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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. The study indicated that the higher experience users have, the less usability catastrophe they face.**

***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 [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

[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]. [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. [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. [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 [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 [18] and [19]. [17] combined (Nielsen, 1994) and (Shneiderman, 1998) 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, [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 as opposed 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.

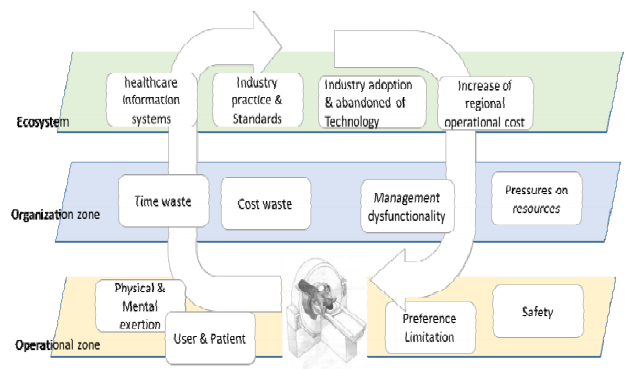


Fig. 1. Interconnectivity and effect of CT scan usability

### 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.

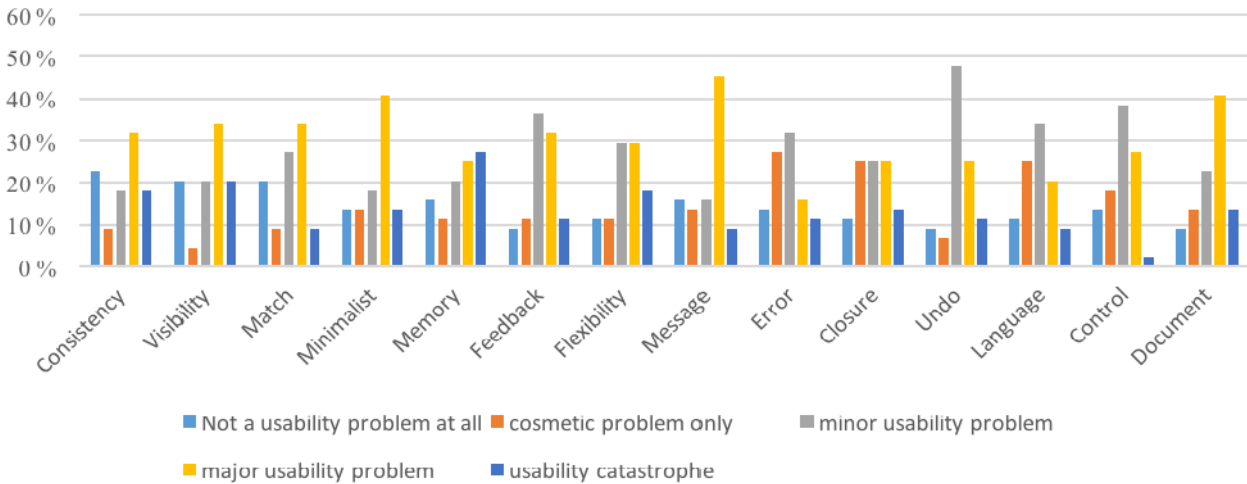


Fig. 2. Usability attributes categorized by severity

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

user experience characteristics are different according to the demographic group. For instance, 33.30% of female technicians reported Consistency as usability catastrophe as opposed 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.

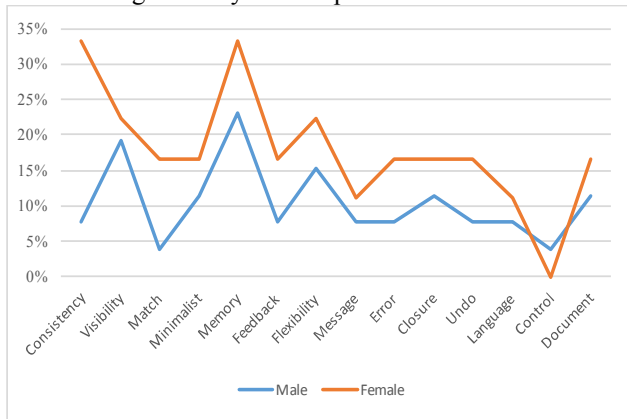


Fig. 3. Usability catastrophe corresponding with gender

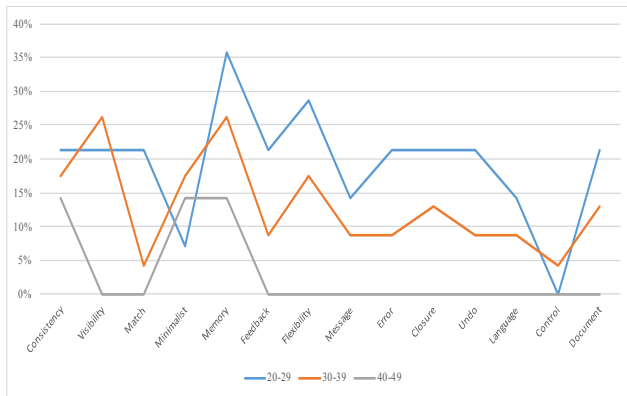


Fig. 4. Usability catastrophe corresponding with age

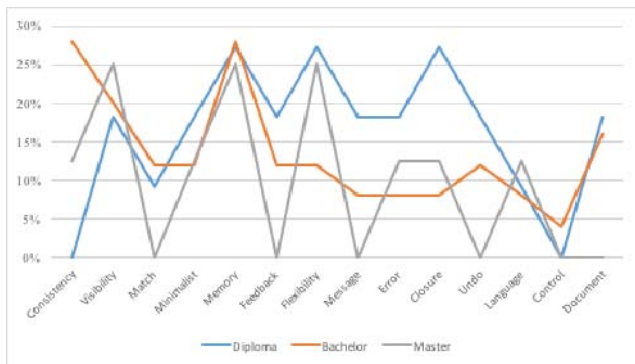


Fig. 5. Usability catastrophe corresponding with education

### B. NASA-TLX

Evidently, exertions exist while operating CT. Technicians reported that exertions are maximum (very high) on mental (22.7%), discomfort (11.4%), physical (6.8%), and frustration (4.5%). As shown in Fig. 6, mental exertion constituted 61.3% on 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%).

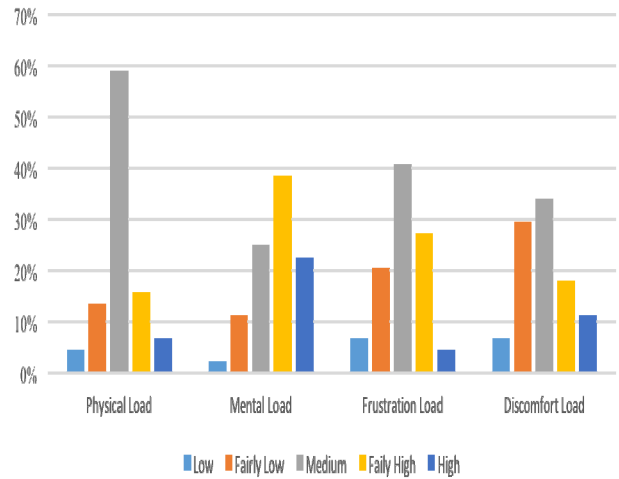


Fig. 6. Exertions by severity

### 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 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 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).

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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