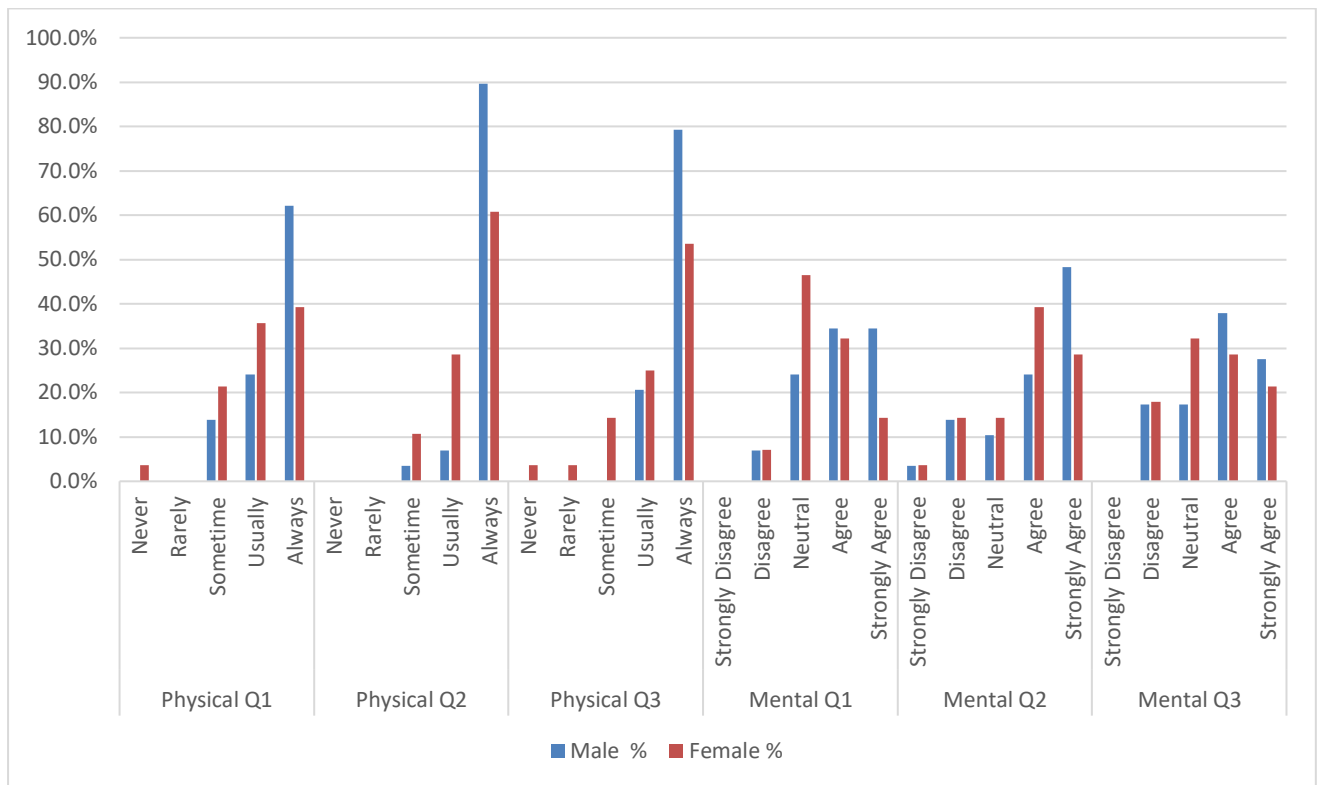


Fig. 5.6: Physical and mental exertion respond based on gender

### Age

Age is a fundamental factor in determining physical and mental exertion. Figure 5.7 shows the proportion of difference between age groups from 20 to 29, 30 to 39, 40 to 49, and over 50. In response to the physical exertion statement in PRQ1, 43.2% of the 20 to 29 age group indicated they always contribute physically to transferring the bedridden patients to the CT table. Similarly, 66.7% of the 30 to 39 age group indicated that they always contribute physically, whereas all of the 40 to 49 and over 50 age groups indicated that they always contribute physically. In response to PRQ2, 75% of the 20 to 29 age group responded with “always” for preparing the examination room for the next patient, compared to 66.7% of the 30 to 39 age group. Both the 40 to 49 and over 50 age groups stated that they always prepare the examination room for the next patient. In response to PRQ3, 63.6% of the 20 to 29 age group reported that they prepare and administrate

the media contrast for the next patient, compared to 77.8% of the 30 to 39 age group, 50% of the 40 to 49 age group, and 100% of the over 50 age group.

In response to the statements regarding mental exertion, in MRQ1, 20.5% of the 20 to 29 age group strongly agree that they work in an understaffed environment in comparison with 33.3% of the 30 to 39 age group, 50% of the 40 to 49 age group, and 50% of the over 50 age group. In response to MRQ2, 38.6% of the 20 to 29 age group reported that they strongly agree that they work in the Radiology Department with fewer CT scans in operation, in contrast to 33.3% of the 30 to 39 age group and 50% of both the 40 to 49 and over 50 age groups. In response to MRQ3, 20.5% of the 20 to 29 age group reported that the management targets are not aligned with the existing resources, in comparison to 33.3% of the 30 to 39 age group and 50% of both the 40 to 49 and over 50 age groups.

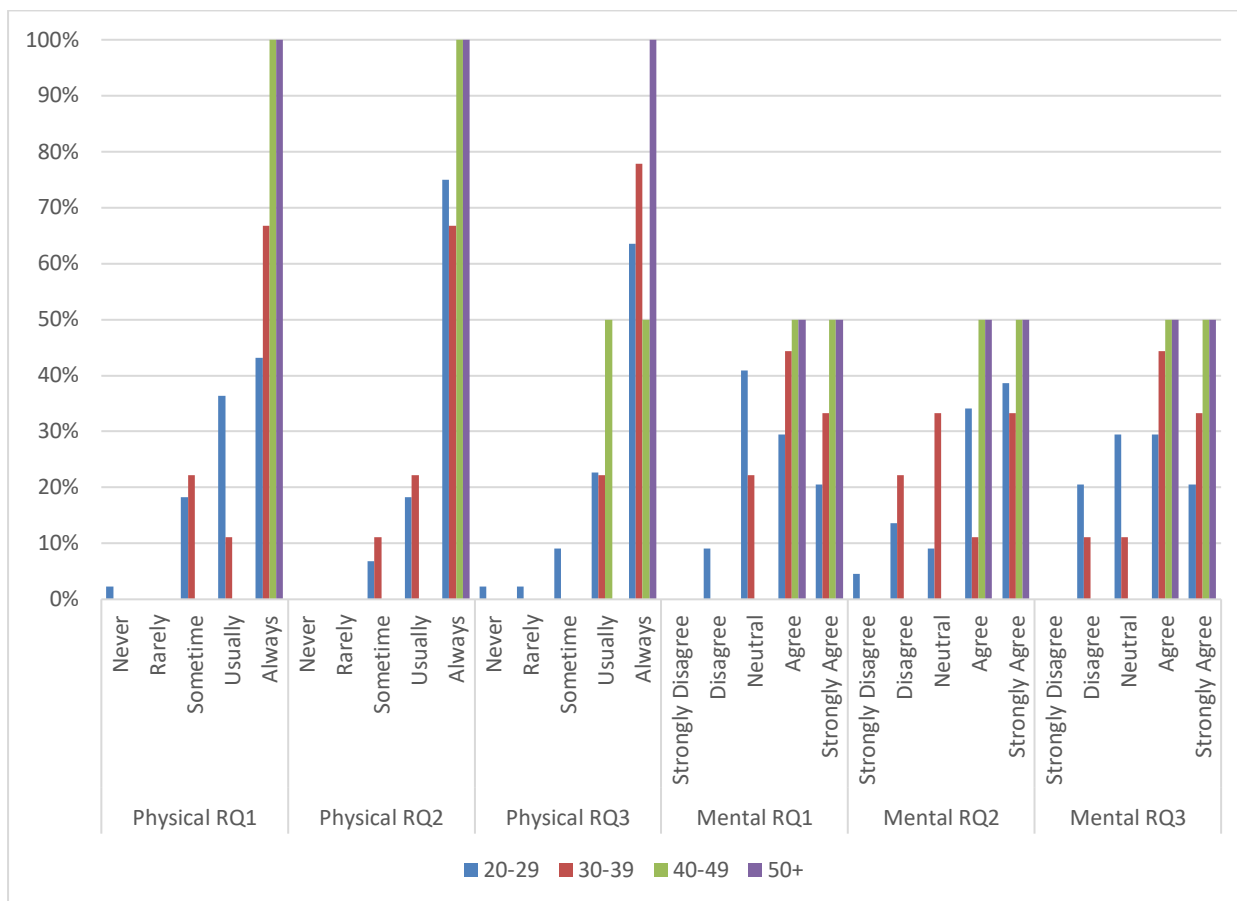


Fig. 5.7: Physical and mental exertion response based on age

### Years of radiology experience

Years of experience is a dominant factor in determining the invisible physical and mental exertion. Figure 5.8 shows the proportion of difference between 0 to 3 years, 4 to 7 years, 8 to 11 years, and more than 12 years. In response to the physical exertion statement in PRQ1, 46.2% of those with 0 to 3 years of experience reported that they always contribute physically to transferring bedridden patients to the CT table, in comparison to 20% of those with 4 to 7 years of experience, 66.7% of those with 8 to 11 years of experience, and 85.7% of those with more than 12 years of experience. In response to PRQ2, 74.4% of those with 0 to 3 years of experience reported that they always prepare the examination room for the next patient, in contrast to 80% of those with 4 to 7 years of experience, 66.7% of those with 8 to 11 years of experience, and 85.7% of those with more than

12 years of experience. In response to PRQ3, 61.5% of those with 0 to 3 years of experience reported that they prepare and administrate the media contrast for the next patient, in comparison to 80% of those with 4 to 7 years of experience, 66.7% of those 8 to 11 years of experience, and 85.7% of those with more than 12 years of experience.

In response to the mental exertion statement in MRQ1, 17.9% of those with 0 to 3 years of experience reported that they strongly agreed that they work in an under- staffed environment in contrast to 40% of those with 4 to 7 years of experience, 33.3% of those with 8 to 11 years of experience, and 42.9% of those with more than 12 years of experience. In response to MRQ2, 41% of those with 0 to 3 years of experience reported that they strongly agree that they work in a Radiology Department with fewer CT scans in operation, compared to 20% of those with 4 to 7 years of experience, 50% of those with 8 to 11 years of experience, and 28.6% of those with more than 12 years of experience. In response to MRQ3, 23.1% of those with 0 to 3 years of experience reported that the management targets are not aligned with existing resources, in contrast to 33.3% of those with 8 to 11 years of experience and 42.9% of those with more than 12 years of experience.

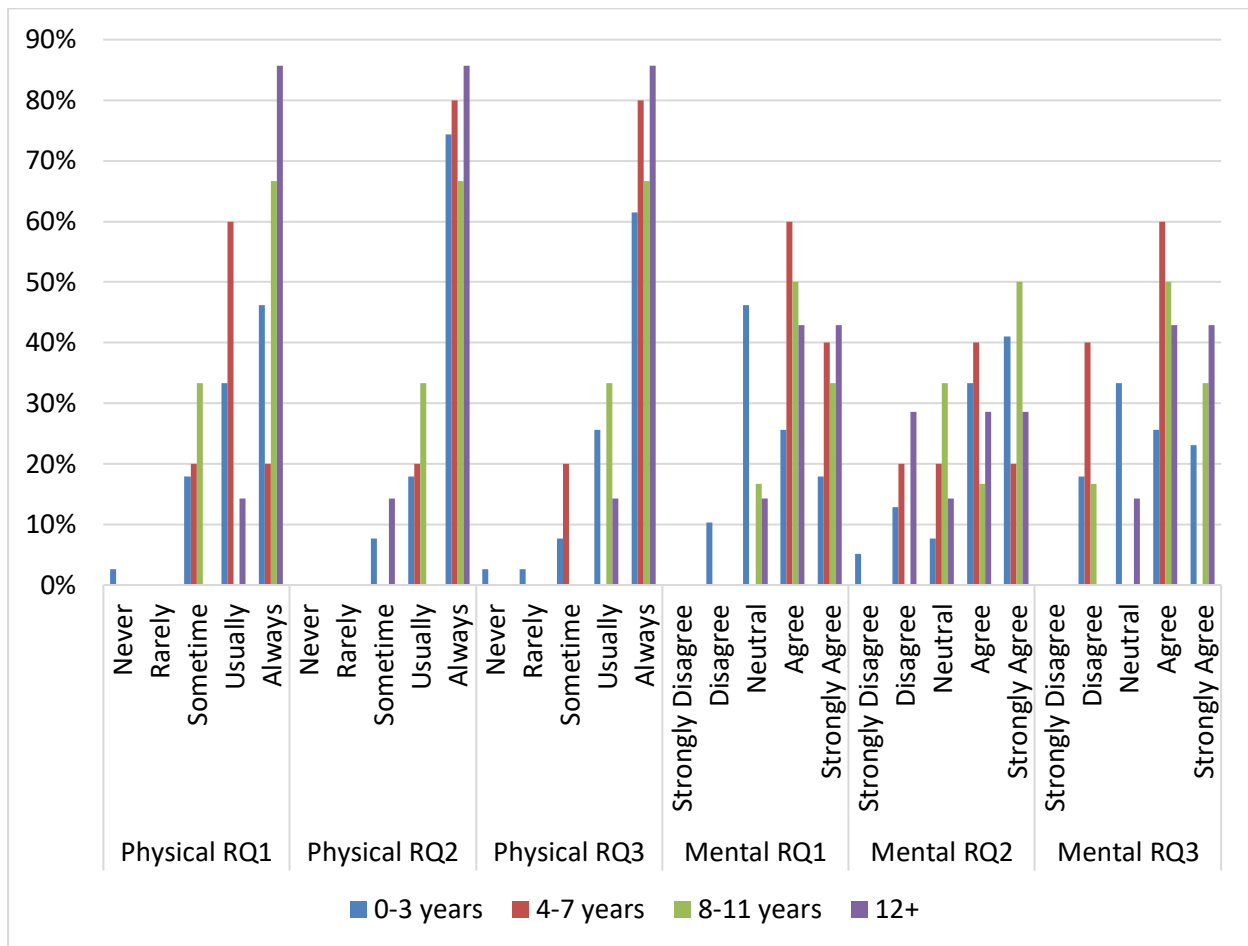


Fig. 5.8: Physical and mental exertion response based on years of experience

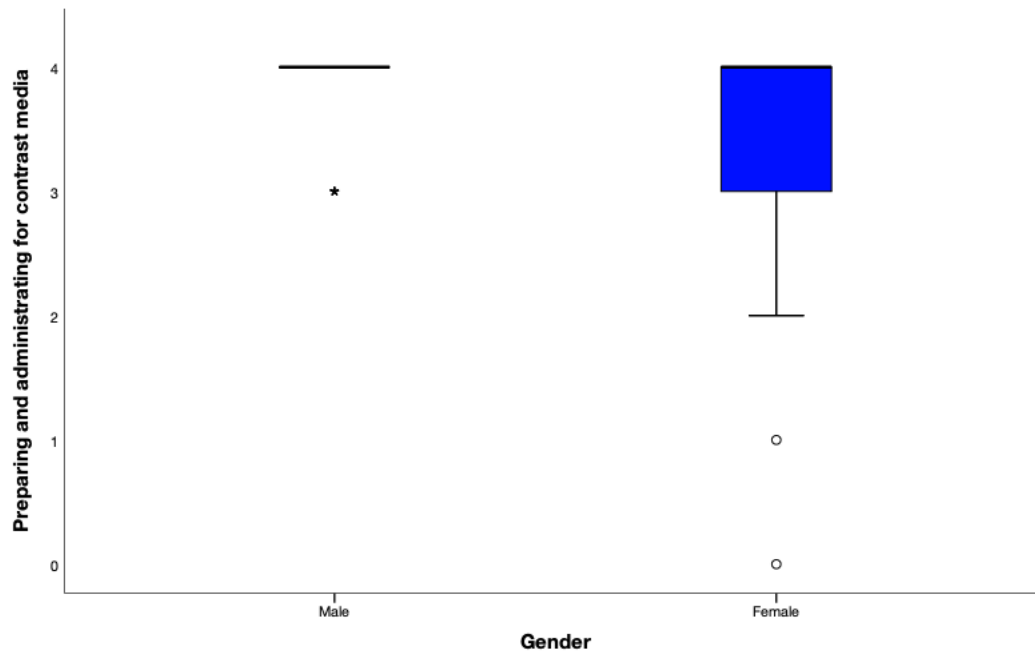
## Differences in Demographic Variables

### Gender

#### Invisible Physical Exertion

Male respondents (Mdn = 25.46) did not appear to differ from female (Mdn = 32.41) in the amount of transferring bedridden patients from a hospital bed onto a CT table ( $U = 307$ ). However, males (Mdn = 24.84) did significantly differ from females (Mdn = 33.02) in preparing the examination room for the next patient ( $U = 289.5$ ,  $z = -2.47$ ,  $p = 0.013$ ). Males (Mdn = 24.62) also significantly differed from females (Mdn = 33.22) in preparing and administering the contrast media for

patients ( $U = 283.5$ ,  $z = -2.35$ ,  $p = 0.019$ ). Figure 5.9 and 5.10 provide box plots for these differing variables.



*Fig. 5.9: Gender difference in preparing and administering the contrast media.*

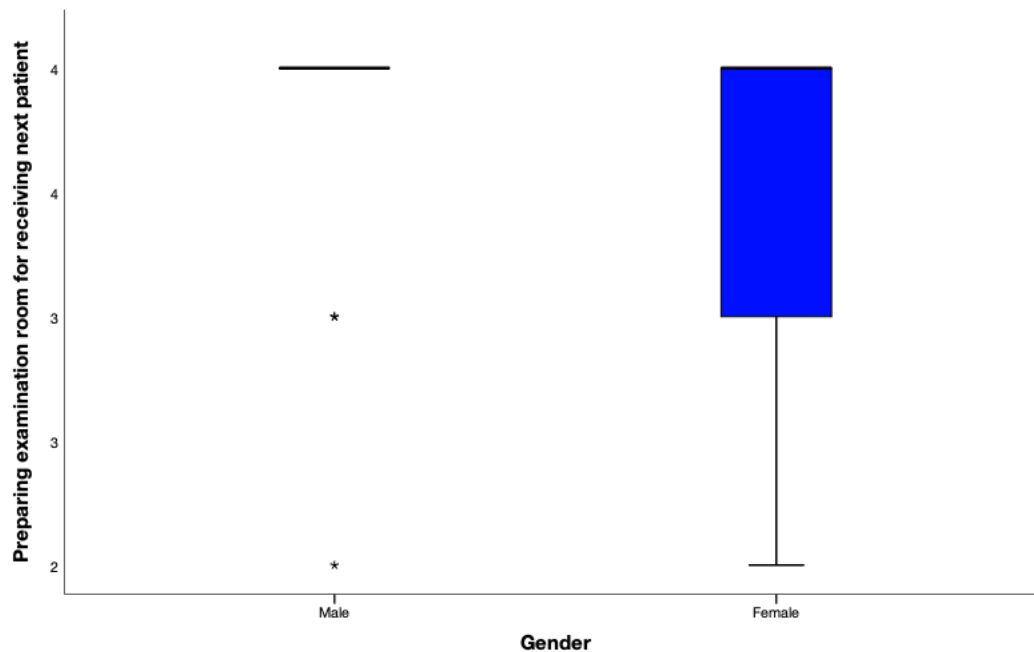


Fig. 5.10: Gender difference in preparing the exam room for the next patient.

#### Invisible Mental Exertion:

A Mann Whitney test shows no difference between the males and females across all invisible mental variables.

#### Age

A Kruskal-Wallis test evaluated differences across the in- visible physical and mental variables, and no significant differences were identified based on age groups

#### Level of Education

A Kruskal-Wallis test evaluated differences between three educational levels (diploma, bachelor's, and master's) regarding the participants helping transfer bedridden patients from a hospital bed onto the CT table. The test was significant  $H(2, N = 57) = 7.91, p = .01$ .

Follow-up tests were performed to examine pairwise differences among these education group to control for type I errors using the Bonferroni approach. The results of these tests indicate a significant difference between bachelor's and master's degrees as illustrated in Figure 5.10.

Additionally, the other invisible physical and mental variables do not appear to differ based on the level of education.

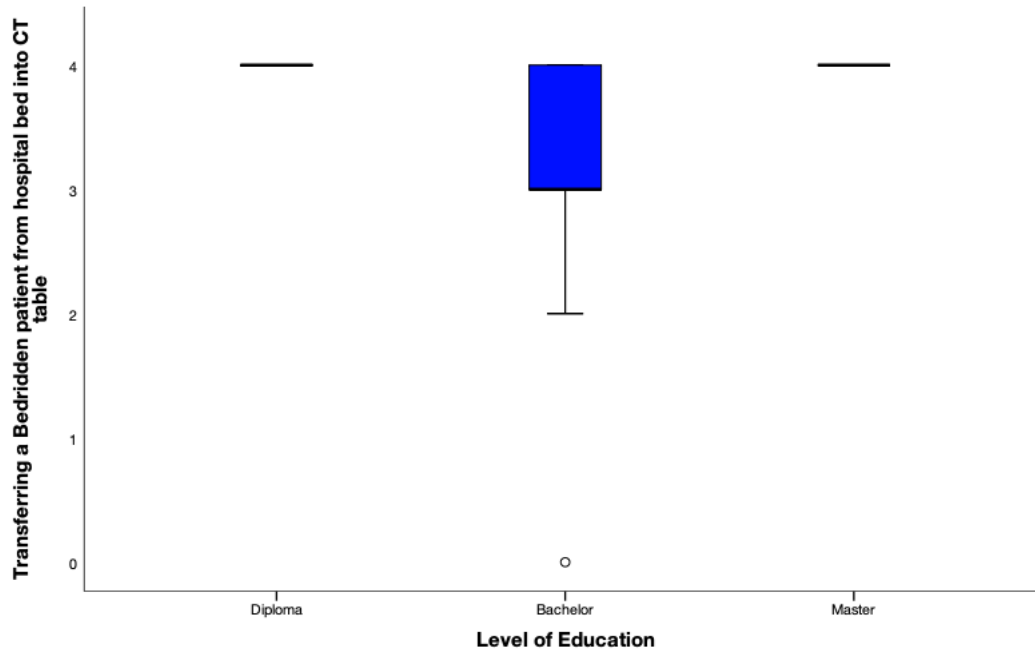


Fig. 5.10: The differences based on the level of education.

### Years of Experience

A Kruskal-Wallis test was conducted to evaluate the difference between the groups with similar years of experience (0 to 3, 4 to 7, 8 to 11 years, and more than 12 years) on working in an understaffed environment. The test resulted in a significant  $H(3, N = 57) = 9.23, p = .02$ .

Follow-up tests were performed to examine the pairwise differences among these groups to control for type I errors across the tests using the Bonferroni approach. The results of these tests indicate significant differences between the 0 to 3 and 4 to 7 years groups and between the 0 to 3 years and more than 12 years groups as are illustrated in Figure 5.11.

Additional tests were conducted on the other invisible physical and mental variables with no differences identified.



Additional tests also were conducted on all invisible physical and mental variables and no differences were found.

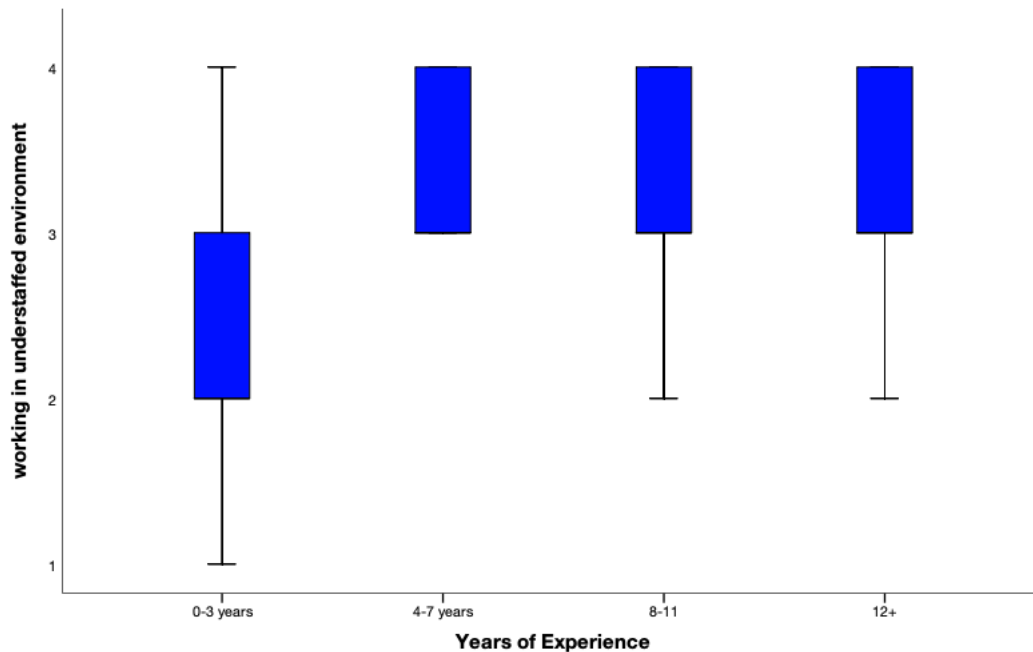


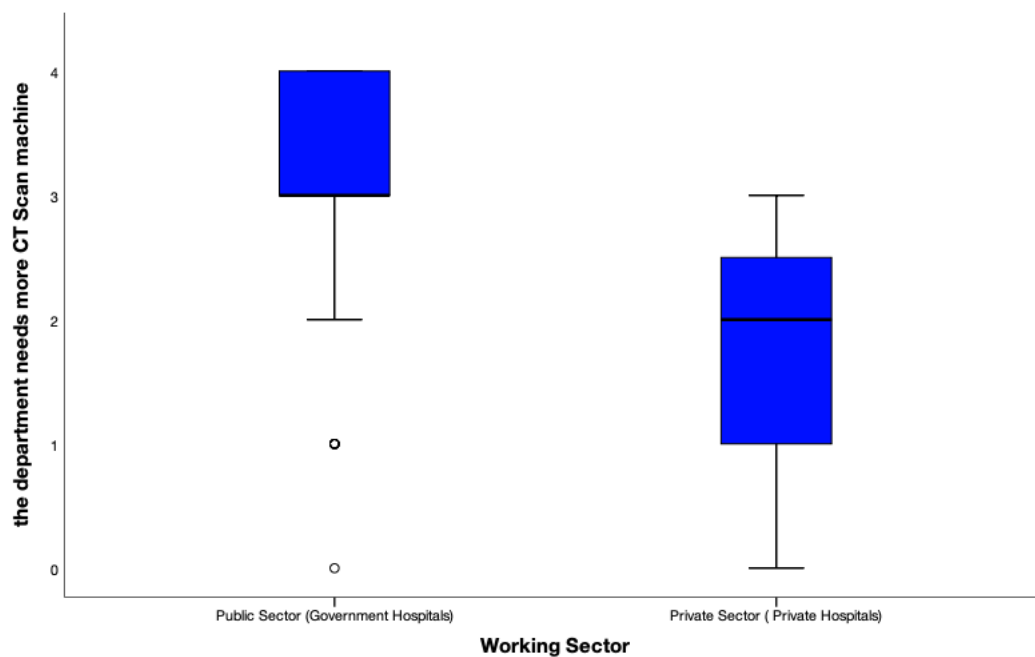
Fig. 5.11: Differences based on years of experience.

