FÁBIO APARECIDO CÂNDIDO DA SILVA

USABILITY AND ORGANIZATIONAL FACTORS IN RADIOLOGY SYSTEMS:
A STUDY WITH HEALTH PROFESSIONALS IN BRAZIL

LAVRAS – MG

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USABILITY AND ORGANIZATIONAL FACTORS IN RADIOLOGY SYSTEMS: A STUDY WITH HEALTH PROFESSIONALS IN BRAZIL
USABILIDADE E FATORES ORGANIZACIONAIS EM SISTEMAS DE RADIOLOGIA: UM ESTUDO COM PROFISSIONAIS DE SAÚDE NO BRASIL

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ABSTRACT

Medical systems have been increasingly important in medical practice and clinical interventions and are crucial for physicians and other health professionals to perform their routine activities in a hospital environment. Such systems include such as HIS (Hospital Information System), RIS (Radiology Information System) and PACS (Picture Archiving and Communication System), for instance. In Radiology, for example, proper usability and alignment with the tasks of these systems are essential, as they often involve thorough analyses that require attention to detail and complex image manipulation techniques for diagnosis. The images generated and manipulated by radiology systems are essential assets to support diagnosis in the health area. However, these radiology systems may present usability problems in handling. Considering the complexity of the tasks and the effects that errors can have, usability problems can be harmful, as they compromise the efficiency of the process, generating incorrect diagnoses and delays in service and results. Despite some research on radiology systems in several countries, few studies report usability in small and medium-sized health facilities, especially in the Brazilian context. This study evaluated organizational factors and the usability of radiology systems in the Brazilian scenario and compared the findings with the results of usability evaluations in the literature. The issues identified in this study are essential to improve the interaction of health professionals in more complex activities. The study involved interviews with ten health professionals from different regions of Brazil and remote usability evaluations of a radiology system with six professionals. The study aims to fill gaps, such as identifying the challenges for designers and the interaction of radiology systems in Brazil. Interviews with radiology professionals resulted in five themes: "How the characteristics of the radiology system affect usability for the user", "How situations or processes affect the characteristics of radiology professionals' tasks", "What influences the behavior of the radiology professional concerning their routine", "What determines a radiology professional's experience and knowledge", and "Radiology professionals deal with system failures and data loss risk". These themes describe the factors that interfere in the radiology professional's routine and their interaction with radiology information systems. Usability testing resulted in 20 categories of usability issues organized into four themes: "Visual Presentation", "Content", "Information Architecture", and "Interactivity".The results consolidate a set of recommendations for the design and evaluation of radiology systems. They incorporate the aspects identified and related to the Brazilian context, the variety of availability of resources in health facilities, which are still limited in the sense of being based on textual descriptions of problems reported in the literature and not in detailed tests.

Keywords: Usability Issues. Radiology Systems. Qualitative Analysis.

RESUMO

Os sistemas médicos têm sido cada vez mais importantes na prática médica e nas intervenções clínicas e são cruciais para que médicos e demais profissionais de saúde desempenhem suas atividades rotineiras em ambiente hospitalar. Tais sistemas incluem o HIS (Hospital Information System – Sistema de Informação Hospitalar), RIS (Radiology Information System – Sistema de Informação Radiológico) e PACS (Picture Archiving and Communication System – Sistema de Arquivamento e Comunicação de Imagens), por exemplo. Na Radiologia, por exemplo, a usabilidade adequada e o alinhamento com as tarefas desses sistemas são essenciais, pois muitas vezes envolvem análises minuciosas que exigem atenção aos detalhes e técnicas complexas de manipulação de imagens para diagnóstico. As imagens geradas e manipuladas pelos sistemas de radiologia são ativos essenciais para apoiar o diagnóstico na área da saúde. No entanto, esses sistemas de radiologia podem apresentar problemas de usabilidade no manuseio. Considerando a complexidade das tarefas e os efeitos que os erros podem ter, os problemas de usabilidade podem ser prejudiciais, pois comprometem a eficiência do processo, gerando diagnósticos incorretos e atrasos no atendimento e nos resultados. Apesar de encontrar algumas pesquisas sobre sistemas de radiologia em diversos países, poucos estudos relatam usabilidade em unidades de saúde de pequeno e médio porte, principalmente no contexto brasileiro. Este estudo avaliou fatores organizacionais e de usabilidade de sistemas de radiologia no cenário brasileiro e comparou os achados com os resultados de avaliações de usabilidade na literatura. As questões identificadas neste estudo são essenciais para melhorar a interação dos profissionais de saúde em atividades mais complexas. O estudo envolveu entrevistas com dez profissionais de saúde de diferentes regiões do Brasil e avaliações remotas de usabilidade de um sistema de radiologia com seis profissionais. O estudo visa preencher lacunas, como identificar os desafios para os projetistas e a interação dos sistemas de radiologia no Brasil. As entrevistas com profissionais de radiologia resultaram em cinco temas: “Como as características do sistema de radiologia afetam a usabilidade para o usuário”, “Como situações ou processos afetam as características das tarefas dos profissionais de radiologia”, “O que influencia o comportamento do profissional de radiologia em relação à sua rotina”, “O que determina a experiência e o conhecimento de um profissional de radiologia” e “Os profissionais de radiologia lidam com falhas de sistema e risco de perda de dados”. Esses temas descrevem os fatores que interferem na rotina do profissional de radiologia e sua interação com os sistemas de informação em radiologia. Os testes de usabilidade resultaram em 20 categorias de questões de usabilidade organizadas em quatro temas: “Apresentação Visual”, “Conteúdo”, “Arquitetura da Informação” e “Interatividade”. Os resultados consolidam um conjunto de recomendações para o projeto e avaliação de sistemas de radiologia. Eles incorporam os aspectos identificados e relacionados ao contexto brasileiro, a variedade de disponibilidade de recursos nas unidades de saúde, que ainda são limitados no sentido de serem baseados em descrições textuais de problemas relatados na literatura e não em testes detalhados.