### Working Sector

The public sector technicians (Mdn = 31.15) appeared to differ from the private sector (Mdn = 13.64) in the response to the department needs more CT scan machines ( $U = 67.5$ ,  $z = -2.7$ ,  $p = .007$ ) as is illustrated in Figure 5.12.

Additional tests were conducted on the other invisible physical and mental variables with no differences found.

Additional tests also were conducted on all invisible physical and mental variables and no differences were found.



*Fig. 5.12: Differences based on working sector.*

## CONCLUSION

Radiology practices are impacted by many challenges that eventually require more exertion on the operators. The current standards in practice are categorized to drive for more efficiency in terms of consuming resources as they try to maximize productivity and optimization. Many requirements have been added to the processes of radiology, such as safety and ethics, to compromise a minimum for industry best practice. These requirements now reflect on the working load of the technicians and add complexity to the overall process. This study identifies this additional exertion that affects the technician as is experienced through invisible exertion.

Generally, the findings suggest that there is indeed invisible physical and mental exertion associated with the operation of CT scans. Regarding the agreement rate in response to the

physical statement in PRQ1, 80.7% of radiologists confirmed that they commonly transfer bedridden patients to the CT table. Therefore, manufacturers should pay extra attention when designing the machine because meeting the technical requirements is not enough for delivering a suitable machine that meets all work environment requirements. It is fundamentally ideal if the manufacturing standards cover customization that meets the lowest end-user specifications. Fundamentally, patients are the core reason for the existence of the machine. Therefore, empowerment of the patient's current condition during the exam is highly sought after by many patients, especially during the movement of bedridden patients from and to the CT table. The current CT scan machine on the market lacks the basic habilitation capability that is needed to empower those who are bedridden. The agreement rate in response to the physical statement in PRQ2 indicates that 93% of radiologists confirmed that they frequently prepare the examination room for each patient. Moreover, the agreement rate in response to the physical exertion statement in PRQ3, 89.5% of the radiologists confirmed that they frequently prepare and administrate the contrast media to patients. The findings imply that invisible physical exertion occurs more than invisible mental exertion. The agreement is 57.9% for the mental exertion statement in MRQ1, 70.2% for MRQ2, and 57.9% for MRQ3. Two-thirds of radiologists agree with the mental exertion statement. Nonetheless, they almost consensually agree with the invisible physical exertion general statements. As future work, the authors intend to propose a human-centered system engineering model to integrate usability and exertions at the very beginning of the design flow.

# Factors contributing to CT scan usability

## INTRODUCTION

When evaluating many of today's machines and devices, their usefulness is decidedly determined by their usability. Capitalizing on merely technology execution is myopic. Rather, it must be accompanied by an effective and flourishing user experience. This notion ought to satisfy the execution of tasks with efficiency and effectiveness. Usability is not a monolithic concept. This expression is evidently demonstrated by the definition of usability. Dubey and Rana (2010) found that a variety of usability definitions produced 152 attributes. Nonetheless, usability is vitally important in healthcare because it can offer unparalleled benefits, such as minimized medical errors and utilized times and speeds. Meanwhile, Fairbanks and Caplan (2004) found that current medical devices are profoundly vulnerable to serious human error due to lack of usability, and Peute et al. (2008) postulated that in general, usability in healthcare is ambiguously structured and lacks quality. The primary reason for this is that usability in health-care overemphasizes safety (Aldoihi, Hammami, 2018). Determining the usability of a system is dependent on the parameters the system intended is to serve. Consequently, verifying and identifying the context of use is vitally critical for system acceptance and smoothness. Vincent and Blandford 2017 argued that inadequate usability design is recurrently cited in medical devices incidents. Usability success is exceedingly dependable on the end user's manners and preferences (Ramli et al. 2019).

The context of use is determined by the internal and external environment in which the system is used. Maguire (2001) stated that context of use is utterly significant; even when writing a postcard, the writer typically begins by describing the weather or the outside atmosphere. Principally, the context of use refers to the specific conditions under which the system would be used. These

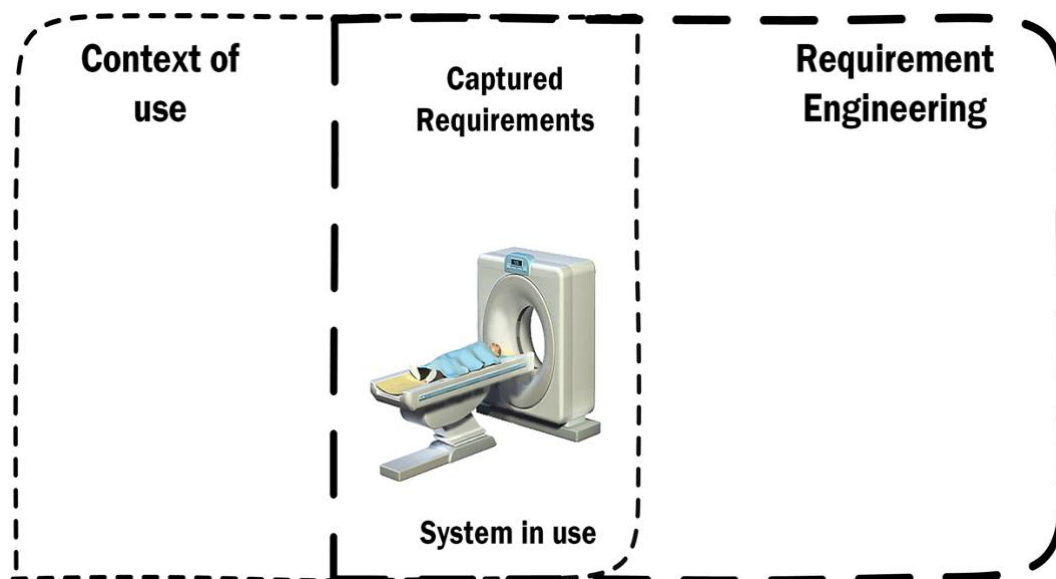
conditions can be straightforwardly expressed by attributes. For instance, a fast-food kiosk describes the general attributes of the user, which are hungry, determined by speed, and specifically chosen from among many lines of product. In other words, it is counterintuitive to measure the success of a system separate from its context of use.

## ROLE OF TECHNOLOGY

Since the introduction of technology, people have perceived it as an enabler attribute. In healthcare, the primary use of technology is to minimize risk and capitalize on safety (Peute et al. 2013). Hospitals are using technology to record and store data from the daily operation process with the purpose of optimizing the user and patient experiences (Cortes and Cortes, 2011). Conceptually, hospitals use technology for their critical core operations. Working in the healthcare environment renders a person enormously receptive to physical and mental extortions, and it is extremely governed by industry requirements and guidelines. Consequently, technology plays an important role in minimizing risks and preventing errors (Aldoihi, Hammami, 2020). The foremost beneficial attributes of technology are as follows:

- Increased productivity
- Increased patient intake
- Increased comfort
- Maximized job accuracy
- Minimized time and costs

Requirement engineering is responsible for capturing context of use requirements. However, context of use varies based on environments and fits of purpose. Eventually, there will be a gap between the context of use and the captured requirement, and the primary role of requirement engineering is to reduce the gap, as shown in Figure 6.1.



*Fig. 6.1: Captured Requirement Engineering*

## METHOD

### Subjects

All CT scan technicians and radiologists whose daily functions to operate the device are invited to participate in this study. In qualitative sampling, large sampling is excessively deemed unnecessary (Holloway and Galvin, 2016). The purpose of the qualitative approach is to investigate a phenomenon in-depth and in length. Hence, Qualitative research usually takes excessive time and very a few samplings (Mir and Jain, 2017). Consequently, the target population is considerably less than that in the Quantitive method.

The participants consist of 11 CT scan technicians and one radiology doctor. They came from hospitals across Saudi Arabia. There were 10 male and two female participants. The participants belong to four age groups. Three participants range from 20 to 29 years old, fives from 30 to 39 years old, three from 40 to 49 years old, and one is over 50 years old. See Table 6.1 for demographic details.

TABLE 6.1: Demographic Characteristic

ID	Gender	Age	Educational level	Radiology Years of Experience
Participant 1	Male	20 - 29	Bachelor	0 - 3 years
Participant 2	Male	30 - 39	Bachelor	12+ years
Participant 3	Male	20 - 29	Bachelor	0 - 3 years
Participant 4	Male	30 - 39	Bachelor	12+ years
Participant 5	Male	30 - 39	Master	4 - 7 years
Participant 6	Male	30 - 39	diploma	12+ years
Participant 7	Male	50+	Diploma	12+ years
Participant 8	Male	20 - 29	Bachelor	0 - 3 years
Participant 9	Male	30 - 39	Bachelor	12+ years
Participant 10	Female	40 - 49	Master	8 - 11 years
Participant 11	Male	40 - 49	Bachelor	12+ years
Participant 12	Female	40 - 49	Bachelor	8 - 11 years

### Questionnaire design

Designing an adequate questionnaire is a critical part of the research process. Evocative and reminiscent responses from the participant can be drawn only if the questionnaire structured competently. Important aspects that need to be taken into consideration are the reliability and validity of the sought information. Planing (2014) presents a comprehensive rule for creating effective questions, and these are:

- Keep the language simple
- Keep the questions short
- Avoid double-barreled questions
- Avoid leading questions

- Ensure that question wording means the same thing

Therefore, the self-administrated questionnaire was developed to meet rigorously the research's objectives. All items were formulated after evaluating the field sites and considering the results from the earlier quantitative studies (Chapter 4 and Chapter 5). In human-machine interaction, the users can be used to formulate the questions (Dey et al. 2009). Accordingly, the questions were formulated to explore the factors contributing to the product usability of the CT scan. Completing the questionnaire required time between 15 to 45 (depend on the experience and knowledge depth of the participant).

#### Reliability and Validity:

The concept of reliability and validity is a critical factor for the success of the research. Thus, Reliability and validity must be applied to the research to ensure that data and findings are evocative. In this study, internal review, feedback, and recommendation were received by the supervisor of this research and Radiologist consultant to ensure the feasibility and practicability of the questionnaire items. In terms of reliability, the questionnaire was dispersed to five CT scan technicians. Therefore, the participants demonstrated a respectable and good understanding of the questions.

#### Data Collection and Analysis

A qualitative approach was used to collect the data for this study. Interviews were utilized to achieve the objective of the study. After conducting the interviews, they were transcribed and translated to constitute the first step of qualitative content analysis. The translations were verified by a certified translator and by the academic supervisor who is well acquainted with the Arabic language. Then, the data were analyzed using the qualitative data analysis software Nvivo 12.



After identifying and classifying the theme, it was given to the supervisor and external reviewer for feedbacks and reviews. See Fig. 6.2 for thematic proportion.



Fig. 6.2: thematic proportion

Saudi Arabia’s CT scan market is dominated by three brands. These brand names have been blinded into brand A, brand B, and brand C. Therefore, any referral to brand functionalities or features will be indicated as brand A, brand B, and brand C.

## RESULTS

All participants agree that usability is tremendously crucial to CT scanning. It benefits patients and hospitals alike. Hospital benefits include reduced appointments, increased productivity, and

greater optimization of time and cost, while patient benefits include increased safety, reduced radiation, and increased comfort.

Also, many hospitals do not recognize the value of usability. among these hospitals, 3 hospitals recognized the significance of usability, and they somehow have Usability tracking procedures. no matter how small or simple the system is. it could be as a registry on notebook See Fig. 6.3.

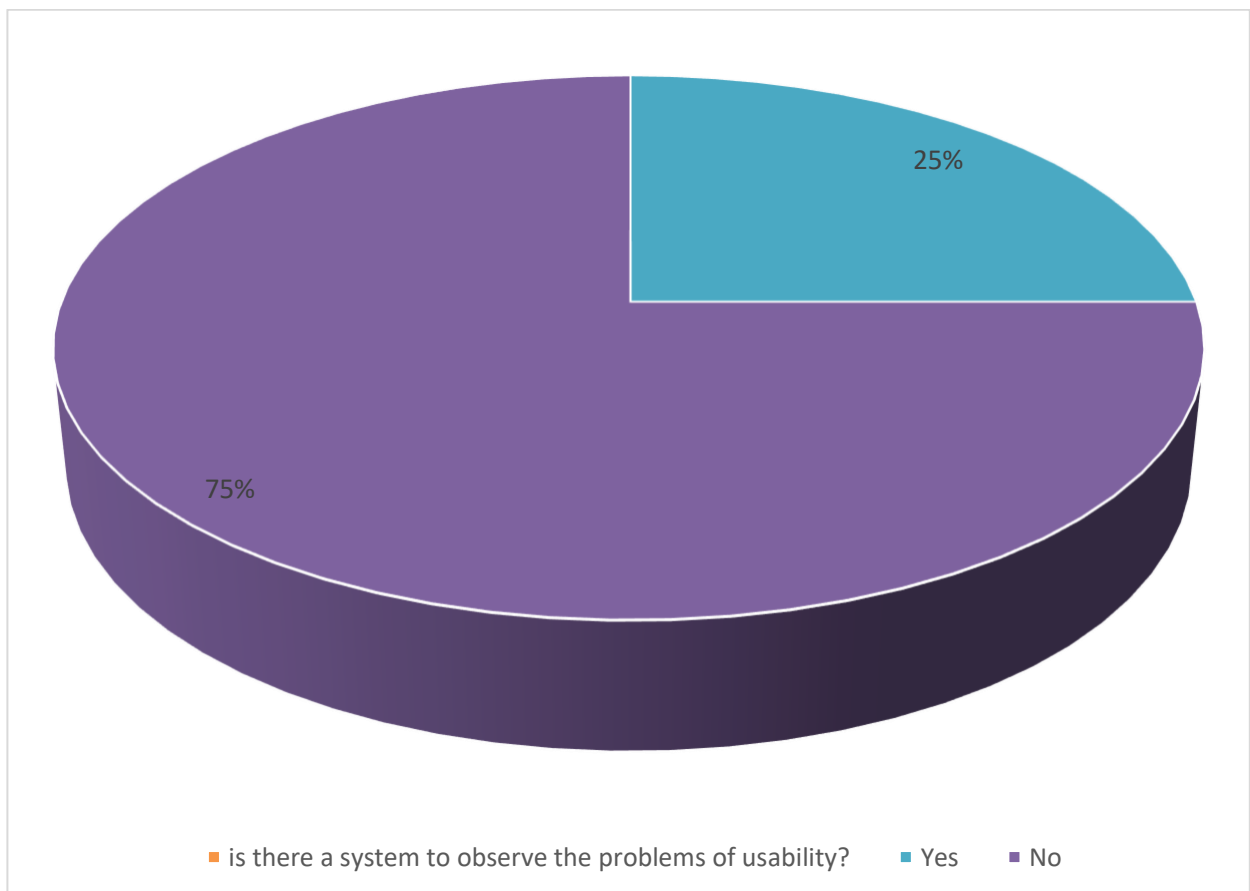


Fig 6.3: Usability system inside Hospitals

*“When the device is easy to use, we can finish examining the patient in a short time. The patient does not feel anxious or afraid during the examination.”*

*Participant 7*

*“Usability affects the speed of scanning and saves time.” Participant 8*

The thematic analysis of the content produces 22 usability attributes (see Table 6.2). The most referenced attributes are Information communicativeness (14 references) and Context of use (13 references). One major reference theme was the technician’s ability to control the table from the control room. Some brands still lack this system functionality.

TABLE 6.2: Produced Attributes

attributes	number of coding references	number of sources
Context of use	13	7
easiness	1	1
effectiveness	4	4
efficiency	3	2
efficient to use	1	1
Error prevention	2	2
functionally correct	2	1
helpfulness	2	2
Image Quality	4	3
Information communicativeness	14	5
Learnability	5	3
Operability	4	3
productivity	4	3
safety	3	3
speed of performance	4	4
Standardization	6	3
system functions	8	3
system performance	2	2
training	7	3
usableness	2	1
usefulness	6	4
user satisfaction	1	1

## Information communicativeness

Information communicativeness comprises the information received from the system, such as icons, system alerts, sound alerts, and language communication. These communications can tremendously ease operation of the system.

*“I think that icons should have detailed instructions, so we are able to know what it does before clicking it. This will improve the usability of the device to a great extent. This is because even people with little information will be able to use the device in such a case. When using the device for the first time, I faced a problem like this, and I was obligated to call another employee to help me understand what these icons meant....” Participant 1*

Another crucial factor related to information communicativeness is audial commands, which direct the patient to take, hold, and release breath during the exam. This attribute is vital to both the technicians and the patients. The CT scan system has audial commands for the patient (for chest examination).

*The device has more than 15 languages: Hindi, Bengali, Turkish, and Russian.*

*I have nearly more than 15 languages on the system. I choose a suitable language for the patient and the device speaks it. Participant 7*

*“One time, we had a patient who only spoke Hindi, and we had to do a chest exam. Hindi exists on the device, but we had to activate it for the first time that day. Participant 8*

*“I know these devices have the ability to give audial instructions in English and Arabic. This is what I know and have experienced. The audial instructions directed to the patients by the device are in the Arabic and English languages. The Brand A device allows me to insert my personal audial instructions. On the contrary, the Brand C device does not have this option as you choose the language of audial instructions, and it takes over the rest of the task. The Brand A device allows me to my personal audial instructions by recording my own voice; I can illustrate the instruction or summarize it as I want. On the contrary, the Brand C device doesn't allow this, as it speaks to the patient according to how it is programmed.” Participant 10*

Despite the technological development to include many languages, some patients found their languages were left out.

*“There was a Somali patient; he did not speak Arabic or French and his father accompanied him. His father spoke English. During the exam, the patient had to take a breath, suppress the breath, and release the breath in precise time. The problem is that he did not speak English or Arabic, so we found ourselves obligated to make his father, who can speak English, wear*

*lead protection and enter the scanning room with him. We were speaking in the speaker from the control room and his father translated sentences, including 'take a breath, suppress the breath, and release the breath.'"*

*Participant 3*

### Context of use

It compromises many activities that affect the operational process, such as movement during the exam and overweight patients. The primary concern in this category is overweight patient, as many CT scan tables jam due to patient weight.

*"Unfortunately, movement during the exam can definitely ruin the quality of the image. We have repeated cases like these, especially when dealing with children. Because of their repeated movement, you may be obligated to retake the image once again." Participant 7*

*"I found myself obligated to tell the patient that he/she is overweight and as a result, the table will not move." Participant 2*

*"We have trouble with overweight patients, as mainly the table does not move quickly." Participant 1*

### Image quality

It can be affected by many attributes. As stated above, movement is a major contributing factor, but movement is categorized within the context of use, as technicians need to deal with it as an

operational context. When conducting an exam, it is observed that contrast dye leaks and eventually it affects the quality of the image.

*“Sometimes a small proportion of the dye seeps inside the device. Eventually, this may affect image quality, as the device in such a case may produce incorrect images. Consequently, the technician may need to retake images more than once.” Participant 9*

*“Regardless of the image quality, we have a general policy to avoid retaking images as much as possible.” Participant 2*

*“There is no doubt that it is crucial that we rely on Axiology, as it has an important effect; if the image is clear, we can diagnose the case and if the image isn't clear, we can't diagnose the case. . . . If we are able to conclude a diagnosis, this will help the patient, as if we are able to conclude a diagnosis, the doctor will be able to as well. We can help the patient any way, but if things aren't clear and we can't conduct a diagnosis, then the scan can be considered useless and in such a case the patient is most affected by this.”*

*Participant 5*

*“The system gives audial instructions for the patients, like take a breath, suppress the breath, and release the breath. In the case of ‘take a breath,’ the device takes about a minute before taking an image so the lunge may fill with air. Some patients cannot suppress a breath for more than a minute, as originally, he/she is a patient. As a result, when the device takes the image, it takes the image when the breath is being released. This is the cause of taking an incorrect image. The point is that the orders from the system take a long time before taking the image. This affects the image greatly, as we re-examine the patient many times. This accordingly raises the radical dose for the patient.” Participant 3*

## CONCLUSION

Requirement engineering is utterly critical to enhanced usability and the user experience. As evidently shown in this study, when users cannot utilize the final product to suit the context of use, they tend to modify the product in accordance with their context of use requirement. As observed in one case, the radiology department installed a camera in the exam room because when the patient performs the exam, the patient became invisible from the control room. Therefore, improving patient visibility is crucial for safety reasons.

One extremely vital theme of this study is the audial command. It directs patients to follow an important exam protocol. Unfortunately, there are cases where the patient neither knows the local language (Arabic) nor other languages that already exist within the system. Audial commands can tremendously affect the safety of the patients and their immediate family members. In one particular case, a father was obligated to stay in the room to translate the audial orders for his ill



son as a result of the unavailability of the language the patient speaks. Consequently, CT scanner manufacturers need to pay special attention to extremely diverse markets, such as the Gulf Cooperation Council (GCC) countries.

In essence, system engineering plays an important role in the context of use. The need to model a system in which the operational context of use is collected, stored, and analyzed is essential. The author's future work aim is to model an engineering system for capturing operational data for the purpose of implementing a more intelligent business model so certain activities can be improved.

# CONCLUSION

Increasingly, usability becomes a critical component of every product. Several studies have reported the significance of incorporating usability into the final product or service. Among such visible significance is increasing in user's acceptance, safety, user satisfaction, and user productivity. Usability evaluations and methods are extensive and diverse, and the reason for that is the context of use. Usability has been applied to a variety of products and systems across different industries. Thus, the context of use has been widened and so is usability attributes. ISO standards recognize the context of use effect on usability. Consequently, ISO definition has been recognized in academia as vague and ambiguous. To design a product or system, it is utterly essential to identify the system's context of use and built the usability attribute to suit the specified context.

This research aimed to investigate CT scan usability based on its context of use. First, it evaluated the usability of a CT scan based on 14 attributes. These attributes are specifically deemed important to the healthcare context of use (Zheng et al. 2003). Additionally, it adds NASA-TLX evaluation to identify the associated workload, as many researchers recognize the fact that there is tremendous pressure on healthcare worldwide. This research developed and deployed additional research measures to identify invisible physical and mental exertion. Also, it investigates the contributing factors from a system engineering perspective.

## Connectivity with current condition

In December 2019, a cluster of patients showed up at a local hospital in Wuhan, Hubei province, with severe pneumonia-like symptoms. Most of the patients reported either they work or live near

the local Huanan seafood wholesale market (Chen, 2020). The symptoms were later named Corona Virus 2019 (COVID 19) by the World Health Organization WHO. At the time of writing this thesis, COVID 19 has infected over 5 million and caused over 330,000 death. The patients are spread in over 215 countries, territories, Areas (WHO). As a new and a novel virus, testing methods have been developed and tested for accuracy. As of now (the time of writing this thesis), real-time polymerase chain reaction (RT-PCR) is considered the most effective and accurate method. However, many studies have emerged and suggested that a CT scans is more reliable methods. Fang et al. (2020) tested 51 patients. 15 out of 51 patients with negative RT-PCR and positive CT scans at initial presentation (RT\_PCR became positive between 1 and 7 days later). 35 out of 51 patients with positive CT scan at initial presentation and positive RT-PCR. Several studies have popped up (Da Zhuang et al. 2020)(Huang et al. 2020) to describe the radiology department under this extreme condition, and it remains to re-evaluate over scanning (Schwartz et al. 2018), effective doses (Sulieman et al. 2018) and medical errors when data will be available (Zhao et al. 2020) (Algaissi et al. 2020) and how it will impact the evolution of CT scan and its user interface (Parlangeli et al. 2018).

## Future Direction

Although this research has demonstrated its significance, it is far from the “final word” on product usability. There is a venue that would be considered for further research, particularly regarding those areas that fell outside the scope of the research.

One significant topic that fell outside the research is usability through system modeling. The researcher recognizes the significance of this venue. Thus, future studies will continue to venture through this path. A future study will model a system that can be integrated into a CT scan by making the use of product data usage. Such a system would be integratable to existing business

intelligence (BI) system to form Large data where the analytic of operation ground can be used to prevent error. For instance, if a CT scan technician asked to scan a patient, certain parameters will be recorded such as the patient name, the doctor who ordered the scan, type of examination, technician id, etc. Supposedly, the patient has been asked to undertake an examination, and the system finds duplicate parameters. The system would send a memo to the human resource department to suggest a training session to the technician who performs the examination.

Another future study will examine the natural voice command that embedded into the CT scan system. Many of today's CT scan systems have natural voice commands designed to direct the patient to follow the procedure of certain examinations. Such a procedure includes asking the patient to take a breath, hold breath, and release the breath. The study will examine these commands and track the patient's understandability of such commands.

#### Link of future work with other domains

Enhancement in science and technology demanded a new approach to handle complexity and compatibility. Thus, many domains emerge to boost compatibility and reduce complexity. Such domains include Human-computer interaction (HCI), activity recognition, and process modification. Due to safety emphasis in the healthcare and aviation industry, the use of usability is rapidly gained momentum. The studies of HCI have been used in healthcare to enhance human productivity and reduce complexities.

The results obtained in this work demonstrate that the CT scan procedure cannot be considered as a deterministic and fixed time task. This cannot be ignored in the general theoretical well-known hospital scheduling problem which is NP-Hard. This runs counter to most hospital scheduling techniques (Erhard et al. 2018) (Schoenfelder et al. 2020) (Marynissen & Demeulemeester, 2019)

(Lan et al. 2019) (Burdett & Kozan, 2018). Although some techniques have taken into account the nature of stochastic medical resources for the dynamic configuration scheduling problem (Huang et al. 2018), or a fuzzy programming approach for the multi-objective patient appointment scheduling problem under uncertainty in a large hospital (Moreno & Blanco, 2018). only one work has addressed work schedule flexibility associated with emotional exhaustion (Dhaini et al. 2018): a case study among registered nurses in Swiss hospitals.

In order to take into account, the results achieved in this Ph.D. scheduling should take into account a CT scan technicians' profile database as well as a CT scan equipment profiles database as described in figure 7.1.

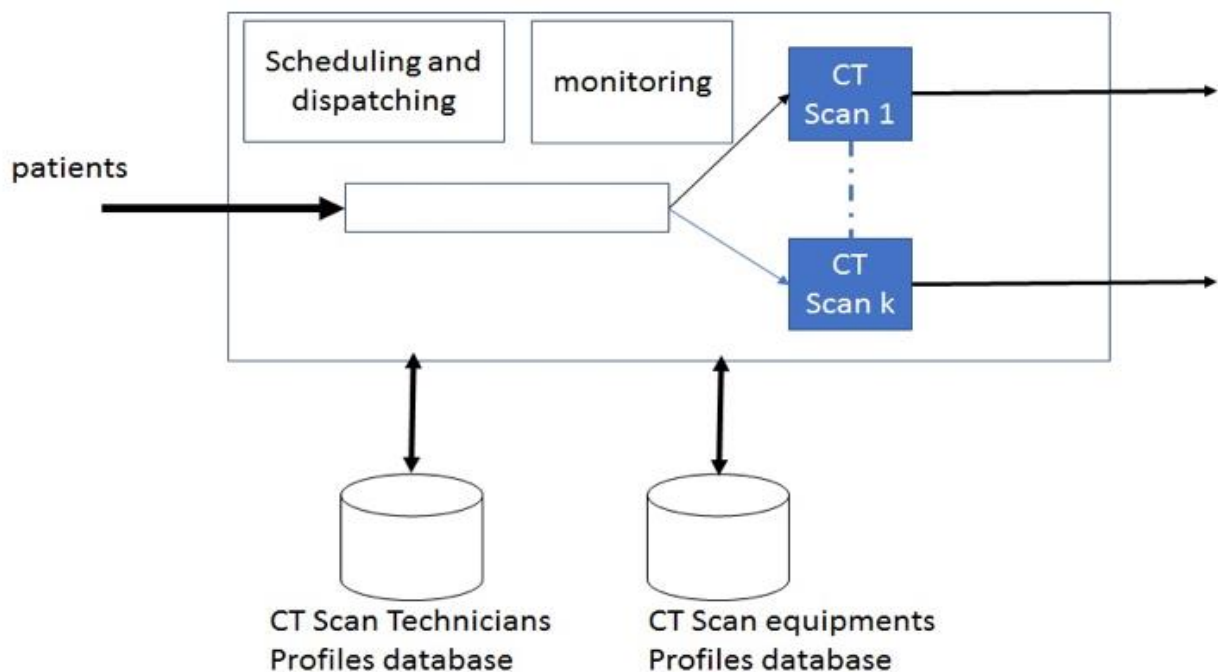


Fig. 7.1: Product Usability /technician CT Scan Dynamic Scheduling

These profiles would be continuously enhanced through user behavior monitoring and taken into account for customized scheduling matching CT scan equipment profile. AI techniques with

machine learning could be added for forecasting technicians' fatigue (Pimenta et al. 2016) and at the same time contribute to more precise scheduling. This approach of customizing at the user level goes beyond the early explorative optimization proposed in (Oulasvirta et al. 2017).

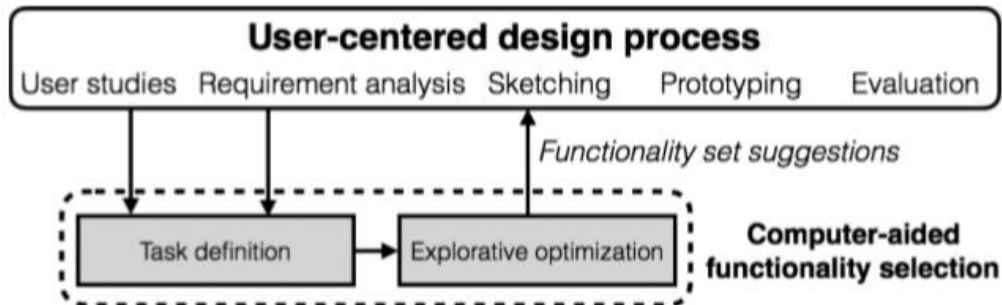


Fig. 7.2: Static optimization of User interface

In the sense that customization is a continuous process. The CT Scan procedure could also gain by being formalized through BPMN modeling in phase with existing work on Framework for Evaluating Usability of Business Process Models with BPMN in Health Sector (Rolón et al. 2015) and BPMN approach in Healthcare and Case Study of End-User Interaction with EHR Interface (Gomes et al. 2018). The objective is to formally verify procedures taking into account human factors impact.

Major domains that have vast benefit when used with CT scan is the use of automated procedures, Intelligent process modification, and robotic assistance. For instance, as presented by Avellino et al. (2019) the use of Telemanipulation in Robotic-Assisted Surgery can be equally adopted by CT scan operating especially in a time where COVID 19 is changing the role of human interaction with an infected patient. CT scan examination can be conducted remotely and with minimal interaction with the patient. In addition, the use of data to proactively improve operational procedures (Ltifi et al. 2020). CT scan machines should use the product data usage data to actively evaluate the safety of the patient and constant evaluation of the users. For instance, if a technician

repeatedly exposes patients to extra-Radiological dose, a training request should be self-generated from the machine to the human resource department requesting a Radiological dose protocol training for that technician. This approach is called Context-Aware Systems (Cherfia, Belala & Barkaoui, 2014). Also, the Recommender System (RS) has tremendous value when introduced to CT scan operation. Zammali, Arour & Bouzeghoub (2015) have introduced a new context feature and selection method where it can be adopted to CT scan operation with immense benefits. CT scan has many operators inside a hospital, so when context feature and selection method applied, CT scan can feature and introduce the most-used short-cut to enable the technician to fast forward most of his/her examination procedures.

Another major direction is to adopt the system engineering view to CT scan product usability issues. The following figure 7.3 describes part of the strategy to model in Human-centered approach product usability.

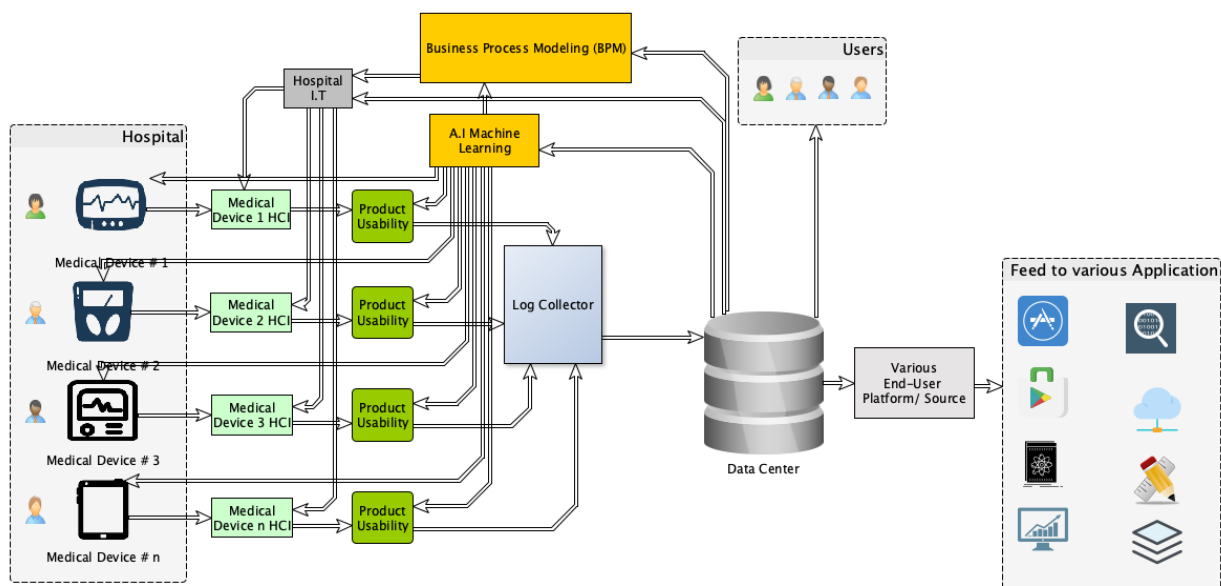


Fig. 7.3: System overview

In this regard, we plan to integrate the ontology in the general process of support of product usability (Yang et al. 2019).

Finally, CT Scan is expensive and with long product cycle life equipment. The landscape of these equipments in a country like Saudi Arabia is heterogeneous with brand new equipments and older equipments. This remains true for most countries worldwide. This study has worked in the context of this realistic heterogeneity and has not focused exclusively on new generation equipments or on future generation equipments. The results achieved advocates for the integration of HCI factors in the PLM (Product Lifecycle Management) of CT Scan equipments with upgrades driven by human factors and product usability.



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# Appendices

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## Appendix 1 Ministry of Health approval



المملكة العربية السعودية  
وزارة الصحة  
الإدارة العامة للبحوث والدراسات

الموضوع: بحث الطالب/سعد الضويحي.

المحترم **سعادة / مدير الإدارة العامة للأشعة والخدمات التطبيقية**

السلام عليكم ورحمة الله وبركاته، ، ، ،

إشارة إلى موضوع الطالب / سعد عبدالله محمد الضويحي، المبتعث من مدينة الملك عبد العزيز للعلوم والتقنية لدراسة درجة الدكتوراه في تخصص ( Computer and System Engineering ) بكلية الهندسة جامعة باريس ساكلاي بفرنسا، رقم السجل المدني (١٠٠٢١٤٩٨٢٨) وعنوان الرسالة:

### "Product Usability Driven System Engineering"

نحيطكم علماً بأن الطالب قد إستوفى كافة المستندات المطلوبة وتمت مراجعتها من قبل اللجان المعنية بالإدارة العامة للبحوث والدراسات ولجنة الأخلاقيات بمدينة الملك فهد الطبية بوزارة الصحة، وتمت الموافقة على تسهيل مهمة إجراء هذا البحث، وحيث أن المذكور عاليه سينفذ جزء من دراسته في الإدارة العامة للأشعة والخدمات التطبيقية بوزارة الصحة.

وعليه، نأمل من سعادتكم التفضل بالإطلاع والإيعاز لمن يلزم بتسهيل مهمته بعد موافقة الجهات المختصة لديكم، لجمع البيانات اللازمة بما يضمن أن لا يكون هناك أي تأثير على خدمة المراجعين خلال قيامه بمهام بحثه، مع العلم بأن وزارة الصحة تضمن حقوقها في نتائج هذا البحث من خلال إتفاقية المشاركة في البيانات والتي تم توقيعها بين الباحث والإدارة العامة للبحوث والدراسات.

وتفضلوا بقبول خالص تحياتي ، ، ،

مرفق مستندات وملخص المقترح البحثي، ، ، ،

مساعد مدير عام الإدارة العامة للبحوث والدراسات

ص. عذارى فيصل العتيبي

هاتف: ٠١١٤٧٣٥٠٣٩

فاكس: ٠١١٤٧٣٥٠٣٨

ص.ب الرياض: ٢٧٧٥

الرمز البريدي: ١١١٧٦

e-mail: research@moh.gov.sa

## Appendix 2 KSMC Approval



المملكة العربية السعودية  
وزارة الصحة  
الإدارة العامة للبحوث والدراسات

الموضوع: بحث الطالب/سعد الضويحي.

المحترم  
ص. لسعادة / مدير مركز الأبحاث بمدينة الملك سعود الطبية  
المحترم  
ص. لسعادة / رئيس لجنة الأخلاقيات بمدينة الملك سعود الطبية  
السلام عليكم ورحمة الله وبركاته، ، ، ،

إشارة إلى موضوع الطالب / سعد عبدالله محمد الضويحي، المبتعث من مدينة الملك عبد العزيز للعلوم والتقنية لدراسة درجة الدكتوراه في تخصص ( Computer and System Engineering ) بكلية الهندسة جامعة باريس ساكلاي بفرنسا، رقم السجل المدني (١٠٠٢١٤٩٨٢٨) وعنوان الرسالة:

### "Product Usability Driven System Engineering"

نحيطكم علماً بأن الطالب قد إستوفى كافة المستندات المطلوبة وتمت مراجعتها من قبل اللجان المعنية بالإدارة العامة للبحوث والدراسات ولجنة الأخلاقيات بمدينة الملك فهد الطبية بوزارة الصحة، وتمت الموافقة على تسهيل مهمة إجراء هذا البحث، وحيث أن المذكور عاليه سينفذ جزء من دراسته في قسم الأشعة بمدينة الملك سعود الطبية بالرياض.

وعليه، نأمل من سعادتكم التفضل بالإطلاع والإيعاز لمن يلزم بتسهيل مهمته بعد موافقة الجهات المختصة لديكم، لجمع البيانات اللازمة بما يضمن أن لا يكون هناك أي تأثير على خدمة المراجعين خلال قيامه بمهام بحثه، مع العلم بأن وزارة الصحة تضمن حقوقها في نتائج هذا البحث من خلال إتفاقية المشاركة في البيانات والتي تم توقيعها بين الباحث والإدارة العامة للبحوث والدراسات.

وتفضلوا بقبول خالص تحياتي ، ، ،

مرفق مستندات وملخص المقترح البحثي، ، ، ،

مساعد مدير عام الإدارة العامة للبحوث والدراسات

ص. عذاري فيصل العتيبي

هاتف: ٠١١٤٧٣٥٠٣٩

فاكس: ٠١١٤٧٣٥٠٣٨

ص.ب الرياض: ٢٧٧٥

الرمز البريدي: ١١١٧٦

e-mail: research@moh.gov.sa

## Appendix 3 KFMC Approval



المملكة العربية السعودية  
وزارة الصحة  
الإدارة العامة للبحوث والدراسات

الموضوع: بحث الطالب/سعد الضويحي.

المحترم  
ص. لسعادة/ رئيس لجنة الأخلاقيات بمدينة الملك فهد الطبية  
السلام عليكم ورحمة الله وبركاته، ، ، ،

إشارة إلى موضوع الطالب / سعد عبدالله محمد الضويحي، المبتعث من مدينة الملك عبد العزيز للعلوم والتقنية لدراسة درجة الدكتوراه في تخصص ( Computer and System Engineering ) بكلية الهندسة جامعة باريس ساكلاي بفرنسا، رقم السجل المدني (١٠٠٢١٤٩٨٢٨) وعنوان الرسالة:

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نحيطكم علماً بأن الطالب قد إستوفى كافة المستندات المطلوبة وتمت مراجعتها من قبل اللجان المعنية بالإدارة العامة للبحوث والدراسات ولجنة الأخلاقيات بمدينة الملك فهد الطبية بوزارة الصحة، وتمت الموافقة على تسهيل مهمة إجراء هذا البحث، وحيث أن المذكور عاليه سينفذ جزء من دراسته في قسم الأشعة بمدينة الملك فهد الطبية بالرياض.

وعليه، نأمل من سعادتكم التفضل بالإطلاع والإيعاز لمن يلزم بتسهيل مهمته بعد موافقة الجهات المختصة لديكم، لجمع البيانات اللازمة بما يضمن أن لا يكون هناك أي تأثير على خدمة المراجعين خلال قيامه بمهام بحثه، مع العلم بأن وزارة الصحة تضمن حقوقها في نتائج هذا البحث من خلال إتفاقية المشاركة في البيانات والتي تم توقيعها بين الباحث والإدارة العامة للبحوث والدراسات.

وتفضلوا بقبول خالص تحياتي ، ، ،

مرفق مستندات وملخص المقترح البحثي، ، ، ،

مساعد مدير عام الإدارة العامة للبحوث والدراسات

ص. عذارى فيصل العتيبي

هاتف: ٠١١٤٧٣٥٠٣٩

فاكس: ٠١١٤٧٣٥٠٣٨

ص.ب الرياض: ٢٧٧٥

الرمز البريدي: ١١١٧٦

e-mail: research@moh.gov.sa

## Appendix 4 King Fahad Medical City Research Ethic Committee approval

Kingdom of Saudi Arabia  
Ministry of Health  
King Fahad Medical City  
(162)



المملكة العربية السعودية  
وزارة الصحة  
مدينة الملك فهد الطبية  
(١٦٢)

IRB Registration Number with KACST, KSA: H-01-R-012  
IRB Registration Number with OHRP/NIH, USA: IRB00010471  
Approval Number Federal Wide Assurance NIH, USA: FWA00018774

June 14, 2017  
IRB Log Number: 17-217E  
Department: External  
Category of Approval: EXEMPT

Dear Saad Aldoihi,

I am pleased to inform you that your submission dated June 12, 2017 for the study titled '**Product Usability Driven System Engineering**' was reviewed and was approved. Please note that this approval is from the research ethics perspective only. You will still need to get permission from the head of department or unit in KFMC or an external institution to commence data collection.

We wish you well as you proceed with the study and request you to keep the IRB informed of the progress on a regular basis, using the IRB log number shown above.

Please be advised that regulations require that you submit a progress report on your research every 6 months. You are also required to submit any manuscript resulting from this research for approval by IRB before submission to journals for publication.

As a researcher you are required to have current and valid certification on protection human research subjects that can be obtained by taking a short online course at the US NIH site or the Saudi NCBE site followed by a multiple choice test. Please submit your current and valid certificate for our records. Failure to submit this certificate shall a reason for suspension of your research project.

If you have any further questions feel free to contact me.

Sincerely yours,

**Prof. Omar H. Kasule**  
Chairman, Institutional Review Board (IRB)  
King Fahad Medical City, Riyadh, KSA  
Tel: + 966 1 288 9999 Ext. 26913  
E-mail: okasule@kfmc.med.sa



## Appendix 5 KFMC Requirement (Email)



### IRB Log No. 17-217E

Dear Saad Aldoihi,

Greetings!

Attached herewith is the approval letter for the study titled '**Product Usability Driven System Engineering**'.

As a researcher you are required to have current and valid certification on protection human research subjects that can be obtained (<https://phrp.nihtraining.com/users/login.php>) or the Saudi NCBE site followed by a multiple choice test. Please submit your **this certificate shall a reason for suspension of your research project.** (*Note: Please ignore this if you have already submitted*)

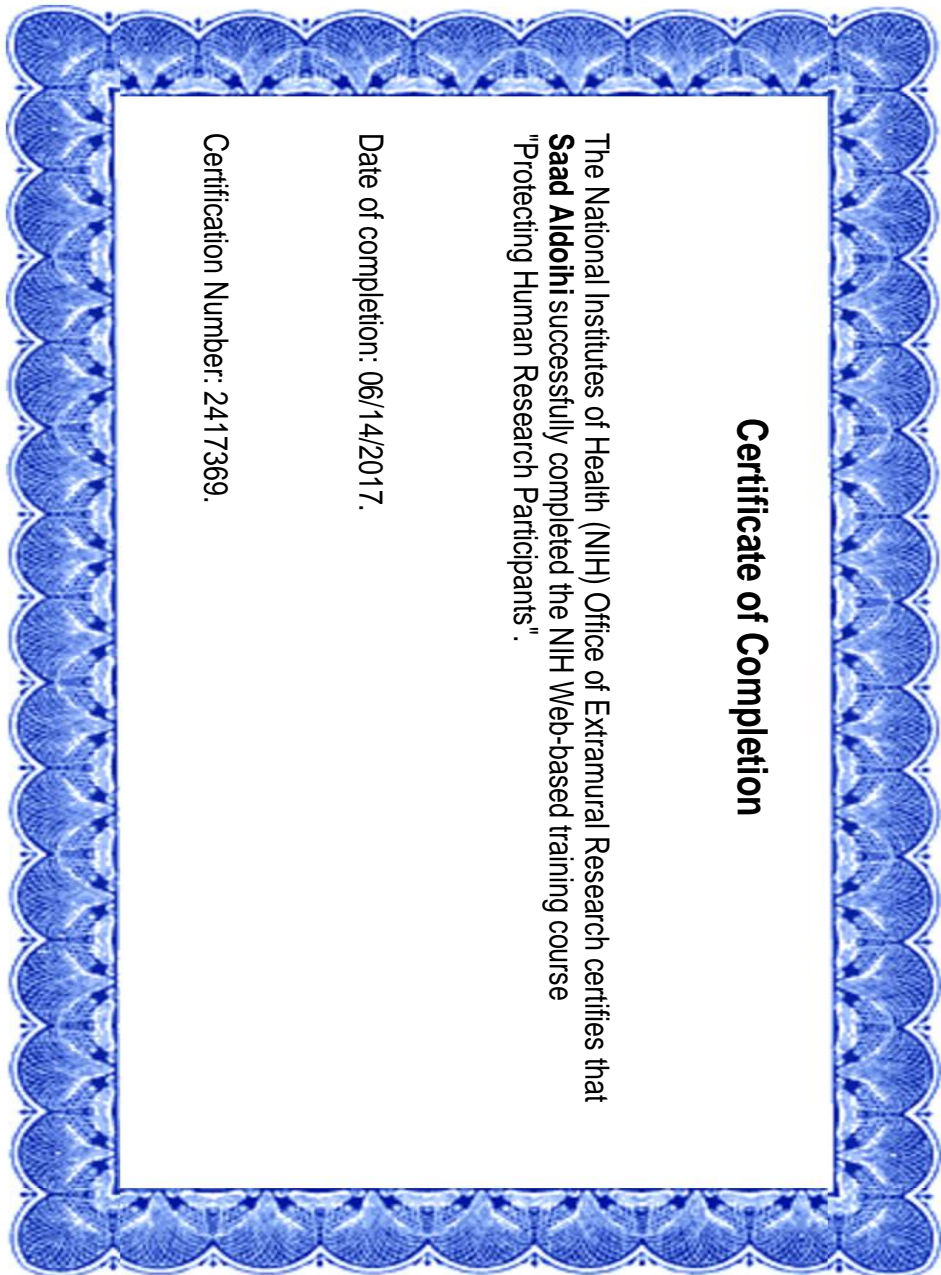
The original stamped copy is available in our office located at the 1st Floor of the Faculty of Medicine.

Thank you.

**Respectfully yours,**  
**Ms. Cecile S. Arce**  
Secretary, Institutional Review Board  
King Fahad Medical City  
✉ [irb1@kfmc.med.sa](mailto:irb1@kfmc.med.sa)  
☎ (011) 288-9999, ext. 26943

*for and on behalf of:*  
**Prof. Omar Hasan Kasule Sr.**  
**Chairman, Institutional Review Board**  
King Fahad Medical City  
✉ [okasule@kfmc.med.sa](mailto:okasule@kfmc.med.sa)  
☎ (011) 288-9999, ext. 26913 / 18304





## Consent Form

(Please read and sign this form)

Thank you for agreeing to participate in this study. The study is granted official approval from Ministry of Health after fulfilling the requirement of Radiology Department, and Research and Study Department. The aim of this study is to evaluate CT-scan usability factors from user experience perspective. You are encouraged to share your experience and thoughts freely. As study requirement, it is necessary to record the conversation for further analysis in later part of the study. Please keep in mind that the recorded data is highly confidential and will be used only for the purpose of this study alone. The data is strictly follow the University of Paris Saclay's data protection policy. Please remember that your participation is fully voluntary, and you can withdraw at any given time. The data will be destroyed after the purpose of this study is fulfilled.

Please fill the information bellow if you wish to participate in this study.

Participant Name

\_\_\_\_\_

Signature of Participant

\_\_\_\_\_

Date

\_\_\_ / \_\_\_ /2017

Contact Details:

Researcher :

Saad AlDoihi

[Saad.aldoihi@ensta-paristech.fr](mailto:Saad.aldoihi@ensta-paristech.fr)

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Supervisor:

Omar Hammami

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+33 (0) 181 87 2033

## Appendix 8 closed-ended questionnaire

4/18/2020

Usability of Radiology Questionnaire

### Usability of Radiology Questionnaire

My name is Saad Aldoihi, and I am a PhD student at Univeristy of Paris Saclay. Research will be a part of Saad Aldoihi's doctoral degree. The questionnaires aim to identify the major radiology Usability issues in Saudi Arabian Hospitals. It seeks to grasp radiology staff feedback about radiology Devices performance.

Your participation in this study will allow me to identify your perspective on Usability of radiology Devices performance. Also, it would be quite helpful to understand what aspects of device that you have concern on.

The collected responses will be strictly confidential and data from this research will be reported anonymously. Your answers are highly valuable to us.

If you have a question, Please contact the research team.

Professor Omar Hammami  
Chef du groupe Ingenierie Système  
Unité d'Informatique et Ingénierie des Systèmes - Groupe de Recherche Ingenierie Système  
Tel : +33 1 81 87 20 33  
[Omar.Hammami@ensta-paristech.fr](mailto:Omar.Hammami@ensta-paristech.fr)

Saad Aldoihi  
Cell: +33 68257545 , or +966 533331798  
[saad.aldoihi@ensta-paristech.fr](mailto:saad.aldoihi@ensta-paristech.fr)

\* Required

#### Consent Form

Thank you for agreeing to participate in this study. The study is granted official approval from Ministry of Health after fulfilling the requirement of Radiology Department, and Research and Study Department. The aim of this study is to identify usability issues associated with CT scan based on 14 usability attributes. You are encouraged to share your experience and thoughts freely. As study requirement, it is necessary to store the data for further analysis in later part of the study.

Please keep in mind that the stored data is highly confidential and will be used only for the purpose of this study alone. The data is strictly follow the university of Paris Saclay's data protection policy. Please remember that your participation is fully voluntary, and you can withdraw at any given time. The data will be destroyed after the purpose of this study is fulfilled.

Please tick Agree bellow if you wish to participate in this study.

#### 1. I agree to Participate on this Study

*Check all that apply.*

Agree

[https://docs.google.com/forms/d/1Jy4aNz2M1MS\\_jaq9\\_j4JgSwM3eY\\_Bo\\_myzROwYtYUko/edit](https://docs.google.com/forms/d/1Jy4aNz2M1MS_jaq9_j4JgSwM3eY_Bo_myzROwYtYUko/edit)

1/19



**Terminology:**

ISO defines usability as "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" (ISO, 1998), and user experience as "a person's perceptions and responses that result from the use or anticipated use of a product, system or service" (ISO, 2010). In McGraw-Hill Concise Encyclopedia of Science and Technology specifies: "A concept in product design, sometimes referred to as ease of use or user-friendliness, that is related directly to the quality of the product and indirectly to the productivity of the work force" (McGraw-Hill, 2006)

Please note that this study does NOT test you or your ability, rather this study tests the usability of CT-Scan. In addition, Please note that the device and the system used interchangeably where it means the system of the device.

**مصطلحات:**

الاستفادة من الجهاز وإمكانياته بسهولة على اكمل وجه بدون مصاعب مباشرة او غير مباشرة (Usability) نقصد بـ

فمثلا: يأتي مريض سمين فلا يستطيع عمل الفحص له لأن الطاولة صغيرة او لا تتحمل الأوزان الزائده

مثال آخر : طريقة ادخال البيانات تأخذ وقت طوله ومعقده

مثال : في الرنين المغناطيسي الجهاز المغلق يجعل المريض يرفض الفحص

بـ " مدى استخدام المنتج من قبل مستخدمين محددين لتحقيق أهداف محددة مع الفعالية والكفاءة والرضا في سياق محدد من الاستخدام" (الايزو، Usability الايزو تعرف (١٩٩٨). وتجربة المستخدم بـ" تصورات وردود الشخص التي تنتج عن استخدام او توقعات استخدام إزاء استخدام منتج او خدمة محددة"(الايزو، ٢٠١٠). ماكجرو هيل عرفها بـ" مفهوم في تصميم المنتجات، ويشار إليها أحيانا بسهولة الاستخدام أو القابلية المبسطة للاستخدام، التي ترتبط مباشرة إلى جودة المنتج وبشكل غير مباشر إلى إنتاجية قوة العمل

تعتبران the device و the system امل الاخذ بالاعتبار ان هذا البحث لا يعتبر قياس ولا اختبار للمستخدم بل هو اختبار للجهاز وسهولة استخدامه. بالإضافة، ان كلمة متقارنتان لنفس المعنى

**2. Gender \***

Mark only one oval.

Male

Female

**3. Nationality \***

Mark only one oval.

Saudi

Other: \_\_\_\_\_

**4. Age \***

Mark only one oval.

20-29

30-39

40-49

50+

## 5. Educational level \*

Mark only one oval.

- Diploma
- Bachelor
- Master
- PhD +

## 6. Radiology Years of Experience \*

Mark only one oval.

- 0 - 3 years
- 4 - 7 years
- 8 - 11 years
- 12+ years

## 7. What is your Radiology Title

Mark only one oval.

- Technician
- Technician Specialist
- Senior Technician Specialist
- Consultant Technician
- Registrar
- Senior Registrar
- Consultant

## 8. What is your primary CT-Scan brand usage? \*

Mark only one oval.

- GE
- Philips
- Siemens
- Other: \_\_\_\_\_

## Consistency

Consistency and standards. Users should not have to wonder whether different words, situations, or actions mean the same thing. Standards and conventions in product design should be followed.

### Rating Scales

- 0, not a usability problem at all;  
 1, cosmetic problem only. Need not be fixed unless extra time is available;  
 2, minor usability problem. Fixing this should be given low priority;  
 3, major usability problem. Important to fix. Should be given high priority;  
 4, usability catastrophe. Imperative to fix this before product can be released.

9. Are Sequences of actions consistent? (are they tailored to skills acquisition) \*

*Mark only one oval.*

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

10. Are categorizations labeled by colors? \*

*Mark only one oval.*

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

11. Are Layout and position consistent? \*

*Mark only one oval.*

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

12. Are Font and capitalization consistent across display? \*

*Mark only one oval.*

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

13. Are Terminology (delete, del, remove, rm) and language (words, phrases) reflective to reality? \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

14. Are Standards (e.g., blue underlined text for unvisited hyperlinks) positioned? \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

### Visibility

Visibility of system state. Users should be informed about what is going on with the system through appropriate feedback and display of information.

### Rating Scales

- 0, not a usability problem at all;  
 1, cosmetic problem only. Need not be fixed unless extra time is available;  
 2, minor usability problem. Fixing this should be given low priority;  
 3, major usability problem. Important to fix. Should be given high priority;  
 4, usability catastrophe. Imperative to fix this before product can be released.

15. Does the display show What is the current state of the system? \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

16. Does the display show What can be done at current state? \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

17. Does the display show Where you can go? \*

Mark only one oval.

	0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

18. Does the display show What change is made after an action? \*

Mark only one oval.

	0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

### Match

Match between system and world. The image of the system perceived by users should match the model the users have about the system.

### Rating Scales

- 0, not a usability problem at all;
- 1, cosmetic problem only. Need not be fixed unless extra time is available;
- 2, minor usability problem. Fixing this should be given low priority;
- 3, major usability problem. Important to fix. Should be given high priority;
- 4, usability catastrophe. Imperative to fix this before product can be released.

19. Does system image match User model? \*

Mark only one oval.

	0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

20. Does Actions realized by the system match actions performed by users? (what you do is what you get) \*

Mark only one oval.

	0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

21. Does Objects on the system match objects of the task? \*

Mark only one oval.

0	1	2	3	4	
<input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/>					Usability Catastrophe

Minimalist

Minimalist. Any extraneous information is a distraction and a slow-down.

### Rating Scales

- 0, not a usability problem at all;  
 1, cosmetic problem only. Need not be fixed unless extra time is available;  
 2, minor usability problem. Fixing this should be given low priority;  
 3, major usability problem. Important to fix. Should be given high priority;  
 4, usability catastrophe. Imperative to fix this before product can be released.

22. Is the System designed for Less is more (minimal action to reach task objective)? \*

Mark only one oval.

0	1	2	3	4	
<input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/>					Usability Catastrophe

23. Is the System designed for simplicity and detailed information? \*

Mark only one oval.

0	1	2	3	4	
<input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/>					Usability Catastrophe

24. Is Simplicity of design associate with efficient? \*

Mark only one oval.

0	1	2	3	4	
<input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/>					Usability Catastrophe

25. Is the System designed for Progressive levels of detail? \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

### Memory

Minimize memory load. Users should not be required to memorize a lot of information to carry out tasks. Memory load reduces users' capacity to carry out the main tasks.

### Rating Scales

- 0, not a usability problem at all;
- 1, cosmetic problem only. Need not be fixed unless extra time is available;
- 2, minor usability problem. Fixing this should be given low priority;
- 3, major usability problem. Important to fix. Should be given high priority;
- 4, usability catastrophe. Imperative to fix this before product can be released.

26. Does the System provide Perceptual procedures? \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

27. Does the System provide Hierarchical structure for interaction? \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

28. Does the procedure of System provide Default values? \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

29. Does the System provide Concrete examples? e.g (DD/MM/YY, e.g., 10/20/99). \*

Mark only one oval.

	0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

30. Can the device do Generic rules and actions? (e.g., drag objects) \*

Mark only one oval.

	0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

### Feedback

Informative feedback. Users should be given prompt and informative feedback about their actions.

### Rating Scales

- 0, not a usability problem at all;  
 1, cosmetic problem only. Need not be fixed unless extra time is available;  
 2, minor usability problem. Fixing this should be given low priority;  
 3, major usability problem. Important to fix. Should be given high priority;  
 4, usability catastrophe. Imperative to fix this before product can be released.

31. Can feedback Information be directly perceived, interpreted, and evaluated? \*

Mark only one oval.

	0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

32. Do the device provide multiple Levels of feedback (novice and expert)? \*

Mark only one oval.

	0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe



33. Is the feedback information Concrete and specific, not abstract and general? \*

Mark only one oval.

0	1	2	3	4		
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

34. Is the feedback information provided with appropriate response time : e.g.-0.1 s for instantaneously reacting;-1.0 s for uninterrupted flow of thought;-10 s for the limit of attention \*

Mark only one oval.

0	1	2	3	4		
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

### Flexibility

Flexibility and efficiency. Users always learn and users are always different. Give users the flexibility of creating customization and shortcuts to accelerate their performance.

### Rating Scales

- 0, not a usability problem at all;
- 1, cosmetic problem only. Need not be fixed unless extra time is available;
- 2, minor usability problem. Fixing this should be given low priority;
- 3, major usability problem. Important to fix. Should be given high priority;
- 4, usability catastrophe. Imperative to fix this before product can be released.

35. Does the device provide Shortcuts for experienced users? \*

Mark only one oval.

0	1	2	3	4		
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

36. Does the device provide Shortcuts or macros for frequently used operations? \*

Mark only one oval.

0	1	2	3	4		
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

37. Does the device provide Skill acquisition through chunking? \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

#### Message

Good error messages. The messages should be informative enough such that users can understand the nature of errors, learn from errors, and recover from errors.

#### Rating Scales

- 0, not a usability problem at all;
- 1, cosmetic problem only. Need not be fixed unless extra time is available;
- 2, minor usability problem. Fixing this should be given low priority;
- 3, major usability problem. Important to fix. Should be given high priority;
- 4, usability catastrophe. Imperative to fix this before product can be released.

38. Does the device provide phrased Messages in clear language, avoid obscure codes?

Example of obscure code: "system crashed, error code 147." \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

39. Does the device provide precise, not vague or general Messages? Example of general comment: "Cannot open document." \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

40. Does the device provide Constructive error message? \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

41. Does the device provide polite messages? Examples of impolite message: "illegal user action," "job aborted," "system was crashed," "fatal error," etc. \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

#### Error

Prevent errors. It is always better to design interfaces that prevent errors from happening in the first place.

#### Rating Scales

- 0, not a usability problem at all;  
 1, cosmetic problem only. Need not be fixed unless extra time is available;  
 2, minor usability problem. Fixing this should be given low priority;  
 3, major usability problem. Important to fix. Should be given high priority;  
 4, usability catastrophe. Imperative to fix this before product can be released.

42. Does the device provide Interfaces that make errors impossible? \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

43. Does the device avoid providing multiple modes? \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

44. Does the device provide sound experience appropriate with information feedback? \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

45. Does the device differentiate execution error vs. evaluation error? \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

46. Is the device able to handle various types of slips and mistakes? \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

#### Closure

Clear closure. Every task has a beginning and an end. Users should be clearly notified about the completion of a task.

#### Rating Scales

- 0, not a usability problem at all;
- 1, cosmetic problem only. Need not be fixed unless extra time is available;
- 2, minor usability problem. Fixing this should be given low priority;
- 3, major usability problem. Important to fix. Should be given high priority;
- 4, usability catastrophe. Imperative to fix this before product can be released.

47. Does the device track Clearly beginning, middle, and end of all task? \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

48. Is any action with device be Completed in 7-stages ? (cognitive studies proved that human brain cannot handle in general hierarchy of 7 levels depth.) \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

49. Does the system provide clear feedback to indicate goals are achieved and current stacks of goals can be released? Examples of good closures include many dialogues. \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

Undo

Reversible actions. Users should be allowed to recover from errors. Reversible actions also encourage exploratory learning.

### Rating Scales

- 0, not a usability problem at all;  
 1, cosmetic problem only. Need not be fixed unless extra time is available;  
 2, minor usability problem. Fixing this should be given low priority;  
 3, major usability problem. Important to fix. Should be given high priority;  
 4, usability catastrophe. Imperative to fix this before product can be released.

50. Does the device provide reversible action at different levels: a single action, a subtask, or a complete task? \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

51. Does the device provide reversible action with Multiple steps? \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

52. Does the device Encourage exploratory learning through reversible action? \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Usability Catastrophe

53. Does the device Prevent serious errors through reversible action? \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/> Usability Catastrophe

### Language

Use users' language. The language should be always presented in a form understandable by the intended users.

### Rating Scales

- 0, not a usability problem at all;
- 1, cosmetic problem only. Need not be fixed unless extra time is available;
- 2, minor usability problem. Fixing this should be given low priority;
- 3, major usability problem. Important to fix. Should be given high priority;
- 4, usability catastrophe. Imperative to fix this before product can be released.

54. Does the device use standard meanings of words? \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/> Usability Catastrophe

55. Does the device use specialized language for specialized group? \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/> Usability Catastrophe

56. Does the device provide to the user defined aliases? \*

Mark only one oval.

0	1	2	3	4	
Not a usability problem at all	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/> Usability Catastrophe

57. Does the device provide Users' perspective? Example: "we have bought four tickets for you" (bad) vs. "you bought four tickets" (good). \*

Mark only one oval.

0    1    2    3    4

---

Not a usability problem at all      Usability Catastrophe

### Control

Users in control. Do not give users that impression that they are controlled by the systems.

### Rating Scales

- 0, not a usability problem at all;  
 1, cosmetic problem only. Need not be fixed unless extra time is available;  
 2, minor usability problem. Fixing this should be given low priority;  
 3, major usability problem. Important to fix. Should be given high priority;  
 4, usability catastrophe. Imperative to fix this before product can be released.

58. Does the device oriented to 'Users are initiators of actors, not responders to actions'? \*

Mark only one oval.

0    1    2    3    4

---

Not a usability problem at all      Usability Catastrophe

59. Does the device oriented to 'avoid surprising actions, unexpected outcomes, tedious sequences of actions, etc'? \*

Mark only one oval.

0    1    2    3    4

---

Not a usability problem at all      Usability Catastrophe

### Document

Help and documentation. Always provide help when needed.

### Rating Scales

- 0, not a usability problem at all;  
 1, cosmetic problem only. Need not be fixed unless extra time is available;  
 2, minor usability problem. Fixing this should be given low priority;  
 3, major usability problem. Important to fix. Should be given high priority;  
 4, usability catastrophe. Imperative to fix this before product can be released.

60. Does the device provide Context-sensitive help? \*

Mark only one oval.

0 1 2 3 4

---

Not a usability problem at all      Usability Catastrophe

61. Does the device provide Help embedded in contents? \*

Mark only one oval.

0 1 2 3 4

---

Not a usability problem at all      Usability Catastrophe

**Part 2**

This section measure the task's Physical, Mental, frustration, and Discomfort

**Rating Scales**

- 1, Low
- 2, Fairly Low
- 3, Medium
- 4, Fairly High
- 5, High

62. How much physical activity was required to perform a task? \*

Mark only one oval.

1 2 3 4 5

---

Low      High

63. How much mental effort was required to perform a task? \*

Mark only one oval.

1 2 3 4 5

---

Low      High





64. What level of frustration did you experience when performing a task? \*

Mark only one oval.

	1	2	3	4	5	
Low	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	High

65. What level of discomfort (pain) did you experience when performing a task? \*

Mark only one oval.

	1	2	3	4	5	
Low	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	High

66. Do you have any comment?

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Future Study/ دراسات مستقبلية

67. Do you want to participate in future study?

Mark only one oval.

- Yes  
 No  
 Maybe

68. If yes, Please write your email and phone number!

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## Appendix 9 Open-ended questionnaire

4/18/2020

Usability Contribution Factors of Radiology

# Usability Contribution Factors of Radiology

\* Required

### Consent Form

Thank you for agreeing to participate in this study. The study is granted official approval from Ministry of Health after fulfilling the requirement of Radiology Department, and Research and Study Department. The aim of this study is to evaluate CT-scan usability factors from user experience perspective. You are encouraged to share your experience and thoughts freely. As study requirement, it is necessary to record the conversation for further analysis in later part of the study.

Please keep in mind that the recorded data is highly confidential and will be used only for the purpose of this study alone. The data is strictly follow the university of Paris Saclay's data protection policy. Please remember that your participation is fully voluntary, and you can withdraw at any given time. The data will be destroyed after the purpose of this study is fulfilled.

Please tick Agree bellow if you wish to participate in this study.

#### 1. I agree to Participate on this Study \*

*Check all that apply.*

Agree

#### Introduction

My name is Saad Aldoihi, and I am a PhD student at University of Paris Saclay. Research will be a part of Saad Aldoihi's doctoral degree. The questionnaires aim to identify the major radiology Usability issues in Saudi Arabian Hospitals. It seeks to grasp radiology staff feedback about radiology Devices performance.

Your participation in this study will allow me to identify your perspective on Usability of radiology Devices performance. Also, it would be quite helpful to understand what aspects of device that you have concern on.

The collected responses will be strictly confidential and data from this research will be reported anonymously. Your answers are highly valuable to us.

If you have a question, Please contact the research team.

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[https://docs.google.com/forms/d/1\\_DvM9IA00QoL5WqLkCO5z8XP-6tB7HcA7-x3Ey6n5b8/edit](https://docs.google.com/forms/d/1_DvM9IA00QoL5WqLkCO5z8XP-6tB7HcA7-x3Ey6n5b8/edit)

1/6

**Terminology:**

ISO defines usability as "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" (ISO, 1998), and user experience as "a person's perceptions and responses that result from the use or anticipated use of a product, system or service" (ISO, 2010). In McGraw-Hill Concise Encyclopedia of Science and Technology specifies: "A concept in product design, sometimes referred to as ease of use or user friendliness, that is related directly to the quality of the product and indirectly to the productivity of the work force" (McGrawHill, 2006)

Please note that this study does NOT test you or your ability, rather this study tests the usability of CT Scan. In addition, Please note that the device and the system used interchangeably where it means the system of the device.

**مصطلحات:**

الاستفادة من الجهاز وإمكانياته بسهولة على الكمل وجه بدون مصاعب مباشرة أو غير مباشرة فمثلا: يأتي مريض سمين فلا يستطيع عمل الفحص له لأن Usability) نقصد به الطاولة صغيرة أو لا تتحمل الأوزان الزائدة مثال آخر : طريقة ادخال البيانات تأخذ وقت طوله ومعقده مثال : في الرنين المغناطيسي الجهاز المغلق يجعل المريض يرفض الفحص بـ " مدى استخدام المنتج من قبل مستخدمين محددين لتحقيق أهداف محددة مع الفعالية والكفاءة والرضا في سياق محدد من الاستخدام" (الايزو، ١٩٩٨). Usability الأيزو تعرف وتجربة المستخدم بـ" تصورات وردود الشخص التي تنتج عن استخدام أو توقعات استخدام إزاء استخدام منتج أو خدمة محددة"(الايزو، ٢٠١٠). ماكجرو هيل عرفها بـ" مفهوم في تصميم المنتجات، ويشار إليها أحيانا بسهولة الاستخدام أو القابلية المبسطة للاستخدام، التي ترتبط مباشرة إلى جودة المنتج وبشكل غير مباشر إلى إنتاجية قوة العمل

## 2. Gender \*

Mark only one oval.

- Male
- Female

## 3. Nationality

Mark only one oval.

- Saudi
- Other: \_\_\_\_\_

## 4. Age \*

Mark only one oval.

- 20 - 29
- 30 - 39
- 40 - 49
- 50+

## 5. Educational level \*

Mark only one oval.

- Diploma
- Bachelor
- Master
- PhD

## 6. Radiology Years of Experience \*

Mark only one oval.

- 0 - 3 years
- 4 - 7 years
- 8 - 11 years
- 12+ years

## 7. What is your Radiology Title? \*

Mark only one oval.

- Technician
- Technician Specialist
- Senior Technician Specialist
- Consultant Technician
- Registrar
- Senior Registrar
- Consultant

## 8. What is your primary CTScan brand usage?

Mark only one oval.

- GE
- Philips
- Siemens
- Other: \_\_\_\_\_

9. What are the most obvious impacts of usability on your work & productivity?

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10. What are the most obvious impact of usability on Patient?

---

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11. In your opinion, what is the most important factor of usability?

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12. From your experience, can you list contributing factors associated with usability issues?

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13. In your work, is there reporting system for Usability issues? If yes, explain that system?

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- 14. In corresponding with Usability issues reporting, what actions are usually taken to prevent usability issues?

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- 15. Have you identified operating error related to difficulty to operate the device? please explain, , and what actions are taken?

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- 16. Why usability issues are still happening?

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- 17. From your experience, how to prevent usability issues?

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- 18. How do you think we can improve usability?

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19. In your opinion, what is the the most annoying about the device?

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20. If you could propose some improvements in the devices, what would it be?

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21. What the effect of culture on Usability?

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22. Do you have further suggestion?

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Google Forms



## Appendix 10 invisible Questionnaire

4/18/2020

The invisible of Physical and mental load of CT scan technicians

# The invisible of Physical and mental load of CT scan technicians

\* Required

### Consent Form

Thank you for agreeing to participate in this study. The study is granted official approval from Ministry of Health after fulfilling the requirement of Radiology Department, and Research and Study Department. The aim of this study is to identify the invisible physical and mental exertion associated with CT/MRI scan within working environment. You are encouraged to share your experience and thoughts freely. As study requirement, it is necessary to store the data for further analysis in later part of the study.

Please keep in mind that the stored data is highly confidential and will be used only for the purpose of this study alone. The data is strictly follow the university of Paris Saclay's data protection policy. Please remember that your participation is fully voluntary, and you can withdraw at any given time. The data will be destroyed after the purpose of this study is fulfilled.

Please tick Agree bellow if you wish to participate in this study.

#### 1. I agree to Participate on this Study \*

*Check all that apply.*

Agree

#### 2. Gender \*

*Mark only one oval.*

Male

Female

#### 3. Age \*

*Mark only one oval.*

20-29

30-39

40-49

50+

<https://docs.google.com/forms/d/1tXS4hHG1q5SaEgETcuvDgOIPemrCkbuUbGdlGmaelRA/edit>

1/5



## 4. Educational level \*

Mark only one oval.

- Diploma
- Bachelor
- Master
- PhD +

## 5. Radiology Years of Experience \*

Mark only one oval.

- 0 - 3 years
- 4 - 7 years
- 8 - 11 years
- 12+ years

## 6. Working Sector \*

Mark only one oval.

- Public Sector (Government Hospitals)
- Private Sector ( Private Hospitals)

## 7. I have helped to transfer a Bedridden patient from hospital bed to Radiology table? \*

Mark only one oval.

- Always
- Usually
- Sometime
- Rarely
- Never

8. Comment

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9. it is my duty to preparing examination room for receiving next patient? \*

*Mark only one oval.*

- Always
- Usually
- Sometime
- Rarely
- Never

10. Comment

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11. it is my duty to preparing for contrast media administration as needed? \*

*Mark only one oval.*

- Always
- Usually
- Sometime
- Rarely
- Never



12. Comment

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13. I think that I work in understaffed environment? \*

*Mark only one oval.*

- Strongly agree
- Agree
- Neutral
- Disagree
- Strongly disagree

14. Comment

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15. I think that the department needs more CT Scan/ MRI machine? \*

*Mark only one oval.*

- Strongly agree
- Agree
- Neutral
- Disagree
- Strongly disagree



16. Comment

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17. I think that management targets are unreasonable (not in alignment with existing resources)? \*

Mark only one oval.

- Strongly agree
- Agree
- Neutral
- Disagree
- Strongly disagree

18. Comment

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## Appendix 11 PMP Certificate



# Evaluation of CT Scan Usability for Saudi Arabian Users

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**Abstract**— Like consumer electronic products, medical devices are becoming more complicated, with performance doubling every two years. With multiple commands and systems to negotiate, cognitive load can make it difficult for users to execute commands effectively. In the case of medical devices, which use advanced technology and require multidisciplinary inputs for design and development, cognitive workload is a significant factor. As these devices are very expensive and operators require specialized training, effective and economical methods are needed to evaluate the user experience. Heuristic evaluation is an effective method of identifying major usability problems and related issues. This study used heuristic evaluation to assess the usability of a CT scan and associated physical and mental loads for Saudi Arabian users. The findings indicate a gender difference in terms of consistency, flexibility, and document attributes, with a statistically significant gender difference in mental load.

**Keywords**— Usability, CT scan Heuristic Evaluation, Human-computer Interaction.

## I. INTRODUCTION

In performing a CT scan, it is important to ensure effective interaction between the radiologist and the CT scan device itself as well as the patient. In particular, the impeded speech command, which directs the patient to take, hold, and release their breath (available in many languages) is a key interaction between operator and machine. This fundamental task involves multiple disciplines, including Human Computer Interaction, Human Computer Design, and Usability. As much of the scan's accuracy depends on how fluently the operator can interact with the machine, designers are under pressure to extend the machine's capabilities and usability. According to the FDA database MAUDE [1], 437 incidences of "User used incorrect product for intended use" were reported in the years 2016 and 2017, 11 of which resulted in death. For that reason, designers have a serious responsibility to ensure devices usability. This is not a straightforward matter like following a cooking recipe but depends on rules that emphasize goals rather than sets of actions [2]. In most tasks, the interactions between operator and device are goal-oriented; once the user completes the desired task successfully and efficiently, the goal can be said to have been met [3]. In the case of a CT scan, the goal is achieved when the radiologist effectively completes successful testing of the patient.

In relation to usability, safety is a critical consideration when assessing the success of a CT scan. One study [4] showed that CT emits as much radiation as 200 chest X-rays, which for the average person is equivalent to more than seven years exposure in a natural setting. The same article reported that children commonly received adult doses of radiation. In her Testimony [5] before The United States House of Representatives Health Committee Subcommittee on Energy and Commerce, Rebecca Smith-Bindman MD stated that the most common type of CT scan emits a level of radiation equivalent to 1500 dental X-rays, and that in some CT scan models, the level is equivalent to 5,000 such X-rays. In most cases, whether on the basis of fact and reason or unfounded speculation, patients express concern about the possible effects of a CT scan on their health.

As it is difficult to determine or evaluate current usability practices within the medical device industry, medical device usability issues need to be publicized, analyzed, and explained [6]. Other industries such as air traffic control and nuclear energy have benefited immensely from human factors and usability practices to eliminate errors and improve safety [7]–[9]. Ultimately, whatever the industry, human factors and usability analyses are safety-driven [10]. To the best of our knowledge, no existing study has applied heuristic evaluation specifically to CT scans. Any related studies have not measured CT scans as a direct product but rather as part of a picture archiving and communication system (PACS) or medical imaging software. To the best of our knowledge, this is the first paper to specifically apply heuristic evaluation to CT scans.

## II. CONSOLIDATED USABILITY ATTRIBUTES

### A. Baseline attributes

Nielsen and Molich [11] proposed a new method for evaluating usability, which they called "heuristics", and heuristic evaluation has since become a popular tool because of its effectiveness and low cost. Following its successful application in evaluating the user interface, heuristic evaluation has since been adopted in other domains [12]. Nielsen [13] introduced ten heuristics that serve as an evaluation guide for practitioners: 1) visibility of system status; 2) match between system and real world; 3) user control and freedom; 4) consistency and standards; 5) error prevention; 6) recognition rather than recall; 7) flexibility and efficiency of use; 8) aesthetic and minimalist design; 9)

help for users to recognize, diagnose, and recover from error; and 10) help and documentation. As many authors in the usability field have sought to develop definitions and a holistic approach to usability, it may be inferred that usability cannot be consolidated as a single attribute, and many attempts have been made to compile a list of attributes. Similarly, Makoid [14] noted that there is no single agreed definition of usability; instead, different definitions may incorporate different parameters and attributes. Nevertheless, there is consensus on the importance of usability, and international organizations such as ISO have introduced usability attributes for the purposes of standardization. As noted by Shneiderman and Plaisant [15], standardization accelerates industry adoption

### B. Improved attributes

Shneiderman and Plaisant [15] postulated that it is extremely difficult to designers to accomplish the final design without being forced to tradeoffs between attributes. In other word, increasing effectiveness of one attribute comes on the expenses of the another attributes. In order to achieve better yield of discovering usability problem, traditional heuristic evaluation has been modified, extended, and improved to suit a specific domain or task [16]. To Ling and Salvendy [16] heuristics evaluation categorized into three approaches: 1) alteration of the evaluation procedure, 2) expansion of the heuristics evaluation procedure, and 3) extending the HE method with a conformance rating scale. In the medical equipment domain, Zhang, et al (2003) developed heuristics evaluation which are extended and modified version of Nielsen [17] and Shneiderman [18]. Zhang et al. [19] combined Nielsen [17] and Shneiderman [18] to constitute an extended and more fitted heuristics to medical devices.

## III. METHOD

### A. Participant

Careful sampling is a crucial element of successful research. In user research studies, recruiting participants who meet precisely determined criteria can prove very challenging [20]. Cairns and Cox [21] insisted that recruiting people with specialist knowledge is essential to user study success. To ensure scientific integrity, the authors carefully specified a rigorous pre-qualification procedure to eliminate unwanted participants. To qualify as a participant, candidates had to meet three criteria: 1) their primary work involved handling and operating CT scans; 2) their job category was radiology (Radiologist or Technician); and 3) they were currently working in the Saudi public healthcare system. At the time of this study, there were 400 CT scan technicians working in the public sector, and there were about 191 CT scan devices (according to the Radiology Department in the Ministry of Health, November 2017). In total, there were 44 participants, ranging in age from 20 to 49 years (26 male and 18 female). Table 1 shows the participants' demographic data.

TABLE I. PARTICIPANT DEMOGRAPHIC

Variable	Frequency	N %
Gender		

Male	26	59.10%
Female	18	40.90%
Total	44	100%
<b>Age</b>		
20-29	14	31.80%
30-39	23	52.30%
40-49	7	15.90%
Total	44	100%
<b>Level of Education</b>		
Diploma	11	25.00%
Bachelor	25	56.80%
Master	8	18.20%
Total	44	100%
<b>Years of Experience</b>		
0-3 years	16	36.40%
4-7 years	11	25.00%
8-11 years	9	20.50%
12+	8	18.20%
Total	44	100%
<b>Radiology Job Title</b>		
Consultant Technician	1	2.30%
Registrar	3	6.80%
Senior Technician Specialist	9	20.50%
Technician	15	34.10%
Technician Specialist	16	36.40%
Total	44	100%
<b>Nationality</b>		
Filipino	7	15.90%
Indian	1	2.30%
Pakistani	2	4.50%
Saudi	33	75.00%
Sudanese	1	2.30%
Total	44	100%

### B. Instrument

The study instrument comprised two elements, the first of which was a two-part questionnaire. The first part gathered information about participant characteristics including gender, age, educational level, years of experience, job title, and nationality. The six measured variables included the following options: (1) Gender (Male, Female); (2) Age (20–29, 30–39, 40–49); (3) Level of Education (Diploma, Bachelor, Master); (4) Years of Experience (0–3 years, 4–7 years, 8–11 years, 12+ years); (5) Radiology Job Title

(Technician, Technician Specialist, Senior Technician Specialist, Consultant Technician, Registrar); (5) Nationality (Open).

As shown in Fig. 1, the second element comprised two adapted questionnaires. The first section adapted the standard heuristic evaluation approach to identify major usability issues vis-à-vis CT scan, based on Zhang et al.'s [19] approach to heuristic evaluation. As shown in Table 2, heuristic evaluation tends to measure CT scan usability in terms of 14 attributes: (1) Consistency; (2) Visibility; (3) Match; (4) Minimalism; (5) Memory; (6) Feedback; (7) Flexibility; (8) Message; (9) Error; (10) Closure; (11) Undo; (12) Language; (13) Control; (14) Document. Each attribute was measured by items ranked on a five-point Likert scale (0 = *No Problem*, 1 = *Cosmetic*, 2 = *Minor*, 3 = *Major*, 4 = *Usability Catastrophe*).

In a third step, NASA-TLX [22] was used to assess the physical and mental loads associated with operating a CT scan. The questionnaire measured the following variables: (1) Physical, (2) Mental, (3) Frustration, (4) Discomfort. Responses were again based on a five-point Likert scale (1 = *Low*, 2 = *Fairly Low*, 3 = *Medium*, 4 = *Fairly High*, 5 = *High*).

□

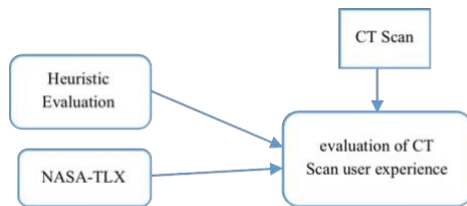


Fig. 1. Model Framework

The second set was field observation. The first author conducted 16 hours of on-site observations at King Saud Medical City (KSMC) to investigate technicians' use of the CT scan in terms of usability and physical and mental loads. During that time, 8 hours were dedicated to CT scan operation in the Emergency Room (ER), and the other 8 hours were dedicated to CT scan operation in the Radiology Department. KSMC was chosen as the observation site after careful evaluation of several Riyadh hospitals in terms of throughput and diversity of patients.

The observed technicians were made aware of the study's purpose, and a consent form was distributed and obtained from each participant.

TABLE II. USABILITY ATTRIBUTES AS DEFINED BY ZHANG [19]

Attribute	Explanation
Consistency	Consistency and standards: Users should not have to wonder whether different words, situations, or actions mean the same thing. Standards and conventions in product design should be followed.

Visibility	Visibility of system state: Users should be informed about what is going on with the system through appropriate feedback and display of information.
Match	Match between system and world: The image of the system perceived by users should match the model the users have about the system.
Minimalist	Minimalist: Any extraneous information is a distraction and a slow-down.
Memory	Minimize memory load: Users should not be required to memorize a lot of information to carry out tasks. Memory load reduces users' capacity to carry out the main tasks.
Feedback	Informative feedback: Users should be given prompt and informative feedback about their actions.
Flexibility	Flexibility and efficiency: Users always learn and users are always different. Give users the flexibility of creating customization and shortcuts to accelerate their performance.
Message	Good error messages: The messages should be informative enough such that users can understand the nature of errors, learn from errors, and recover from errors.
Error	Prevent errors: It is always better to design interfaces that prevent errors from happening in the first place.
Closure	Clear closure: Every task has a beginning and an end. Users should be clearly notified about the completion of a task.
Undo	Reversible actions: Users should be allowed to recover from errors. Reversible actions also encourage exploratory learning.
Language	Use users' language: The language should be always presented in a form understandable by the intended users.
Control	Users in control: Do not give users that impression that they are controlled by the systems.
Document	Help and documentation: Always provide help when needed, ideally context-sensitive help.

## IV. RESULTS

### A. Questionnaires reliability

The reliability of the heuristic questionnaire and NASA-TLX was measured using Cronbach's alpha. For the heuristic questionnaire, alpha was .98; for NASA-TLX, alpha was .79. As a rule of thumb, Leary [23] suggested that a Cronbach alpha in excess of .70 is generally adequate for newly developed questionnaires.

### B. Usability attributes

A heuristic evaluation was conducted to identify usability issues faced by CT scan technicians. As shown in Fig. 2, the evaluation indicated a potentially catastrophic usability issue (i.e., leading to death) on all 14 tested usability attributes. The results in Fig. 3 show that technicians identified 529 issues in operating the CT scan, ranging in severity from Cosmetic to Catastrophe. Fig. 3 shows the combined severity for all 14 attributes, incorporating Cosmetic (88.2 cases), Minor (193.2 cases), Major (180.7 cases), and Catastrophe (66.9 cases).



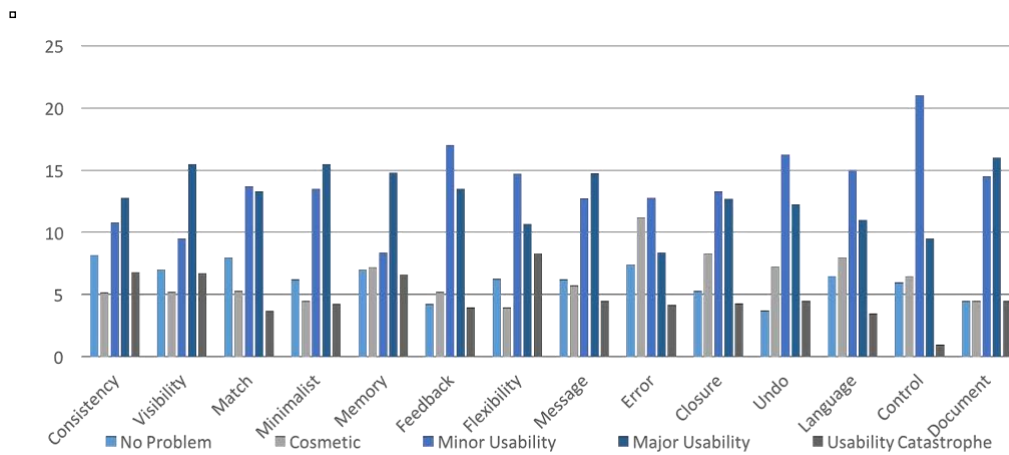


Fig. 2. Usability issues by attribute

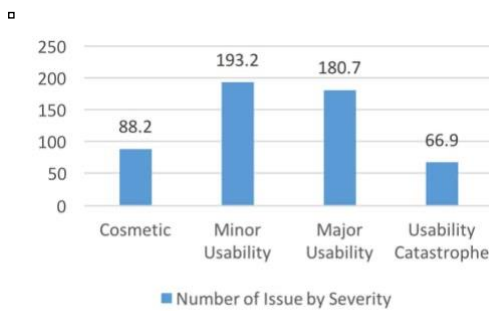


Fig. 3. Number of issues categorized by severity

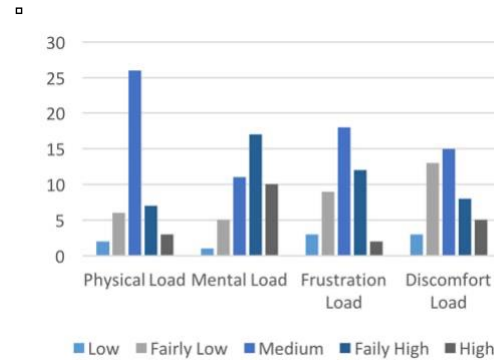


Fig. 4. NASA-TLX severity

1) Gender

Of 14 attributes, Mann Whitney tests showed a difference between Male and Female on Consistency ( $z = 2.21$ ,  $p = .027$ , 2-sided); Flexibility ( $z = 1.99$ ,  $p = .046$ , 2-sided); and Document ( $z = 2.09$ ,  $p = .036$ , 2-sided).

2) Age, Level of Education, and Years of Experience

The nonparametric Kruskal-Wallis test showed no differences between category groups.

C. NASA-TLX

NASA-TLX was used to identify the physical and mental loads associated with operating the CT scan. As shown in Fig. 4, a total of 3 cases registered high on physical load; 10 cases registered high on mental load; 2 cases registered high on frustration; and 5 cases registered high on discomfort.

1) Gender

A Mann Whitney test showed a difference between Male and Female on mental load ( $z = 3.23$ ,  $p = .001$ , 2-sided).

2) Age and Level of Education

The nonparametric Kruskal-Wallis test showed no difference between category groups.

3) Years of Experience

A Kruskal-Wallis test showed a statistically significant difference by years of experience for at least one group on Frustration ( $\chi^2 = 10.9$ ,  $p = .012$ ) and Discomfort ( $\chi^2 = 9.2$ ,  $p = .026$ ). Dunn's pairwise test was performed for the six pairs of groups. There was strong evidence ( $p = .006$ , adjusted using the Bonferroni correction) of a difference in Frustration between 0–3 years and 8–11 years. The same pair also differed significantly ( $p = .036$ , adjusted using the Bonferroni correction) on Discomfort.

## V. CONCLUSION

Advances in technology entail advances in systems, increasing the pressure on users to manage complexity safely and efficiently. These findings support the mounting evidence of physical load (high = 3, fairly high = 7, medium = 26) where users see themselves as contributing physically to operate a CT. As 86.3% of users believed that operating CT scan involves medium to high mental load, manufacturers should pursue designs that reduce both physical and mental loads. Across the 14 usability attributes, 66.9 cases of Catastrophic usability were recorded. These should be fixed immediately before allowing the product to go to market. To ensure that users are willing and able to operate within the confines of rigid safety and regulatory guidelines, manufacturers should devote more effort to CT scan usability.

These findings add to mounting evidence that users differ according to gender and years of experience. In the context of CT scan operation, males and females different on the Consistency attribute (Sequence of action, Color, Layout, Font, Terminology, and Standards). For that reason, it is recommended that designers should provide customizable options to suit end-user needs and requirements. In addition, as males and females differed significantly on mental load, designers should take account of these differences in the design process and should actively iterate to the end of the process, testing and comparing in order to accommodate the usability needs of both genders.

## ACKNOWLEDGMENT

Saad Aldoihi thanks King Abdulaziz City Of Science and Technology for making this research possible by providing scholarship assistance. A thank you goes to Saudi Health Ministry for providing access to its hospitals and employees. A special thanks go to all participants who made the time and effort to participate in this study.

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# User Experience of CT Scan: A Reflection of Usability and Exertions

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**Abstract**—Medical devices follow a trend, just like consumer electronic products, where they are becoming more complicated and performance is doubling every two years. Consequently, medical devices require a multidisciplinary team for design and development. Therefore, with so many commands and systems to deal with, users cognitive loads are challenged to effectively execute commands. In medical devices, the cognitive workload will play more of a role because it uses advanced technology, is extremely expensive and takes a great deal of specialization to operate. Thus, effective and economical methods are required to evaluate user experience. Heuristic evaluation is an effective method to identify major usability problems and highlight issues faced by users. Heuristic evaluation was adapted, to identify the usability of a CT scan on Saudi Arabian users and to identify if operating the CT scan can lead to physical and mental load effort. Contrary to the expected belief that young people are savvy in technology, this study found that this is not the case with CT, but rather working experience is more valuable in encountering usability catastrophic.

**Keywords**—CT scan Usability; User Experience; Heuristic Evaluation; Human machine Interactions

## I. INTRODUCTION

Within the context in which radiologists operate CT scans, much effort and interaction ought to be established between the radiologist and the CT scan device itself - and to some extent, the patient. In the CT scan case, the impeded speech command which directs the patient to take, hold, and release breathe, is available in many languages. This interaction between the operator and machine, has many fields of science, which tends to make it a primary focus of their existence. Most notable of these, are, human computer interaction, human computer design, and usability. When much of the accuracy of the job is placed on how fluently the operator can deal with the machine, it creates pressure on designers to make the machine extend its capabilities by usability means. According to the FDA database [1], in the years of 2017 and 2016, there were 437 incidents reported as “User used

incorrect product for intended use”, and 11 cases of which resulted in death. Therefore, the pressure on the designers is tremendous as Johnson [2] depicted that designing for Usability is not as straightforward as following cooking recipes, but rather - it is all about rules that build crucial emphasis on reaching goals rather than following sets of actions. In most of the tasks, the interactions between the operator and the device is goal-oriented. Once users achieve the desired tasks successfully and efficiently, they can declare that his/her goal has been met [3]. Similarly, in a CT scan, when the radiologist effectively achieves and completes testing the patient successfully, the radiologist goal is ultimately achieved.

Another important associate concept with usability is the notion of safety. It is deemed as critically vital regarding the operations of a CT scan. An article [4] showed that CT emits radiation on patients as much as 200 chest X-rays. Such amounts of radiation would take over seven years on the average person to get exposed in a natural setting. Also, the same article showed that most frequently, children received adult-sized doses of radiation. In a Testimony of Rebecca Smith-Bindman, [5] before The Subcommittee on Health Committee on Energy and Commerce United States House of Representatives stated that most common type of CT scan emits radiation that is equivalent to getting 1,500 dental x-rays, and in some CT scan models, the radiation is equivalent to getting 5,000 dental x-rays. In most cases, when getting a CT scan, patients come with concern of the CT scan on their health. Their knowledge either comes from reasonable facts or exaggerated speculations. The safety notion is elevated to constitute the medical device’s usability baseline attribute.

Within the medical device industry, present practice of usability is not feasible to determine and eventually make evaluations. As a result, current medical device usability issues need to be publicized, analyzed, and explained [6]. Similarly, other industries have benefited immensely from human factors and usability practices to alleviate errors and recuperate safety guidelines. Such examples include air traffic control and nuclear energy [7]–[9]. In essence, regardless of industry, human factor and usability analysis are safety driven [10].

To the best of our knowledge, there is no existing paper that uses heuristic evaluation on CT scans specifically. All

mentions of CT scans within heuristic evaluation, did not precisely measure CT scans as a direct product - but rather as a part of picture archiving and communication system (PACS) or medical imaging software. Therefore, this is the first paper which specifically evaluates CT scans heuristically.

Operating a complex device implies many limitations, such as gender, physical property and preferences. Therefore, at current, the research explores the following questions:

How usability attributes correspond between users' demographic characteristics?

What kind of exertions exist while operating a CT scan?

## II. CONSOLIDATED USABILITY ATTRIBUTES

### A. Baseline attribute

Nielsen and Molich [11] proposed a new method for evaluating usability which they called "heuristics". Ever since, heuristic evaluation as an evaluation tool has taken popularity. This is due to the high effectiveness and low cost. Due to heuristics evaluation success in the user interface, it has been adopted in other domains [12]. Nielsen [13] introduced ten heuristics that serve as an evaluation guide to practitioners. The ten heuristics are: 1) visibility of system status, 2) match between system and the real world, 3) user control and freedom, 4) consistency and standards, 5) error prevention, 6) recognition rather than recall, 7) flexibility and efficiency of use, 8) aesthetic and minimalist design, 9) help users recognize, diagnose, and recover from error, and 10) help and documentation. Many authors from the usability field tried to give a holistic approach and definitions regarding usability. Therefore, it is observed that usability cannot be consolidated as a single attribute. Rather, over the course of time, many authors attempted to consolidate usability as list of attributes. Makoid [14] noted that there is not a unification approach to the definition of usability, but rather, different definitions and attributes may include different parameters. Even though there are many different attributes, consensus on the importance of usability is the unification factor of all the differences. Consequently, international organizations such as ISO, have introduced usability attributes as standardization. Shneiderman and Plaisant [15] implied that standardization accelerates industry adoption.

### B. Improved attributes

[15] postulated that it is extremely difficult for designers to accomplish the final design without being forced into trade-offs between attributes. In other words, increasing the effectiveness of one attribute, comes at the expense of others. In order to achieve a better yield for discovering the usability problem, traditional heuristic evaluation has been modified, extended, and improved, to suit a specific domain or task [16]. To Ling and Salvendy [16], heuristics evaluation can be categorized into three approaches: 1) alteration of the evaluation procedure, 2) expansion of the heuristics evaluation procedure, and 3) extending the HE method with a conformance rating scale. In the medical equipment domain, [17] developed a heuristics evaluation which is an extended and modified version of Nielsen [18] and Shneiderman [19]. Zhang et al [17] combined Nielsen

[18] and Shneiderman [19] to constitute an extended and more fitted heuristics to medical devices.

### C. Usability in medical devices

Incorporated usability to medical devices is starting to gain momentum in today's healthcare-lucrative environment. Manufacturers understand the power of usability in gaining a competitive advantage and to stay compliant with a highly rigid regulations system. In recent years, ergonomics of physical exertion has been gradually alleviated since most devices shrink in size and gain more computing power. Subsequently, Matern and Büchel [20] put forward that medical device manufacturers shifted their attention from reducing physical exertion to reducing mental exertion. It is fair to say that medical devices do not require a physical load to operate them. However, the mental load will always be present since operators (physicians) have different levels of complexity tolerance attitudes. Traditionally, medical errors associated with these devices, are attributed to users or operators.

However, after many years of reviewing and tracking errors, an excessive emphasis has been placed on design, which contributed to usage error [21]. When introducing medical devices to the market, manufacturers pressure designers and engineers to generate features that give the devices a marketing competitive advantage. However, such strategies contribute to the general added complexity and pose more mental, frustration, and discomfort exertion threat (but not necessarily physical exertion). Medical devices usability attributes must go hand-in-hand with physical, mental, and discomfort attributes. In other words, evaluating medical device's usability must take into account with exertion as a contributing factor, incorporated with targeted attributes

Medical devices usability is of vital importance in contrast to devices from the different field for the following reasons:

- Its direct impact on patient
- Its direct impact to diagnoser
- It can alter a decision
- Its potential serious effect (death, chronic harm)

Usability of CT is fundamental to the hospital and healthcare provider because CT is extremely interconnected to other functioning domains. Fig. 1 shows the interconnectivity and effect of CT usability on other systems and functioning zone.

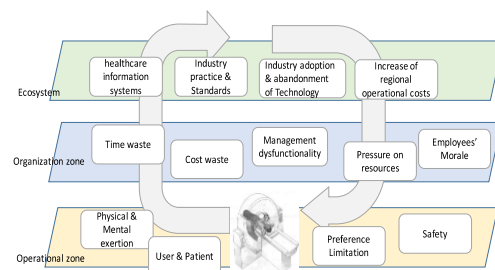


Fig. 1. Interconnectivity and effect of CT scan usability

### III. METHOD

A survey study was performed making use of a questionnaire in order to answer the research questions (1) How usability attributes correspond between users' demographic characteristics? And (2) What kind of exertions exist while operating a CT scan?

#### A. Participants

The target population consisted of 400 CT technicians at the time of conducting this study (According to the Radiology Department in the Ministry of Health Nov-2017). The study total participant was 44. The participant gender compromised as follow 59.10% were male and 40.90% were female. The age range was from 20 to 49 years old, and they consisted as following 31.80% were aged from 20 to 29 years old, 52.30% were aged from 30 to 39 years old, and 15.90% were aged from 40 to 49 years old. Educational levels of the participants were 25% Diploma, 56.80% Bachelor, and 18.20% Master. The nationalities of the participants were 75% Saudi, 15.90% Filipino, 4.50% Pakistani, 2.30% Indian, and 2.30% Sudanese. All participants were recruited by an email or through hospital visits.

#### B. Procedure

Two volunteers were recruited during the making of this study. One volunteer was responsible for the communication with the Ministry of Health. The other volunteer was responsible for recruitment from inside hospitals. An official email was sent from volunteer 1 to invite all CT scan technicians to participate in the study. The email contained a web link to the questionnaire. Volunteer 2 were visited all mega-hospital cities in Riyadh and offer paper-based questionnaires. All participants were

characteristics. The second part was adopted from NASA-TLX to identify what kind of exertions exist while operation a CT scan.

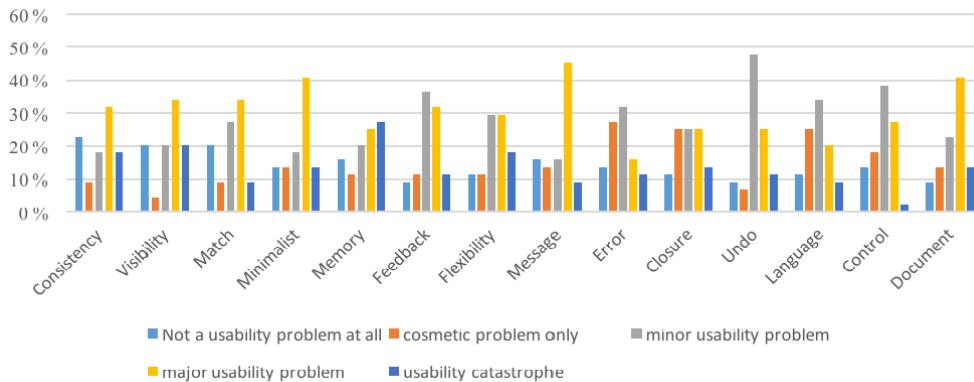
#### C. Measurement

The study measures 14 usability attributes. Each attribute consist of multiple dimensions as following: 1. Consistency (6 dimensions), 2. Visibility (4 dimensions), 3. Match (3 dimensions), 4. Minimalist (4 dimensions), 5. Memory (5 dimensions), 6. Feedback (4 dimensions), 7. Flexibility (3 dimensions), 8. Message (4 dimensions), 9. Error (6 dimensions), 10. Closure (3 dimensions), 11. Undo (4 dimensions), 12. Language (4 dimensions), 13. Control (2 dimensions), and 14 Document (2 dimensions). the mean of dimensions and standard deviations are calculated as cohesive whole to constitute the overall attributes score. NASA-TLX measures four attributes which are 1. Physical, 2. Mental, 3. Frustration, and 4. Discomfort.

### IV. RESULT

#### A. Usability attributes

Each participant scored the CT scan based on his/her user experience on multiple dimensions. In total, 529 issues were found ranging from cosmetic to catastrophic. These issues can be split down into 88.2 for cosmetic, 193.2 minor usability, 180.7 major usability, and 66.9 usability catastrophe. On a catastrophic scale, technicians found Memory (27.30%), Visibility (20.50%), Consistency (18.20%), Flexibility (18.20%), Minimalist (13.6%), Closure (13.6%), and Document (13.6%) most troubling see Fig. 2. On major usability problem scale, technicians reported Message (45.9%), Minimalist (40.9%), Document (40.9%), Visibility (34.1%), and Match (34.1%) as the highest among other attributes.



given the choice to fill up the questionnaire either by web-link or paper-based. The questionnaire consisted of two parts. The first was questionnaire adopted from Zhang et al [17] approach to evaluate usability in medical devices. The approach measures 14 usability attributes heuristically. Overall, the 14 attributes consist of 54 dimensions (question). The primary concept to use questionnaire is to answer the research question which is How usability attributes correspond between users' demographic

Fig. 2. Usability attributes categorized by severity

user experience characteristics are different according to the demographic group. For instance, 33.30% of female technicians reported Consistency as usability catastrophe in contrast to 7.70% of male. Also, 33.30% of female technicians reported catastrophic on Memory whereas 23.10% of male sees it as catastrophic see Fig. 3. In general, female technicians catastrophic rating surpassed

male counterpart (except for Control attribute). Age is another crucial factor in the demographic group. As shown in Fig 4, as the age group increase, the less usability catastrophe is reported. This finding supports the fact that increase in age is corresponding to an increase in the working experience. As a result, the older the user is, the more working experience the person has. 20-29 age group reported that Memory (35.7%), and Flexibility (28.6%) are most troubling according to usability catastrophe scale whereas 30-39 age group reported Memory (26.1%) and Visibility (26.1%). On the other hand, 40-49 age group is the lowest group in encountering usability catastrophe issues. Education level is essential factor in the demographic group see Fig. 5. For education group, Diploma category registered the highest group in encountering usability catastrophe issues.

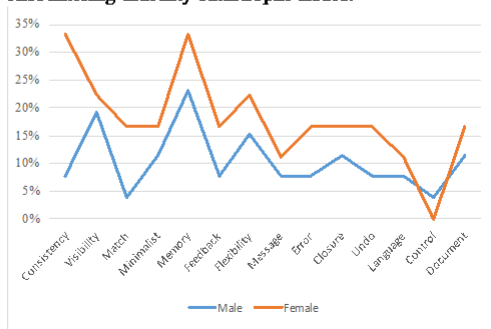


Fig. 3. Usability catastrophe corresponding with gender

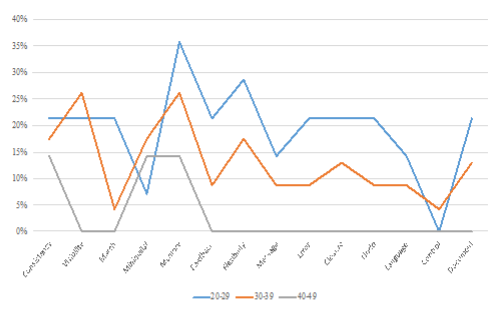


Fig. 4. Usability catastrophe corresponding with age

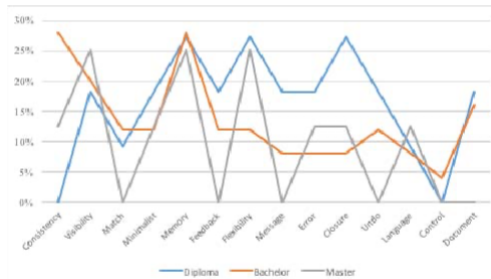


Fig. 5. Usability catastrophe corresponding with education

### B. NASA-TLX

Evidently, exertions exist while operating CT. Technicians reported that exertions are maximum (very high) on the mental (22.7%), discomfort (11.4%), physical (6.8%), and frustration (4.5%). As shown in Fig. 6, mental exertion constituted 61.3% in the high category. The largest category is medium physical exertion as reported by 59.1%. For fairly high category, technicians reported mental (38.6%), frustration (27.3%), discomfort (18.2%), and physical (15.9%). As illustrated in Fig. 7, exertion is different according to user demographic characteristics. For mental exertion, 38.9% of female reported High as opposed to 11.5% of male. Age is a captivating factor in the socio-demographic element Fig. 8 shows the rate of exertion in correspondence with age. It is unblemished to say that the mental exertion is high across all age group. The 20-29 age group shows high present of all exertions compared to any other group

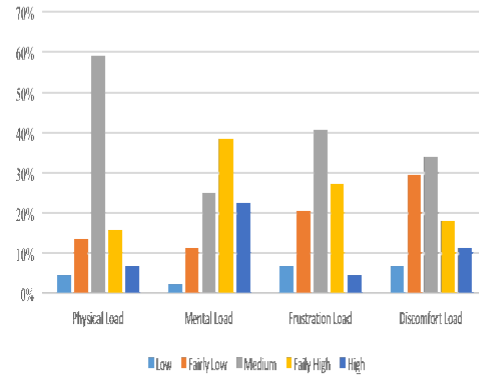


Fig. 6. Exertions by severity

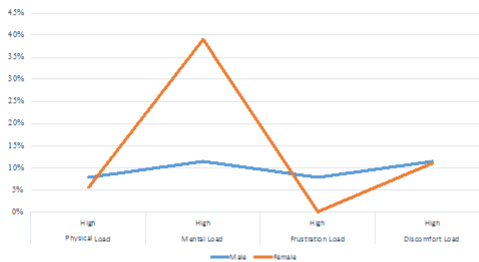


Fig. 7. High exertion corresponding with gender

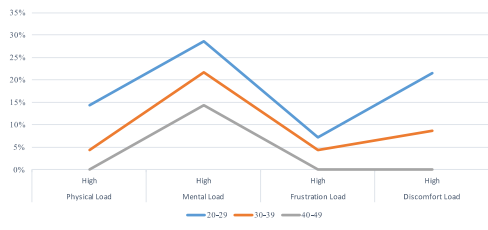


Fig. 8. High exertion corresponding with age

## V. CONCLUSION

Advancement in technology comes in correlation with advancement in systems, increasing the pressure on users to manage complexity safely and efficiently. These findings support the mounting evidence of physical loads (high = 6.8%, fairly high = 15.9%, medium = 59.1%) where users see themselves as contributing physically to operate a CT. As 86.3% of users believed that operating CT scans involved medium to high mental load, manufacturers should pursue designs that reduce both physical and mental loads. Evidently, the results show that mental load, in particular, is high, regardless of differences in demographic characteristics such as gender, age, level of education, and years of experience. Therefore, the CT scan manufacturers should update their usability expectation, to include mental loads minimizing procedures and techniques. Acknowledging mental load peaks from the industry would encourage academics and professionals to propose solutions and generally tackle the problem. As of now, there is no manufacturer who points to this problem specifically. A prominent question which comes to mind immediately, concerns industry awareness of high mental loads in the CT. On the other hand, across the fourteen usability attributes, 66.9 cases of Catastrophic usability were recorded. These should be fixed immediately before allowing the product to go to market. To ensure that users are willing and able to operate within the confines of rigid safety and regulatory guidelines, manufacturers should devote more effort to CT scan usability.

The result indicates a vitally important trend. That is the higher the age is the less usability catastrophe user encounter. That hints at the possibility that users' working experience is fundamentally essential in reducing catastrophic usability problems. In the long term, users learn how to minimize usability catastrophe as they progress at work. It also suggests that there is a positive correlation between the age and usability catastrophe category. To minimize usability catastrophe, manufacturers are encouraged to embed helping features to CT scan's operating systems. One important concept is to make the machine learn about its users by introducing machine learning capabilities. Another equally essential concept is to make use of business intelligence capabilities within the operating context of the CT scan. For instance, if one user is known for making one type of operating error, CT can self-generate a report and send to human resource department to elevate user's priority to gain a training on

that type of error. Since 27.3 % of technicians reported memory attribute as usability catastrophe, manufacturers should elaborate more effort to memory dimensions (Perceptual procedures, hierarchical structure, default values, concrete examples, and generic rules and actions).

In daily CT operations, the study observation finds that examining patients rigidly, requires technicians to go to the exam room and center the patient accurately on the CT's table. Obviously, this procedure contributes to the physical and mental load. Evidently, there are non-machine related activities that contribute to general physical and mental load. For instance, in emergency rooms, technicians are expected to help the nursing team transfer the patient from the bed to the CT table. The non-machine related loads could come in many forms such as management targets, assigned departmental duties and status of exam room, for example. Knowing what contributes to physical and mental loads is essential to CT manufacturers, even if it is not machine-related because such knowledge could be a gate to future developmental growth, in terms of techniques or integrations

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## Usability Evaluation and Assessment of Computed Tomography Scan

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### Abstract

Usability is a vital characteristic in operating medical machines, especially radiological machines, such as computed tomography (CT) scans and X-rays. The more the body is exposed to it, the greater the negative effect has. If usability is crucial to a specific industry, it is more crucial in the medical health industry due to its tremendous effect on safety and the patient's health. This study examines the usability of CT scans based on 14 attributes from hospitals across Saudi Arabia. The study revealed that usability consistency, visibility, minimalism, memory, and flexibility have the most usability catastrophic complaints, where the overall catastrophic rate exceeds 20%. Creating a shortcut for frequently used operations is critically important, because it has a fundamental effect in minimizing physical and mental exertion.

### Keywords

Usability Evaluation, CT Scan Usability Assessment, User Experience

### 1. Introduction

The usefulness of medical devices is marked by the extent to which they can execute tasks effectively, effortlessly, and easily. Advances in science and technology have made executing tasks increasingly complex. It requires years of learning and practice to efficiently operate modern medical devices, such as computed tomography (CT) scans or magnetic resonance imaging (MRI) [1]. A key contribution to such complexity is the fact that contemporary systems consist of multiple layers with extreme compatibility and intractability. When constituting a multi-layer system based on safety and security only, it becomes negative goals. Rather, it should constitute more layers to achieve overall functionality [2]. Moreover, [3] showed that the overall expectation of CT scan technological evo-

lutions is to make the CT scan a more usable with a better user-friendly interface; however, the study showed that more technological evolution introduces increased complexity.

The general assumption for medical devices is that they ought to be usable and suited for their purpose [4]. To efficiently operate a CT scan requires adaptability with other systems, such as radiology information systems (RIS) or picture archiving and communication systems (PACSs). These systems integrate with a superior ecosystem called the hospital information system (HIS). The purpose of the HIS is to collect all patient records and make them retrievable by many of the hospital's applications [5]. Therefore, a CT scan operation is one component of an ecosystem. This isolated component has a tremendous effect on the overall ecosystem, and most importantly, it has a great effect on the indirect user (patient).

This paper will contribute to the general understanding of CT scan usability. Particularly, it explicitly focuses on technicians from Saudi Arabia. It observes and documents the usability encountered by technicians and provides recommendations to manufacturers and designers. The paper is structured as follows. Section 2 discusses the reality of the context of use within the operation of radiology. Section 3 discusses the study justification and objective. Section 4 details the methodology approach. Section 5 presents the results. Finally, Section 6 concludes the paper.

## 2. Context of Use

In general, usability is extremely essential to buyers because it brings certain benefits and, above all, contributes to maximizing safety. Furthermore, in the healthcare environment, usability is crucial because it contributes to safety and the prevention of errors. To [6], usability revolves only around the user, where the user should be involved, engaged, and doing something within the context of the product or system. Working in the healthcare environment makes one susceptible to extreme physical and mental loads as well as industry guidelines and requirements. Furthermore, [7] noted that usability is an essential attribute of safety. Thus, many industries tend to share this attribute [8] [9] [10].

Eventually, the context of use can be measured by calculating influential factors that affect (positively or negatively) the functionality of the product or users. The context of use covers a wide context of an organization's geopolitical atmospheres, such as requirement components and fitness for use (Figure 1). The workload can also negatively pressure the context of use. In addition, [11] has shown that the invisible workload can tremendously affect the working process of the CT scan operation. It was evident that radiologists seek minimal effort to divert invisible physical exertion after a certain operational time. Thus, radiologists maneuver the CT scan testing process so that they can avoid roving back and forth between the CT scan and the control room [12].

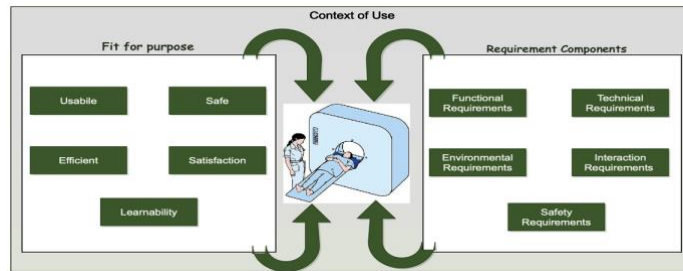


Figure 1. Context of use within the CT scan operation.

### 3. Study Objectives

Most usability evaluations that targeted healthcare in Saudi hospitals tend to discuss the obstacles of introducing new technologies. Nonetheless, literature progress that offers a sense of solution has been extremely limited. One fundamental reason is that many researchers have adopted their methods and evaluated attributes from a pure software perspective. It is fundamentally essential to examine and evaluate healthcare products based on the context of use and, in particular, involving the direct user (technician) and indirect user (patient) together. This study closely examines 14 usability attributes of the CT scan in Saudi hospitals. It also classifies the usability attributes based on severity. Understanding such severity is expected to help CT scan designers and manufacturers to improve future products to suit a specific market. In addition, the fundamental aim of this study is to explain the user's demographic differences where gender, age, education, and experience pose a threat in handling and operating the CT scan.

### 4. Method

To answer the research questions, a survey questionnaire was adopted. The research questions are 1) What usability attribute is deemed important to CT scan technicians? 2) What usability attribute do technicians have the most trouble with?

#### 4.1. Procedure

The authors surveyed usability questionnaires that measured the lack of usability from different angles. The authors chose to adopt [4] because it was unambiguously intended for medical device use. The questionnaire measured 14 usability dimensions (Table 1). The responses to the questionnaire are based on a five-point Likert scale. Prior to the start, we conducted field observations in King Saud Medical City (KSMC). During the observation, the first author evaluated the operational usability in association with the everyday use and the applicability of the questionnaire to the CT scan context of use. The results were analyzed using SPSS 24.

Table 1. Usability attributes as defined by [4].

Attribute	Explanation
Consistency	Consistency and standards: Users should not have to wonder whether different words, situations, or actions mean the same thing. Standards and conventions in product design should be followed.
Visibility	Visibility of system state: Users should be informed about what is going on with the system through appropriate feedback and display of information.
Match	Match between system and world: The image of the system perceived by users should match the model the users have about the system.
Minimalist	Minimalist: Any extraneous information is a distraction and a slow down the process.
Memory	Minimize memory load: Users should not be required to memorize a lot of information to carry out tasks. Memory load reduces the users' capacity to carry out the main tasks.
Feedback	Informative feedback: Users should be given prompt and informative feedback about their actions.
Flexibility	Flexibility and efficiency: Users always learn, and users are always different. Give users the flexibility of creating customizations and shortcuts to accelerate their performance.
Message	Good error messages: The messages should be informative enough such that users can understand the nature of the errors, learn from the errors, and recover from any errors.
Error	Prevent errors: It is always better to design interfaces that prevent errors from happening in the first place.
Closure	Clear closure: Every task has a beginning and an end. Users should be clearly notified about the completion of a task.
Undo	Reversible actions: Users should be allowed to recover from errors. Reversible actions also encourage exploratory learning.
Language	Use the users' language: The language should be always presented in a form that is understandable by the intended users.
Control	Users in control: Do not give users that impression that they are controlled by the systems.
Document	Help and documentation: Always provide help when needed, ideally context-sensitive help.

The authors received ethical approval from the Ministry of Health in Saudi Arabia and satisfied the requirements of dealing with a human as an object of research.

#### 4.2. Participants

Even though radiology technicians are able to operate many radiology machines interchangeably, such as CT scans or MRIs, the study only focused on technicians who were using the CT scan on a daily basis at the time of the study. The total number of participants was 44 CT scan technicians (Table 2 shows demographic characteristics). The technicians were geographically from hospitals in all 13 Saudi regions.

#### 5. Results

Cronbach's alpha was conducted to measure the reliability of the questionnaire

(Table 3). Generally, Cronbach's alpha is acceptable when the value is above 0.80 [13]. All attribute scores were above the acceptable level of 0.80. In terms of usability catastrophe, all attributes have a usability catastrophe percentage. However, seven usability attributes exceeded the 20% range:

Table 2. Demographic characteristics.

Variables	Column1	Frequency	%
Gender	Male	26	59.1%
	Female	18	40.9%
Age	20 - 29	14	31.8%
	30 - 39	23	52.3%
	40 - 49	7	15.9%
Level of Education	Diploma	11	25.0%
	Bachelor	25	56.8%
	Master	8	18.2%
Years of Experience	0 - 3 years	16	36.4%
	4 - 7 years	11	25.0%
	8 - 11	9	20.5%
	12+	8	18.2%

Table 3. Cronbach's alpha.

Usability attribute	No. of items	Cronbach's Alpha
Consistency	6	0.947
Visibility	4	0.903
Match	3	0.901
Minimalist	4	0.919
Memory	5	0.934
Feedback	4	0.907
Flexibility	3	0.877
Message	4	0.909
Error	5	0.902
Closure	3	0.913
Undo	4	0.864
Language	4	0.84
Control	2	0.843
Document	2	0.869

- layout and position,
- terminology,
- current state of the system,
- what can be done at the current state,
- progressive levels of detail at 20%,
- concrete examples at 20%, and
- shortcuts for frequently used operations at 27.3%.

These attributes belong to consistency (two attributes), visibility (two attributes), minimalism (one attribute), memory (one attribute), and flexibility (one attribute). Table 4 illustrates the descriptive statistics for all usability attributes. Evidently, the maximum statistic registers as 4, which is a catastrophe for every attribute. This indication shows that users have varied abilities in handling the CT scan. These variations are in accordance with social demographic characteristics. The statistic means were examined, where the uppermost is 2.34, and the lowermost is 1.55. Figure 2 presents the overall usability score based on the 14 usability attributes. A higher number indicates more usability issues faced by the technicians. As a group, most of the issues were concentrated within the categories of document (56.5%), flexibility (56%), and visibility (55.5%).

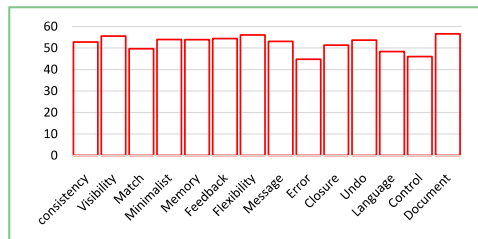


Figure 2. Overall usability percentage encountered by technicians.

Table 4. Descriptive statistics.

	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
Sequences of actions (Consistency)	0	4	2.11	0.173	1.146	1.312
Color (categorization) (Consistency)	0	4	2.14	0.188	1.250	1.562
Layout and position (Consistency)	0	4	2.05	0.213	1.413	1.998
Font, capitalization (Consistency)	0	4	2.11	0.206	1.368	1.871
Terminology (Consistency)	0	4	2.05	0.227	1.509	2.277
Standards (Consistency)	0	4	2.20	0.202	1.340	1.794
the current state of the system (Visibility)	0	4	2.23	0.210	1.395	1.947
does the display show where you can go (Visibility)	0	4	2.34	0.213	1.413	1.997
Where can users go (Visibility)	0	4	2.20	0.197	1.304	1.701

Continued

made change after an action (Visibility)	0	4	2.11	0.163	1.083	1.173
User model matches system image (Match)	0	4	1.91	0.186	1.235	1.526
Actions provided by the system match actions performed by users (Match)	0	4	1.93	0.164	1.087	1.181
Objects on the system match objects of the task (Match)	0	4	2.11	0.204	1.351	1.824
Less is more (Minimalist)	0	4	2.14	0.164	1.091	1.190
Simple is not equivalent to abstract (Minimalist)	0	4	2.11	0.176	1.166	1.359
Simple is efficient (Minimalist)	0	4	2.14	0.171	1.133	1.283
Progressive levels of detail (Minimalist)	0	4	2.25	0.203	1.349	1.820
Perceptual procedures (Memory)	0	4	2.20	0.194	1.286	1.655
Hierarchical structure (Memory)	0	4	2.30	0.183	1.212	1.469
Default values (Memory)	0	4	2.18	0.201	1.334	1.780
Concrete examples (Memory)	0	4	1.98	0.231	1.532	2.348
Generic rules and actions (Memory)	0	4	2.11	0.182	1.205	1.452
Information directly perceived, interpreted, and evaluated (Feedback)	0	4	2.14	0.183	1.212	1.469
Levels of feedback (Feedback)	0	4	2.32	0.168	1.116	1.245
Concrete and specific (Feedback)	0	4	2.02	0.144	0.952	0.906
Appropriate Response Time (Feedback)	0	4	2.23	0.152	1.008	1.017
Shortcuts for experienced users (Flexibility)	0	4	2.32	0.189	1.253	1.571
Shortcuts for frequently used operations. (Flexibility)	0	4	2.39	0.196	1.298	1.684
Skill acquisition through chunking (Flexibility)	0	4	2.02	0.191	1.267	1.604
Phrased in clear language (Message)	0	4	2.14	0.199	1.322	1.748
Precise, not vague or general (Message)	0	4	2.34	0.189	1.256	1.579
Constructive (Message)	0	4	2.02	0.167	1.110	1.232
Polite (Message)	0	4	2.00	0.166	1.100	1.209
Interfaces that make errors impossible (Error)	0	4	1.75	0.181	1.203	1.448
Avoid modes (Error)	0	4	1.57	0.193	1.283	1.646
Sound Experience (Error)	0	4	1.98	0.177	1.171	1.372
Execution error vs. evaluation error (Error)	0	4	1.86	0.180	1.193	1.423
Various types of slips and mistakes (Error)	0	4	1.80	0.183	1.212	1.469
Clear beginning, middle, and end (Closure)	0	4	2.05	0.184	1.219	1.486
Complete 7-stages of actions (Closure)	0	4	2.16	0.159	1.055	1.114
Clear feedback to indicate goals are achieved (Closure)	0	4	1.95	0.187	1.238	1.533
At different levels: a single action, a subtask, or a complete task. (Undo)	0	4	1.98	0.158	1.045	1.092
Multiple steps (Undo)	0	4	2.09	0.165	1.096	1.201

Continued

Encourage exploratory learning (Undo)	0	4	2.23	0.178	1.179	1.389
Prevent serious errors. (Undo)	0	4	2.30	0.154	1.025	1.050
Use standard meanings of words (Language)	0	4	1.82	0.179	1.187	1.408
Specialized language for specialized group (Language)	0	4	2.14	0.171	1.133	1.283
User defined aliases (Language)	0	4	2.23	0.178	1.179	1.389
Users' perspective (Language)	0	4	1.55	0.157	1.044	1.091
Users are initiators of actors (Control)	0	4	1.77	0.159	1.054	1.110
Avoid surprising actions (Control)	0	4	1.91	0.141	0.936	0.875
Context-sensitive help (Documentation)	0	4	2.23	0.175	1.159	1.342
Help embedded in contents	0	4	2.30	0.161	1.069	1.143

## 6. Conclusion and Discussion

Despite the heavily regulated practices in radiology, CT scan technicians are overwhelmingly concentrated on delivering images that can be read easily by doctors and interpreters. Undeniably, usability has a profound effect on both technicians and patients. It empowers the technician's ability to execute more tasks within a defined time and reflects on the patient's overall safety. With pressure for resources, technicians tend to maneuver physical exertion by minimizing movement after a certain time. A technician was observed after 4 hours of CT scan operation trying to divert physical movement (going to the exam room to center the patient) by telling the patient to lay down on the table. Then, the technician examined the patient using the repeat series feature without the necessity to go physically into the room to center the patient on the CT scan table. This attitude agrees with the study finding that 27% of technicians rated CT scans as catastrophic in shortcuts for frequently used operations. Considering that going to the exam room to center the patients is the most frequently used operation while operating a CT scan, one important principle of this study is that CT scan designers should consider enforcing more flexibility in the machine, especially enabling users to easily conduct an exam from the control room without the necessity to summon the technician into the exam room to center and re-center patients. Executing tasks with efficiency might be enough in a particular device, but in a CT scan, it must also come with minimizing physical and mental exertion. Future work will examine the usability for system engineering. A system engineering model will be introduced to handle business intelligence reporting with an emphasis on practical usability principles.

### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.



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# On the Impact of Product Usability on CT Scan Scheduling: The Case of Saudi Hospitals

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**Abstract**—Product usability has been subjected to many evaluation techniques. Many evaluation techniques use heuristics approach to evaluate the overall usability of the product. Considering heuristics works in some particular examples, In the healthcare sector, heuristics approach is hard to implement due to fundamental constraints (stakeholders, safety, and time requirements). This paper examines a scheduling algorithm that correlates to usability problem. The scheduling algorithm has a definite impact on the product Return of investment and customer satisfaction.

**Index Terms**—CT Scan scheduling, CT Scan operational Usability

## I. PURPOSE/AIM AND BACKGROUND

CT scan is sensitive to demographical factors. (Aldoihi, Hammami, 2018) found that CT scan usability attributes are indeed differed based on a demographic characteristic such as gender and years of experience. Many CT technicians are still troubled with CT's usability due to its complexity and interconnectivity with other ecosystems (Aldoihi, Hammami, 2018). One key contributing factor is invisible physical and mental exertion generates while operating a CT scan. (Aldoihi, Hammami, 2019) found mounting evidence that there is an extremely high amount of physical and mental exertions during daily CT operations. Product usability is extremely interconnected with a different operational and organizational ecosystem where the interconnectivity transferred into exertions on the operator. Thus, product usability will have an impact on the operator in term of bonding to its many requirements (such as safety, optimization, and scheduling). Scheduling tasks in hospitals have been the subject of numerous studies and we aim at analyzing in the state of the art of scheduling with the use of product usability and the resulting time uncertainty.

## II. CT SCAN PRODUCT USABILITY FINDINGS

CT scan is an extremely complicated machine. It takes many years of training to master its basic functionality, and it required the involvement of technician, patient, and the machine to maneuver only one task. More importantly, Ct scan is indispensable evaluation tool. It evaluates the patient's internal organs for various conditions. More significantly, such evaluations enable doctors to visualize an instant image of the affected organs, and eventually, doctors are able to take accurate decision based on the severity. Usability is a decisive

element of the CT scan. In a study of evaluating the usability of CT scan, (Aldoihi, Hammami, 2018a) found there is 67 usability Catastrophe that can lead to death or major injury while operating CT scan. Additionally, there are 181 major usability, 193 minor usability, and 88 cosmetic problems. These usability issues in total are 529. (Aldoihi, Hammami, 2018b) evaluated CT scan usability based on 14 attributes, and they found Memory (scored 27% on the catastrophic scale), Visibility (scored 20% on the catastrophic scale), Consistency, (scored 18% on the catastrophic scale), and Flexibility (scored 18% on the catastrophic scale) are most complaint about by CT scan Technicians. Besides usability, exertions are fundamentally essential factors. (Aldoihi, Hammami, 2018b) found technicians' mental exertion at its maximum (23%) while operation CT scan. In essence, exertions go hand in hand with usability. (Aldoihi, Hammami, 2019) observed some CT scan routine operational practice transformed into exertions. They called it an invisible exertion where action like transferring the bedridden patient from hospital bed onto CT scan's table result in tremendous physical exertions adds-up. (Aldoihi, Hammami, 2019) divided exertions into two parts which are physical and mental. Each part consists of three statements. For the physical exertion, 80% of the radiologist confirmed that they regularly transfer a bedridden patient to CT scan's table. Similarly, 93%of radiologist confirm that they engage in routinely preparing the room for receiving the next patient which include cleaning and disinfecting the CT scan table. A final physical statement, 89% of radiology confirmed that they frequently administrate the contrast media for all patients. For the mental exertion, 57% of radiologist believed that they work in an understaffed environment. 70% of radiologist believed that under current working environment the radiology department needs more CT scan machine. 57% of radiologist believed that management targets are not aligned with the existing resource.

## III. STATE OF THE ART

Several studies have addressed the scheduling of personnel and resources in the hospital context. Among others physician scheduling, multi-period and multi-resource operating room scheduling and block scheduling at magnetic resonance imaging labs. The question addressed by this paper is: what type of

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task duration model has been used in tasks scheduling which can take into account product usability impact ? as an example we take the following models of CT Scan tasks execution time over a day with the assumption of 15 mins baseline examination duration and 20 patients processing.

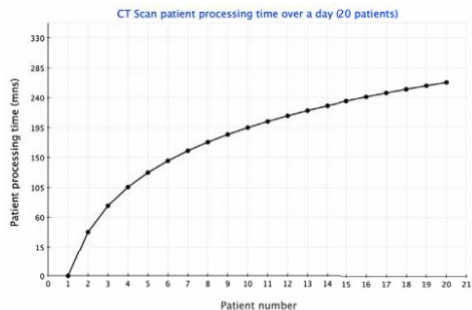


Fig. 1. log distribution

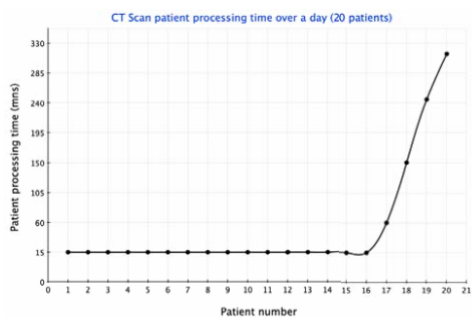


Fig. 2. Exp. distribution

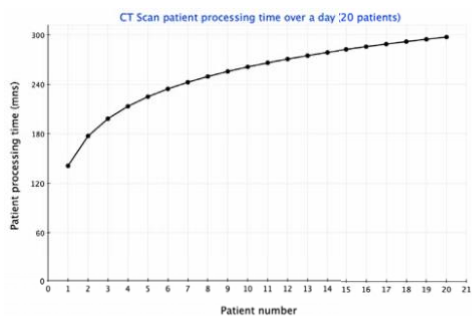


Fig. 3. log distribution (n x 15 mins)

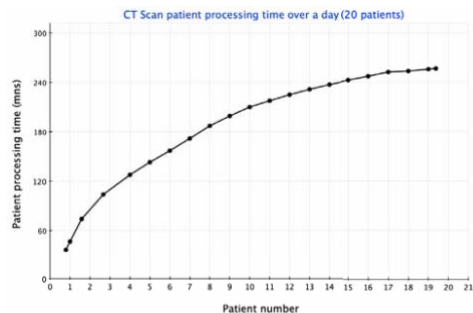


Fig. 4. Exp. distribution (n x 15 mins)

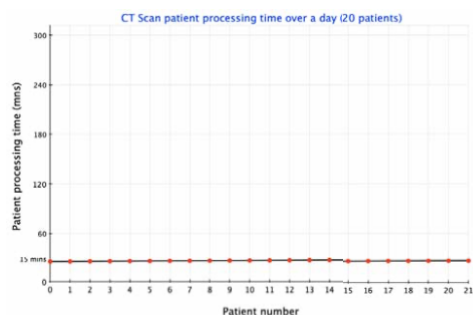


Fig. 5. linear distribution

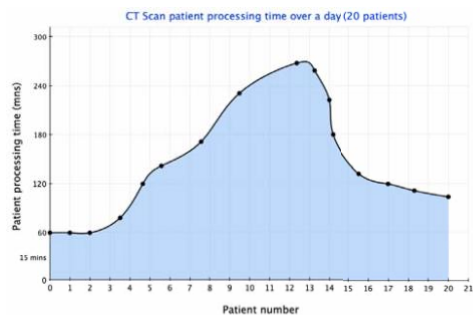


Fig. 6. random distribution

These 6 cases represent the various impact of product usability with Fig. 5 being the theoretical case where tasks

are conducted with constant duration while the exponential distribution describes the situation where tasks duration grows exponentially over the day with last tasks being the longest reflecting cumulative effects of product usability. The random distribution describes variations during the day (start of the day, end of the morning, after lunch and before the end of the day).

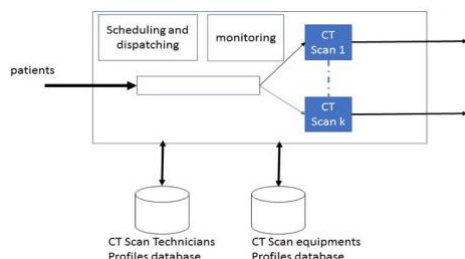


Fig. 7. Product Usability /technician CT Scan Dynamic Scheduling

The assumption here is that task duration per CT scan is collected for each task execution part of the HCI. This monitoring only purpose is to avoid considering artificial tasks duration models or tasks duration distributions and rather take into account the actual durations. The objective being to avoid mental and physical exertion on the technician and better overall scheduling for the hospitals. This data collection can also be accessed by the CT scan technician to better also understand his/her own evolution and condition.

#### IV. FINDINGS AND RESULTS

The conducted review of the state of the art in scheduling models proposed in the literature in hospitals context shows that product usability is not taken into account for fine-tuning tasks execution time. Whatever the technician level of education, work experience, age, gender specificities tasks are assumed constant in CT scan operations. Heterogeneity is absent. The dominant optimization technique used for scheduling being linear programming requires constant task execution time which is not appropriate.

Our findings trigger a new avenue of research balancing the existing results achieved in the literature on the estimation of the required consultation time distribution based on the required type of medical treatment and the person's characteristics like age, medical record and the number of previous visits but from the technician side.

The proposed model of CT Scan scheduling is described in figure 7. Patients arrive in FIFO (First-in First-out) order and are scheduled and dispatched over several CT scan machines based on CT scan technician product usability profiles. The CT scan tasks are monitored and tasks duration are collected for every technician operating CT scan machine over the day building a database of CT Scan technician correlated to a database of CT scan equipment. The scheduling and

dispatching unit will apply dynamic scheduling over the CT scan machines exploiting CT scan technician profiles with product usability.

This boils down to scheduling optimization under uncertainty and can be improved in the era of big data and deep learning. The proposal is to integrate machine learning to build predictive models of CT scan technician profiles.

The proposed optimization technique to be used with product usability model per technician being multi-objective evolutionary (NSGA-II).

Future work is to be conducted in collecting data from CT Scan technicians with more data to be collected in hospitals with technician task execution time duration recording.

#### V. CONCLUSION

Product usability studies have large consequences in daily tasks and among them tasks scheduling. It is essential to integrate models of product usability over time in the scheduling of hospitals tasks scheduling for realistic execution of tasks. In the case of the CT scan, we argue that models should be proper to each technician taking into account education level, work experience, age, and several other parameters to allow fine-tuning. Reducing task execution time uncertainty through new predictive models based on product usability will improve return on investment (ROI) for costly CT scan equipment, reduce unnecessary overload and improve hospitals customer satisfaction.

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# Evaluation of Invisible Physical and Mental Exertion from CT Scan Operation in Saudi Arabian Hospitals

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**Abstract**—Advancement in science and technology has increased work exertion tremendously. Many researchers and professionals have noted the importance of work exertion in correlation with the work environment. However, there is no mention of the principle of invisible exertion correlated with the current advancement of science and technology. This paper evaluates the invisible physical and mental exertion for CT scan technicians. Fifty-seven CT scan technicians were surveyed to determine the extent of their invisible physical and mental exertion. The overwhelming majority of technicians reported significant exertion while operating the CT scan. The invisible physical and mental exertion occurred differently in accordance with demographic characteristics. Gender is a significant factor, where male technicians reported more physical invisible exertion than female technicians. The invisible physical exertion occurred more than invisible mental exertion.

**Index Terms**—invisible exertion, CT scan invisible exertion, CT scan overload effects

## I. INTRODUCTION

Heuristics is a popular method to evaluate system and product usability, and it proposes improvements during and after the development. A key component of the success and rising popularity of heuristics is its low cost and effectiveness.

In academia, there are 152 usability attributes [1]. As a customary practice in industry and academia, usability is constructed from a list of attributes to constitute the dimensions of the cohesive whole. Geisen and Bergstrom [2] referred to these dimensions as metrics for evaluation. It is clear from the literature that usability lacks uniformity and unity of dimensions, which has caused some ambiguity among new researchers.

However, it is vitally important to state why usability diverges in dimensions. An important reason is that usability is used to evaluate various products and systems that hold different execution goals and purposes. According to Ferre et al. [3], usability can only be defined in accordance with the intended system and the

intended users. They illustrated their argument regarding a museum kiosk where the dimensions must emphasize minimum training since kiosk users are most likely to use it only once in their lifetime.

Similarly, usability attributes should be representative of the overall environment where the larger scope must be counted as an attribute. For instance, the incorporated usability considers the local environment of the work, including the managerial target and departmental duty that measures the invisible exertion, which can contribute to and affect usability. The obvious objective is to use the usability evaluation to consider human factors that are associated with the work and managerial environments. When evaluating usability attributes, there is a clear indication that they lack an exertion evaluation, such as for physical and mental exertion. Consequently, many authors [4] [5] [6] have included NASA-LTX for a usability evaluation as a substitute for physical and mental exertion, which is lacking in popular heuristic methods.

One of the ISO 9241 usability evaluation settings is “context of use.” In essence, it implies that evaluation usability must consider the work atmosphere in which the device or system would operate. For instance, when evaluating a newly developed CT scan, the natural everyday busy setting of an over-crowded and understaffed hospital must be considered, including the management target and duty expected from the operators. In other words, exertion delivered from any source should be included in an operator’s human factor and usability evaluations. Dimensional attributes such as safety, operator satisfaction, and productivity are the essence that constitutes the overall usability [7]. Furthermore, impeding attributes that consider the organizational context would add more accuracy and validity of the overall usability.

The overall objective of this study is to identify invisible exertion existence while operating CT and to identify

whether the Radiology Department duty and management targets can be transformed into invisible physical and mental exertion. To the best of our knowledge, there is no existing study that measures the invisible exertion of CT scan technicians and correlates the management process to influence technician exertion. The area of this research has not been exploited by other researchers; thus, the authors hope that this study will open a new area of research that considers invisible exertion of whatever kind and correlates it to the overall evaluation.

## II. BACKGROUND

### A. Usability as a factor in medical devices

From the beginning, medical devices have been implemented on the premise of assisting the examiner by providing vital information that could alter the examiner's decisions regarding the patients. As the devices gain more computing power and advanced sensing technology, more functionalities and connectivity with other devices present more challenges to the novice user. Consequently, evaluation methods have been suggested from different fields. In recent years, usability evaluations have dramatically shifted focus to medical devices.

Designing usability for medical devices is not like other electronic devices for the following reasons. Medical devices provide data on decisions regarding the actions of doctors. Medical device usability has a limit, where user characteristics and preferences count for the overall outcome. Aldoithi and Hammami [6] showed that CT scan operators indeed differ in perceiving the usability attributes according to gender and years of experience.

### B. Cognitive and Physical Exertion

Cognitive load is deeply involved in psychology. An obvious sign of such involvement is that cognitive load is only clarified through psychology or behavioral lenses [8]. Key components of cognitive load are the nature of the work and how memory can correspond with it [9]. Mental load has been perceived by early psychological theorists as a multi-dimensional phenomenon where the interpretation of phenomena comes as a result of the outcomes of the interaction between subjective individual characteristics and objective task characteristics [10] [11]. Subsequently, mental load resulting from indirect (invisible) work has not been properly studied.

Mental load studies have heavily concentrated on the direct aspects and have somehow neglected indirect aspects. It is essential to include invisible elements to understand the overall characteristics of the mental load since the mental load is multi-dimensional by nature. Mental load exists whenever there are intractable tasks that demand a great deal of control. There are three main aspects of invisible physical and mental loads, which are

task complexity, management requirements, and pressure of resources (see Fig. 1).

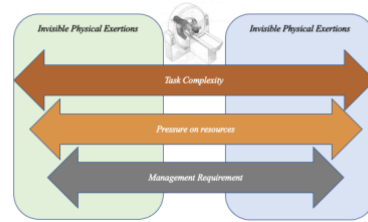


Fig. 1: A conceptual framework of the physical and mental exertion sources

Another extremely important load is the physical load. For CT scan technicians, there is a considerable amount of physical load during the operation of the machine. Nonetheless, there are many tasks performed by the technicians where the physical load is unavoidable. Such tasks are the framework of this study. For instance, it is a customary practice in Saudi Arabia that CT technicians help the bedridden patient transfer to the CT table. Literature has demonstrated the effect of overload on radiologists on many fronts. Various studies have explored the risk factors associated with excessive loads [12] [13] [14]. Bruni et al. [15] noted that considerable discrepancies in interpretation are demonstrated in the late shift for radiologists as opposed to the starting shift. It is critically important to explore and identify the effect of the invisible load on radiologists so that researchers and practitioners can propose reduction procedures.

## III. METHOD

For this research, the authors developed a survey questionnaire that measures invisible exertion while operating the CT. Such exertions can be unintended and come from the inner work environment.

1) *Participants*: The population of the study comprises CT scan technicians who operate the machine on a daily basis and who are geographically located in Saudi Arabia. One vital variable dimension that must be distinguished is the work sector. In Saudi Arabia, the healthcare sector is divided into two categories. That is a public and private sector. It is essential to distinguish these two groups within the demographic characteristics. In total, 57 technicians participated in this study. The participants are all CT scan technicians who, at the time of the study, were working in Saudi Arabia in either the public or private sector. Participants were invited to the study by either online questionnaire link or by

a telephone call. See Table 1 for more details of the demographic characteristics.

TABLE I: Participant Demographic Characteristics

Variable		Total Percentage
Gender	Male	50.90%
	Female	49.10%
Total		100%
Age	20-29	77.20%
	30-39	15.80%
	40-49	3.50%
	50+	3.50%
Total		100%
Educational level	Diploma	3.50%
	Bachelor	86.00%
	Master	10.50%
Total		100%
Years of Radiology Experience	0-3 years	68.40%
	4-7 years	8.80%
	8-11 years	10.50%
	12+	12.30%
Total		100%
WorkingSector	Public Sector	87.70%
	Private Sector	12.30%
Total		100%

2) *Survey method:* After evaluating the causes of invisible physical and mental exertion, a field visit was conducted to King Saudi Medical City (KSMC) to gather and observe technician exertion. Due to the excessive particularity of the measured variables, a questionnaire was developed to suit the special particularity. The questionnaire was sent to technicians across Saudi Arabia, asking them to respond to six statements regarding their views on physical and mental activities while operating a CT. Three statements represent physical exertion (PRQ), and the other three represent mental exertion (MRQ). The statements were as follows:

- 1) PRQ1: I have helped to transfer a bedridden patient from the hospital bed to the radiology table,
- 2) PRQ2: It is my duty to prepare the examination room for receiving the next patient,
- 3) PRQ3: It is my duty to prepare for contrast media administration as needed,
- 4) MRQ1: I think that I work in an understaffed environment,
- 5) MRQ2: I think that the department needs more CT scan machines,
- 6) MRQ3: I think that management targets are unreasonable (not in alignment with existing resources).

In addition, open-ended questions were added after each statement as optional commentary feedback. A self-rating questionnaire was created based on a five-point Likert scale.

#### IV. RESULTS

##### A. Invisible Physical Exertions

Invisible physical exertion is presented clearly in Fig. 2. The research statements demonstrate the invisible physical exertion through the activities that are required

to operate a CT from three dimensions, which are PRQ1-PRQ3, as stated above. For transferring the bedridden patient to the CT table, 29 (50.9%) technicians responded with "always." "Usually" constituted 17 (29.8%) responses. "Sometimes" constituted 10 (17.5%) responses, whereas "never" constituted only 1 (1.8%) response. For preparing the examination room for the next patient, 43 (75.4%) responded with "always." "Usually" constituted 10 (17.5%) responses. "Sometimes" constituted 4 (7%) responses. For preparing and administering the contrast media, 38 (66.7%) responded with "always." "Usually" constituted 13 (22.8%) responses. "Sometimes" constituted 4 (7%) responses. "Rarely" and "never" constituted 1 (1.8%) response.

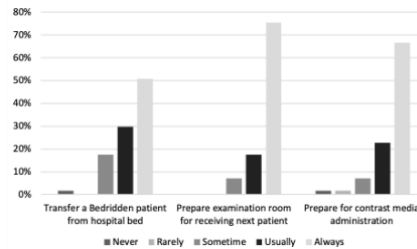


Fig. 2: Physical exertion responses

##### B. Invisible Mental Exertions

Invisible mental exertion is presented clearly in Fig. 3. The research questions demonstrate the invisible mental exertion through activities required to operate a CT from three dimensions, which are MRQ1-MRQ3, as stated above. For working in an understaffed environment, 14 (24.6%) technicians responded with "strongly agree." "Agree" constituted 19 (33.3%) responses. "Neutral" constituted 20 (35.1%) responses. "Disagree" constituted 4 (7%) responses. For suitability of the number of CT machines, 22 (38.6%) technicians responded with "strongly agree." "Agree" constituted 18 (31.6%) responses. "Neutral" constituted 7 (12.3%) responses. "Disagree" constituted 8 (14%) responses. "Strongly disagree" constituted 2 (3.5%) responses. For management alignment with existing resources, 14 (24.6%) technicians responded with "strongly agree." "Agree" constituted 19 (33.3%) responses. "Neutral" constituted 14 (24.6%) responses. "Disagree" constituted 10 (17.5%) responses.

##### C. Demographic Characteristics: Physical and Mental

- 1) *Gender:* Figure 4 shows the proportion of difference between male and female respondents. For the physical exertion statement in PRQ1, 62.1% of male



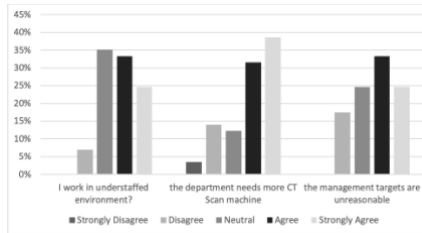


Fig. 3: Mental exertion responses

technicians indicated that they always contribute physically by transferring the bedridden patient to the CT table, in contrast to only 39.3% of female technicians. Interestingly, 3.6% of female technicians stated that they never helped or contributed to transferring the bedridden patients to the CT table. In response to PRQ2, 89.7% of male technicians indicated that they have always prepared the exam room for the next patient, as opposed to 60.7% of female technicians. In response to PRQ3, 79.3% of male technicians indicated that they always prepared the contrast media for the next patient, in contrast to 53.6% of female technicians. Interestingly, 7.2% of female technicians responded with "never" or "rarely."

In response to mental exertion statements, in MRQ1, 34.5% of male technicians indicated that they work in an understaffed environment, as opposed to only 14.3% of female technicians. In response to MRQ2, 48.3% of male technicians indicated that the department needs more CT scanners to accommodate the patient overload, compared to 28.6% of female technicians. In response to MRQ3, 27.6% of male technicians indicated that management targets are not aligned with existing resources, compared with 21.4% of female technicians.

2) *Age*: Age is a fundamental factor in determining physical and mental exertion. Figure 5 shows the proportion of difference between age groups from 20 to 29, 30 to 39, 40 to 49, and over 50. In response to the physical exertion statement in PRQ1, 43.2% of the 20 to 29 age group indicated they always contribute physically to transferring the bedridden patients to the CT table. Similarly, 66.7% of the 30 to 39 age group indicated that they always contribute physically, whereas all of the 40 to 49 and over 50 age groups indicated that they always contribute physically. In response to PRQ2, 75% of the 20 to 29 age group responded with "always" for preparing the examination room for the next patient, compared to 66.7% of the 30 to 39 age group. Both the 40 to 49 and over 50 age groups stated that they always prepare the examination room for the next patient. In response to PRQ3, 63.6% of the 20 to 29 age group

reported that they prepare and administrate the media contrast for the next patient, compared to 77.8% of the 30 to 39 age group, 50% of the 40 to 49 age group, and 100% of the over 50 age group.

In response to the statements regarding mental exertion, in MRQ1, 20.5% of the 20 to 29 age group strongly agree that they work in an understaffed environment in comparison with 33.3% of the 30 to 39 age group, 50% of the 40 to 49 age group, and 50% of the over 50 age group. In response to MRQ2, 38.6% of the 20 to 29 age group reported that they strongly agree that they work in the Radiology Department with fewer CT scans in operation, in contrast to 33.3% of the 30 to 39 age group and 50% of both the 40 to 49 and over 50 age groups. In response to MRQ3, 20.5% of the 20 to 29 age group reported that the management targets are not aligned with the existing resources, in comparison to 33.3% of the 30 to 39 age group and 50% of both the 40 to 49 and over 50 age groups.

3) *Years of radiology experience*: Years of experience is a dominant factor in determining the invisible physical and mental exertion. Figure 6 shows the proportion of difference between 0 to 3 years, 4 to 7 years, 8 to 11 years, and more than 12 years. In response to the physical exertion statement in PRQ1, 46.2% of those with 0 to 3 years of experience reported that they always contribute physically to transferring bedridden patients to the CT table, in comparison to 20% of those with 4 to 7 years of experience, 66.7% of those with 8 to 11 years of experience, and 85.7% of those with more than 12 years of experience. In response to PRQ2, 74.4% of those with 0 to 3 years of experience reported that they always prepare the examination room for the next patient, in contrast to 80% of those with 4 to 7 years of experience, 66.7% of those with 8 to 11 years of experience, and 85.7% of those with more than 12 years of experience. In response to PRQ3, 61.5% of those with 0 to 3 years of experience reported that they prepare and administrate the media contrast for the next patient, in comparison to 80% of those with 4 to 7 years of experience, 66.7% of those 8 to 11 years of experience, and 85.7% of those with more than 12 years of experience.

In response to the mental exertion statement in MRQ1, 17.9% of those with 0 to 3 years of experience reported that they strongly agreed that they work in an understaffed environment in contrast to 40% of those with 4 to 7 years of experience, 33.3% of those with 8 to 11 years of experience, and 42.9% of those with more than 12 years of experience. In response to MRQ2, 41% of those with 0 to 3 years of experience reported that they strongly agree that they work in a Radiology Department with fewer CT scans in operation, compared to 20% of those with 4 to 7 years of experience, 50% of those with 8 to 11 years of experience, and 28.6% of those

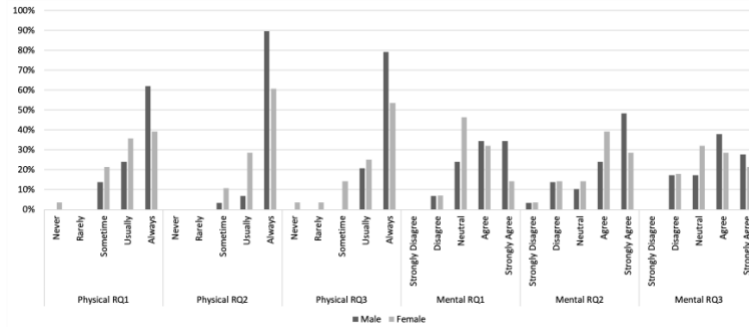


Fig. 4: Physical and mental exertion response based on gender

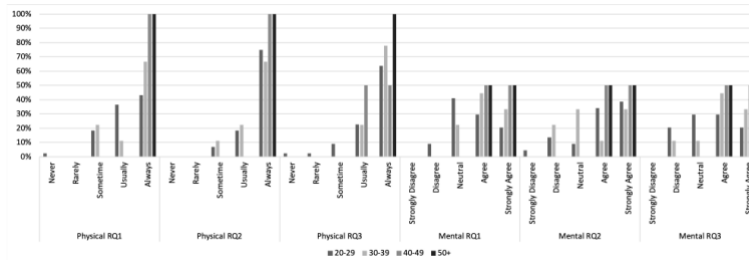


Fig. 5: Physical and mental exertion response based on age

with more than 12 years of experience. In response to MRQ3, 23.1% of those with 0 to 3 years of experience reported that the management targets are not aligned with existing resources, in contrast to 33.3% of those with 8 to 11 years of experience and 42.9% of those with more than 12 years of experience.

V. CONCLUSION

Generally, the findings suggest that there is indeed invisible physical and mental exertion associated with the operation of CT scans. Regarding the agreement rate in response to the physical statement in PRQ1, 80.7% of radiologists confirmed that they commonly transfer bedridden patients to the CT table. Therefore, manufacturers should pay extra attention when designing the machine because meeting the technical requirements is not enough for delivering a suitable machine that meets all work environment requirements. It is fundamentally ideal if the manufacturing standards cover customization that meets the lowest end-user specifications. Fundamentally, patients are the core reason for the existence of the machine. Therefore, empowerment of the patient's current condition during the exam is highly sought after by many patients, especially during the movement

of bedridden patients from and to the CT table. The current CT scan machine on the market lacks the basic habilitation capability that is needed to empower those who are bedridden. The agreement rate in response to the physical statement in PRQ2 indicates that 93% of radiologists confirmed that they frequently prepare the examination room for each patient. Moreover, the agreement rate in response to the physical exertion statement in PRQ3, 89.5% of the radiologists confirmed that they frequently prepare and administrate the contrast media to patients. The findings imply that invisible physical exertion occurs more than invisible mental exertion. The agreement is 57.9% for the mental exertion statement in MRQ1, 70.2% for MRQ2, and 57.9% for MRQ3. Two-thirds of radiologists agree with the mental exertion statement. Nonetheless, they almost consensually agree with the invisible physical exertion general statements. As future work, the authors intend to propose a human-centered system engineering model to integrate usability and exertions at the very beginning of the design flow.

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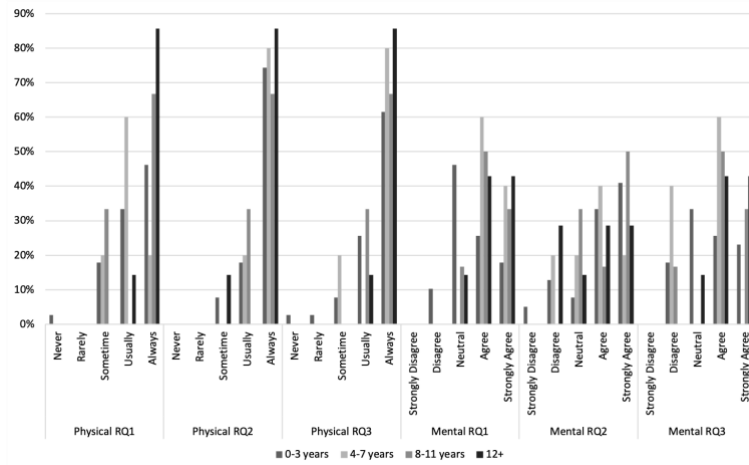


Fig. 6: Physical and mental exertion response based on years of experience

thanks goes to all participants who made the time and effort to participate in this study.

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# Effect of Invisible Exertions on Computed Tomography Radiologists in Saudi Hospitals

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**Abstract**—Current radiology practices face extreme pressure on available resources with demands of multi-dimensional requirements. Technicians are at the center of a constant drive for optimal productivity and optimization with the minimal possible resources. This paper evaluates the invisible physical and mental exertions resulting from operating computed tomography (CT) scans by fifty-seven technicians surveyed following current radiology practices. Demographic characteristics were reviewed to evaluate differences across the study variables based on gender, level of education, years of experience, and working sector.

**Index Terms**—invisible exertions, Evaluation of invisible exertion, CT scan invisible exertion, CT scan overload effects

## I. INTRODUCTION

The effects of physical and mental exertion on technicians working in radiology are overwhelming. Current radiology practice suffers from declining salaries, increasing workload, and workflow complexity [1]. Although a radiology work environment is categorized as shift work, disturbances in daily sleeping cycles are associated with physiological and behavioral effects as well as a loss of the rhythm entrainment [2]. Considerable fatigue and human error affect radiology practices with recent literature covering how diagnostic accuracy is compromised after long working hours [4][5][6][3] [7]. Under financial pressure, radiologists' practices are adopting a faster and more agile productivity style to accommodate larger workloads. Radiologists are now more likely to increase their interpretation error by 26.6% as opposed to 10% under average working speeds [8].

Radiology technicians today experience extreme pressure from many invisible exertion constraints, such as safety requirements, ethical practices, productivity and optimization requirements, system and technology requirements, and industry best practice adaptations. Regardless of the industry, most new requirements are driven by increasing safety [9]. Technicians are expected to facilitate all requirements while retaining the integrity of daily tasks. CT scan working conditions are categorized into the following themes:

- Dim lighting
- Small and confined control rooms
- Safety standards and practices
- Facilitating Technology

This study evaluates existing invisible physical and mental exertions experienced during CT scan operation and identifies

demographic differences among the study participants, such as gender, age, years of experience, and working sector.

Furthermore, the study explores the type of invisible exertion as physical or mental. To the best of our knowledge, no previous research explored and evaluated these invisible exertion effects for CT technicians. As other researchers have not exploited the theme of this study, we expect this work can open a new arena of research for evaluating a variety of invisible exertions and their effects on working environments.

## II. DESCRIPTION OF THE PROBLEM

The current state of hospitals demands a substantial amount of efficiency provided from a minimal amount of resources. So, radiologists today are working with multi-objective aims, such as safety and optimization of space and other resources, and exertions from various directions provide added pressure to radiologists. However, considerable pressure results from invisible sources. The working practice of CT scan radiologists demands proactivity and efficiency with daily operating routines that include helping bedridden patients move to the CT scan table, administrate the contrast media, and re-centering the position of the patient. Therefore, numerous such activities result as invisible exertions, which can be categorized as non-machine-related exertion. As hospital management teams strive to maximize productivity and optimize the intake of resources, identifying primary sources of invisible exertion is imperative to maximize productivity while minimizing human error.

In field observation, radiologists overcome invisible exertion through a variety of techniques and maneuvers. During a CT exam, extensive effort positioning the patient correctly on the CT table is required before the exam. Technicians are required to direct the patient to lay down on the CT table and ensure the patient is precisely centered. Often, after a technician has spent many hours of extensive operating exams, they may try to prevent invisible exertion by maneuvering the CT scanner instead of directly re-centering of each patient. So, without the need to configure a new exam for each patient, the technician modifies the previous exam for the new patient to avoid entering the exam room and re-centering the patient. Figure1 and Figure2 show this repeated series functionality. Figure 3 summarizes the various exertions required during a

CT scan, and this study highlights the impact of these actions on the operating technicians.

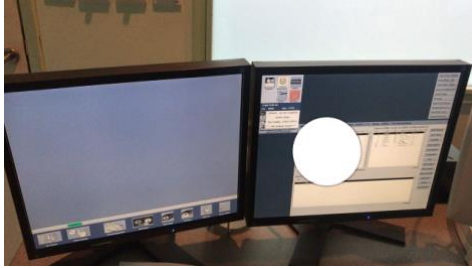


Fig. 1: Repeat Series



Fig. 2: Repeat Series

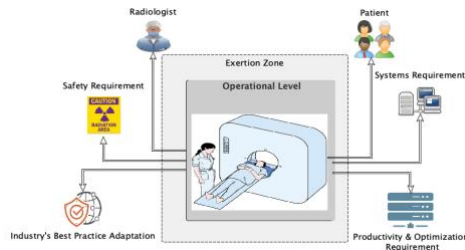


Fig. 3: Overview of the range of invisible exertions required by a CT technician.

### III. METHODS

Eighteen hours of observational field visits were conducted at the Radiology Department in King Saud Medical City. This stage worked as a preliminary phase to collect and observe variables requirements. The purpose of the visits was to pinpoint the various sources of invisible physical and mental exertions. A questionnaire was also developed to measure invisible exertions in terms of the physical and mental aspects while operating a CT scanner.

Ethical approval was sought and approved by the Ministry of Health in Saudi Arabia after satisfying the legal requirements of the Ministry's Institutional Review Board. Also, ethical principles were maintained and preserved for confidentiality, anonymity, and the right to withdraw.

#### A. Participant

The study featured 57 radiology technologists who operate CT scans daily. The participants came from hospitals across all 13 regions. The genders comprised 50.9% male and 49.1% female with an age range from 20 to over 50 years. This range spread included 77.2% from 20 to 29 years, 15.8% from 30 to 39 years, 3.5% from 40 to 49 years old, and 3.5% over 50 years. Education comprises 3.5% as having earned a diploma, 86% with a bachelor's degree, and 10.5% with a master's degree. Years of experience consisted of 68.4% with 0 to 3 years, 8.8% with 4 to 7 years, 10.5% with 8 to 11 years, and 12.3% with more than 12 years. The working sectors included 87.7% in the public sector and 12.3% in the private sector.

#### B. Procedure

Following the initial on-site observations of CT operations, a survey consisting of two parts was developed to measure the invisible physical and mental exertions experienced while operating the CT scanner. The first part collected participant demographic characteristics, as reported in the previous section, and the second included participant responses for two invisible exertion measurements. A volunteer was recruited to visit the hospitals and offer a paper-based questionnaire. In addition, an electronic version of the questionnaire was developed and sent to the participants.

#### C. Measurement

The objective is to measure the physical and mental dimensions of invisible exertion. Table 1 describes these two dimensions each with three associated measurement attributes.

TABLE I: DIMENSION MEASUREMENT

Exertion Dimension	Measurement
Physical	Transfer a Bedridden patient from a hospital bed onto a CT table
	Prepare the examination room for receiving next patient
	Prepare and administrate for contrast media
Mental	working in an understaffed environment
	the department needs more CT Scan machine
	the management targets are unreasonable

### IV. RESULTS

#### A. Gender

1) *Invisible Physical Exertion*: Male respondents (Mdn = 25.46) did not appear to differ from female (Mdn = 32.41) in the amount of transferring bedridden patients from a hospital bed onto a CT table ( $U = 307$ ). However, males (Mdn = 24.84) did significantly differ from females (Mdn = 33.02) in preparing the examination room for the next patient ( $U = 289.5$ ,  $z = -2.47$ ,  $p = 0.013$ ). Males (Mdn = 24.62) also

significantly differed from females (Mdn = 33.22) in preparing and administering the contrast media for patients ( $U = 283.5$ ,  $z = -2.35$ ,  $p = 0.019$ ). Figure 4 and 5 provide box plots for these differing variables.

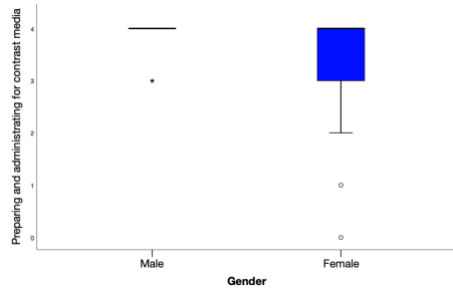


Fig. 4: Gender difference in preparing and administering the contrast media.

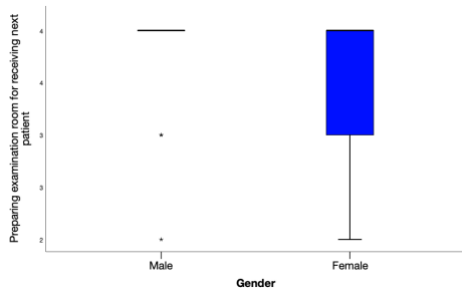


Fig. 5: Gender difference in preparing the exam room for the next patient.

2) *Invisible Mental Exertion*: A Mann Whitney test shows no difference between the males and females across all invisible mental variables.

#### B. Age

A Kruskal-Wallis test evaluated differences across the invisible physical and mental variables, and no significant differences were identified based on age groups

#### C. Level of Education

A Kruskal-Wallis test evaluated differences between three educational levels (diploma, bachelor's, and master's) regarding the participants helping transfer bedridden patients from a hospital bed onto the CT table. The test was significant  $H(2, N = 57) = 7.91$ ,  $p = .01$ .

Follow-up tests were performed to examine pairwise differences among these education group to control for type I errors using the Bonferroni approach. The results of these

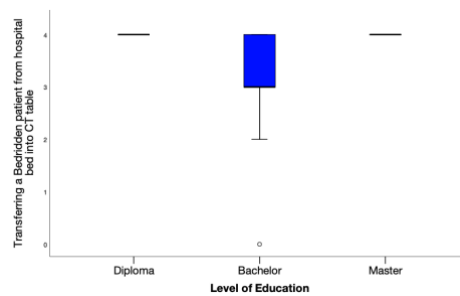


Fig. 6: The differences based on the level of education.

tests indicate a significant difference between bachelor's and master's degrees as illustrated in Figure 6.

Additionally, the other invisible physical and mental variables do not appear to differ based on the level of education.

#### D. Years Of Experience

A Kruskal-Wallis test was conducted to evaluate the difference between the groups with similar years of experience (0 to 3, 4 to 7, 8 to 11 years, and more than 12 years) on working in an understaffed environment. The test resulted in a significant  $H(3, N = 57) = 9.23$ ,  $p = .02$ .

Follow-up tests were performed to examine the pairwise differences among these groups to control for type I errors across the tests using the Bonferroni approach. The results of these tests indicate significant differences between the 0 to 3 and 4 to 7 years groups and between the 0 to 3 years and more than 12 years groups as are illustrated in Figure 7.

Additional tests were conducted on the other invisible physical and mental variables with no differences identified.

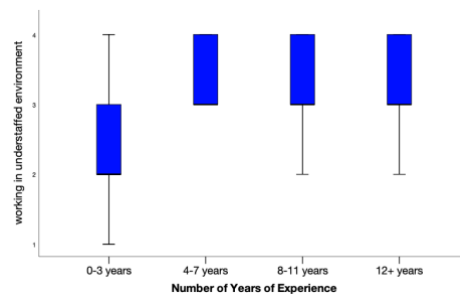


Fig. 7: Differences based on years of experience.

Additional tests were conducted on all invisible physical and mental variables and no differences were found.

#### E. Working Sector

The public sector technicians (Mdn = 31.15) appeared to differ from the private sector (Mdn = 13.64) in the response

to the department needs more CT scan machines ( $U = 67.5$ ,  $z = -2.7$ ,  $p = .007$ ) as is illustrated in Figure 8.

Additional tests were conducted on the other invisible physical and mental variables with no differences found.

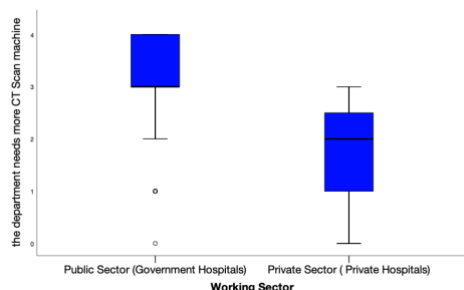


Fig. 8: Differences based on working sector.

Additional tests were conducted on all invisible physical and mental variables and no differences were found.

#### V. CONCLUSION

Radiology practices are impacted by many challenges that eventually require more exertion on the operators. The current standards in practice are categorized to drive for more efficiency in terms of consuming resources as they try to maximize productivity and optimization. Many requirements have been added to the processes of radiology, such as safety and ethics, to compromise a minimum for industry best practice. These requirements now reflect on the working load of the technicians and add complexity to the overall process. This study identifies this additional exertion that affects the technician as is experienced through invisible exertion.

#### ACKNOWLEDGMENT

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# Factors contributing to CT scan usability

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**Abstract**—Abstract—Usability is essential to every functioning system, especially when the system is intertwined with people's safety and needs. Radiological diagnosis is a critical tool to identify diseases and tumors. Therefore, its usefulness is beyond question, despite its radiation risk. Many operational difficulties related to computed tomography (CT) scanning come in the form of non-technical requirements. Hence, there is a need to examine the technical requirements that suit its context of use. This paper examines the barriers and enablers of CT scan usability within its operational context of use. In total, 11 CT scan technicians and one radiology doctor were interviewed to constitute the primary data of this paper. The study reveals that system engineering is critical to improving the current condition. The results show cases wherein the CT scan table jammed due to the weight of the patient.

**Index Terms**—invisible exertion, CT scan invisible exertion, CT scan overload effects.

## I. INTRODUCTION

When evaluating many of today's machines and devices, their usefulness is decidedly determined by their usability. Capitalizing on merely technology execution is myopic. Rather, it must be accompanied by an effective and flourishing user experience. This notion ought to satisfy the execution of tasks with efficiency and effectiveness. Usability is not a monolithic concept. This expression is evidently demonstrated by the definition of usability. [1] found that a variety of usability definitions produced 152 attributes. Nonetheless, usability is vitally important in healthcare because it can offer unparalleled benefits, such as minimized medical errors and utilized times and speeds. Meanwhile, [2] found that current medical devices are profoundly vulnerable to serious human error due to lack of usability, and [3] postulated that in general, usability in healthcare is ambiguously structured and lacks quality. The primary reason for this is that usability in healthcare overemphasizes safety [4]. Determining the usability of a system is dependent on the parameters the system intended is to serve. Consequently, verifying and identifying the context of use is vitally critical for system acceptance and smoothness.

The context of use is determined by the internal and external environment in which the system is used. [5] stated that context of use is utterly significant; even when writing a postcard, the writer typically begins by describing the weather or the outside atmosphere. Principally, the context of use refers to the specific conditions under which the system would be used. These conditions can be straightforwardly expressed by

attributes. For instance, a fast-food kiosk describes the general attributes of the user, which are hungry, determined by speed, and specifically chosen from among many lines of product. In other words, it is counterintuitive to measure the success of a system separate from its context of use.

Often, usability is measured by its flexibility to stretch and cover the maximum context of use. This paper will contribute to an overall understanding of usability within the context of use. It observes the usability of the computed tomography (CT) scan system from the lens of requirement engineering. This paper study the CT scan's system in use within Saudi Arabian hospitals. The paper is structured as follows. Section 2 discusses the role of technology to minimize current obstacles and barriers. Section 3 details the methodological approach. Section 4 illustrates the results. Finally, section 5 presents the discussion and conclusion.

## II. ROLE OF TECHNOLOGY

Since the introduction of technology, people have perceived it as an enabler attribute. In healthcare, the primary use of technology is to minimize risk and capitalize on safety [6]. Hospitals are using technology to record and store data from the daily operation process with the purpose of optimizing the user and patient experiences [7]. Conceptually, hospitals use technology for their critical core operations. Working in the healthcare environment renders a person enormously receptive to physical and mental extortions, and it is extremely governed by industry requirements and guidelines. Consequently, technology plays an important role in minimizing risks and preventing errors [8]. The foremost beneficial attributes of technology are as follows:

- Increased productivity
- Increased patient intake
- Increased comfort
- Maximized job accuracy
- Minimized time and costs

Requirement engineering is responsible for capturing context of use requirements. However, context of use varies based on environments and fits of purpose. Eventually, there will be a gap between the context of use and the captured requirement, and the primary role of requirement engineering is to reduce the gap, as shown in Figure 1.



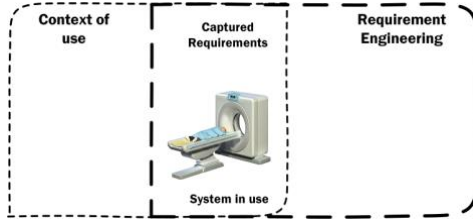


Fig. 1: Captured Requirement Engineering

### III. METHOD

#### A. Subjects

The participants consist of 11 CT scan technicians and one radiology doctor. They came from hospitals across Saudi Arabia. There were 11 male and two female participants. The participants belong to four age groups. Three participants range from 20 to 29 years old, five from 30 to 39 years old, three from 40 to 49 years old, and one is over 50 years old. See Table 1 for demographic details.

TABLE I: Demographic Characteristic

ID	Gender	Age	Educational level	Radiology Years of Experience
Participant 1	Male	20 - 29	Bachelor	0 - 3 years
Participant 2	Male	30 - 39	Bachelor	12+ years
Participant 3	Male	20 - 29	Bachelor	0 - 3 years
Participant 4	Male	30 - 39	Bachelor	12+ years
Participant 5	Male	30 - 39	Master	4 - 7 years
Participant 6	Male	30 - 39	diploma	12+ years
Participant 7	Male	50+	Diploma	12+ years
Participant 8	Male	20 - 29	Bachelor	0 - 3 years
Participant 9	Male	30 - 39	Bachelor	12+ years
Participant 10	Female	40 - 49	Master	8 - 11 years
Participant 11	Male	40 - 49	Bachelor	12+ years
Participant 12	Female	40 - 49	Bachelor	8 - 11 years

#### B. Data Collection and Analysis

A qualitative approach was used to collect the data for this study. Interviews were utilized to achieve the objective of the study. After conducting the interviews, they were transcribed and translated to constitute the first step of qualitative content analysis. Then, the data were analyzed using the qualitative data analysis software Nvivo 12. Saudi Arabia's CT scan market is dominated by three brands. These brand names have been blinded into brand A, brand B, and brand C. Therefore, any referral to brand functionalities or features will be indicated as brand A, brand B, and brand C.

### IV. RESULTS

All participants agree that usability is tremendously crucial to CT scanning. It benefits patients and hospitals alike. Hospital benefits include reduced appointments, increased productivity, and greater optimization of time and cost, while patient benefits include increased safety, reduced radiation, and increased comfort.

*“When the device is easy to use, we can finish examining the patient in a short time. The patient does not feel anxious or afraid during the examination.”*  
Participant 7

*“Usability affects the speed of scanning and saves time.”* Participant 8

The thematic analysis of the content produces 22 usability attributes (see Table 2). The most referenced attributes are Information communicativeness (14 references) and Context of use (13 references). One major reference theme was the technician's ability to control the table from the control room. Some brands still lack this system functionality.

TABLE II: Produced Attributes

Attributes	Number of coding references	Number of sources
Context of use	13	7
Easiness	1	1
Effectiveness	4	4
Efficiency	3	2
Efficient to use	1	1
Error prevention	2	2
Functionally correct	2	1
Helpfulness	2	2
Image Quality	4	3
Information communicativeness	14	5
Learnability	5	3
Operability	4	3
Productivity	4	3
Safety	3	3
Speed of performance	4	4
Standardization	6	3
System functions	8	3
System performance	2	2
Training	7	3
Useableness	2	1
Usefulness	6	4
User satisfaction	1	1

#### A. Information communicativeness

Information communicativeness comprises the information received from the system, such as icons, system alerts, sound alerts, and language communication. These communications can tremendously ease operation of the system.

*“I think that icons should have detailed instructions so we are able to know what it does before clicking it. This will improve the usability of the device to a great extent. This is because even people with little information will be able to use the device in such a case. When using the device for the first time, I faced a problem like this, and I was obligated to call another employee to help me understand what these icons meant...” Participant 1*

Another crucial factor related to information communicativeness is aural commands, which direct the patient to take, hold, and release breath during the exam. This attribute is vital to both the technicians and the patients. The CT scan system has aural commands for the patient (for chest examination).

*The device has more than 15 languages: Hindi, Bengali, Turkish, and Russian. I have nearly more than 15 languages on the system. I choose a suitable language for the patient and the device speaks it. Participant 7*

*“One time, we had a patient who only spoke Hindi, and we had to do a chest exam. Hindi exists on the device, but we had to activate it for the first time that day. Participant 8*

*“I know these devices have the ability to give aural instructions in English and Arabic. This is what I know and have experienced. The aural instructions directed to the patients by the device are in the Arabic and English languages. The Brand A device allows me to insert my personal aural instructions. On the contrary, the Brand C device does not have this option as you choose the language of aural instructions, and it takes over the rest of the task. The Brand A device allows me to my personal aural instructions by recording my own voice; I can illustrate the instruction or summarize it as I want. On the contrary, the Brand C device doesn't allow this, as it speaks to the patient according to how it is programmed.” Participant 10*

Despite the technological development to include many languages, some patients found their languages were left out.

*“There was a Somali patient; he did not speak Arabic or French and his father accompanied him. His*

*father spoke English. During the exam, the patient had to take a breath, suppress the breath, and release the breath in precise time. The problem is that he did not speak English or Arabic, so we found ourselves obligated to make his father, who can speak English, wear lead protection and enter the scanning room with him. We were speaking in the speaker from the control room and his father translated sentences, including ‘take a breath, suppress the breath, and release the breath.’” Participant 3*

#### B. Context of use

It compromises many activities that affect the operational process, such as movement during the exam and overweight patients. The primary concern in this category is overweight patient, as many CT scan tables jam due to patient weight.

*“Unfortunately, movement during the exam can definitely ruin the quality of the image. We have repeated cases like these, especially when dealing with children. Because of their repeated movement, you may be obligated to retake the image once again.” Participant 7*

*“I found myself obligated to tell the patient that he/she is overweight and as a result, the table will not move.” Participant 2*

*“We have trouble with overweight patients, as mainly the table does not move quickly.” Participant 1*

#### C. Image quality

It can be affected by many attributes. As stated above, movement is a major contributing factor, but movement is categorized within the context of use, as technicians need to deal with it as an operational context. When conducting an exam, it is observed that contrast dye leaks and eventually it affects the quality of the image.

*“Sometimes a small proportion of the dye seeps inside the device. Eventually, this may affect image quality, as the device in such a case may produce incorrect images. Consequently, the technician may need to retake images more than once.” Participant 9*

*“Regardless of the image quality, we have a general policy to avoid retaking images as much as possible.” Participant 2*

*“There is no doubt that it is crucial that we rely on Axiology, as it has an important effect; if the image is clear, we can diagnose the case and if the image isn't clear, we can't diagnose the case... If we are able to conclude a diagnosis, this will help the*

*patient, as if we are able to conclude a diagnosis, the doctor will be able to as well. We can help the patient any way, but if things aren't clear and we can't conduct a diagnosis, then the scan can be considered useless and in such a case the patient is most affected by this." Participant 5*

*"The system gives audial instructions for the patients, like take a breath, suppress the breath, and release the breath. In the case of 'take a breath,' the device takes about a minute before taking an image so the lunge may fill with air. Some patients cannot suppress a breath for more than a minute, as originally, he/she is a patient. As a result, when the device takes the image, it takes the image when the breath is being released. This is the cause of taking an incorrect image. The point is that the orders from the system take a long time before taking the image. This affects the image greatly, as we re-examine the patient many times. This accordingly raises the radical dose for the patient." Participant 3*

#### V. DISCUSSION AND CONCLUSION

Requirement engineering is utterly critical to enhanced usability and the user experience. As evidently shown in this study, when users cannot utilize the final product to suit the context of use, they tend to modify the product in accordance with their context of use requirement. As observed in one case, the radiology department installed a camera in the exam room because when the patient performs the exam, the patient became invisible from the control room. Therefore, improving patient visibility is crucial for safety reasons.

One extremely vital theme of this study is the audial command. It directs patients to follow an important exam protocol. Unfortunately, there are cases where the patient neither knows the local language (Arabic) nor other languages that already exist within the system. Audial commands can tremendously affect the safety of the patients and their immediate family members. In one particular case, a father was obligated to stay in the room to translate the audial orders for his ill son as a result of the unavailability of the language the patient speaks. Consequently, CT scanner manufacturers need to pay special attention to extremely diverse markets, such as the Gulf Cooperation Council (GCC) countries.

In essence, system engineering plays an important role in the context of use. The need to model a system in which the operational context of use is collected, stored, and analyzed is essential. The author's future work aim is to model an engineering system for capturing operational data for the purpose of implementing a more intelligent business model so certain activities can be improved.

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**Titre :** Ingénierie système pilotée par la convivialité du produit

**Mots clés :** Évaluation de l'utilisabilité, évaluation de l'utilisabilité de CT Scan, expérience utilisateur

**Résumé :** La convivialité est vitale pour chaque système fonctionnel, en particulier lorsque le système fonctionnel est étroitement lié à la sécurité et aux besoins des personnes. Le diagnostic radiologique est un outil essentiel pour identifier les maladies et les tumeurs. Par conséquent, son utilité est incontestable malgré le risque de rayonnement. En général, les appareils médicaux suivent une tendance, tout comme les produits électroniques grand public, où ils deviennent plus compliqués et les performances doublent tous les deux ans. Par conséquent, les dispositifs médicaux nécessitent une équipe multidisciplinaire pour la conception et le développement. Par conséquent, avec autant de commandes et de systèmes à gérer, les charges cognitives des utilisateurs sont mises au défi d'exécuter efficacement les commandes. En fait, les pratiques actuelles de radiologie sont confrontées à une pression extrême sur les ressources disponibles et aux exigences multidimensionnelles. Les techniciens sont au

centre d'un effort constant pour une productivité et une optimisation optimales avec un minimum de ressources possibles. Dans les dispositifs médicaux, la charge de travail cognitive jouera davantage un rôle car elle utilise une technologie de pointe, est extrêmement coûteuse et nécessite une grande spécialisation pour fonctionner. Ainsi, des méthodes efficaces et économiques sont nécessaires pour évaluer l'expérience utilisateur. L'évaluation heuristique est une méthode efficace pour identifier les principaux problèmes de convivialité et mettre en évidence les problèmes rencontrés par les utilisateurs. L'évaluation heuristique a été adaptée pour identifier l'utilité d'une tomographie par ordinateur sur les utilisateurs saoudiens et pour déterminer si l'utilisation de la tomographie par ordinateur peut entraîner un effort physique et mental. Par la suite, une enquête approfondie a été menée pour identifier les principaux facteurs contribuant à l'utilisation opérationnelle du scanner.

**Title :** Product Usability Driven System Engineering

**Keywords :** Usability Evaluation, CT Scan Usability Assessment, User Experience

**Abstract :** Usability is vital to every functioning system, especially when the functioning system is intertwined with people's safety and needs. Radiological diagnosis is a critical tool for identifying diseases and tumors. Therefore, its usefulness is beyond question despite the risk of radiation. In general, Medical devices follow a trend, just like consumer electronic products, where they are becoming more complicated and performance is doubling every two years. Consequently, medical devices require a multidisciplinary team for design and development. Therefore, with so many commands and systems to deal with, users' cognitive loads are challenged to effectively execute commands. In fact, Current radiology practices face extreme pressure on available resources with demands of multi-dimensional requirements. Technicians are at the center of a

constant drive for optimal productivity and optimization with the minimal possible resources. In medical devices, the cognitive workload will play more of a role because it uses advanced technology, is extremely expensive and takes a great deal of specialization to operate. Thus, effective and economical methods are required to evaluate user experience. Heuristic evaluation is an effective method to identify major usability problems and highlight issues faced by users. Heuristic evaluation was adapted to identify the usability of a CT scan on Saudi Arabian users and to identify if operating the CT scan can lead to physical and mental load effort. Subsequently, an in-depth investigation was conducted to identify major contributing factors impacting operational usability of the CT scan.