Palavras-chave: Problemas de Usabilidade. Sistemas de Radiologia. Análise Qualitativa.

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1 INTRODUCTION

1.1 Contextualization

Medical systems have increasingly become important in medical practice, and clinical interventions (BAIG et al., 2017). Those systems are crucial for medical doctors and other health professionals to perform routine activities in a hospital setting. These tasks typically involve meticulous analyses that demand attention to detail and complex image manipulation techniques to perform diagnosis. In Radiology, for example, the support from interactive systems to enable the analysis by health professionals is fundamental.

In Brazil, the *Sistema Único de Saúde* (SUS) - Unified Health System is one of the largest and most complex public health systems in the world, being the only one that serves a population of more than 200 million people (Brazil, Ministério da Saúde, 2020). Of the countries recognized for having a public and universal health system, such as the United Kingdom, Canada, Denmark, Sweden, Spain, Portugal, and Cuba, none has more than 100 million inhabitants. The most populous of those countries is the United Kingdom, with around 66.4 million people, which is served by the United Kingdom's National Health Service (NHS) (United Kingdom, 2021).

SUS covers everything from simple care for blood pressure assessment to organ transplantation, ensuring complete, universal, and free access for the country's entire population. The network that makes up SUS is broad and encompasses actions and health services. It encompasses primary, medium, and high complexity care, urgent and emergency services, hospital care, actions and services of epidemiological, health and environmental surveillance, and pharmaceutical assistance (NICOLETTI; FARIA, 2017).

Medical systems have a crucial role in health care, particularly in large public systems such as SUS. However, many medical systems have a high level of complexity in their operation. They are also critical in terms of the adverse effects that user errors may have on such systems. This way, performing effective evaluations to identify critical usability problems in such systems is a challenge for Human-Computer Interaction research (JASPERS, 2009; RATWANI et al., 2018).

Different studies have focused on understanding the usability of radiology systems with tasks involving complex image analyses. A previous study (DIAS; PEREIRA; FREIRE, 2017) conducted a systematic mapping of the literature to identify the main problems encountered in empirical studies with health professionals in the field, including evaluation of PACS (Picture Archiving and Communication System) and RIS (Radiological Information System) systems. That study consolidated relevant problems that significantly impact the use of such systems, affecting the correct clinical diagnosis. The method used to assess the problems found in the study by Dias, Pereira e Freire (2017) was based on the classification of problems based on the usability heuristics of Nielsen and Molich, with the heuristic “Flexibility and efficiency of use” and “Consistency and standards” being the most frequent in terms of instances of problems. These heuristics also appear in other articles.

For example, the problems related to “flexibility and efficiency of use” were mapped in seven studies (GELDERMANN et al., 2013; JORRITSMA; CNOSSEN; OOIJEN, 2014; JORRITSMA et al., 2016a; JORRITSMA et al., 2016b; DASUERAN et al., 2014; MARKONIS et al., 2015; MARKONIS et al., 2013) that made analyses in radiology systems. As for the problems related to "Consistency and standards", they were observed in six studies (GELDERMANN et al., 2013; OLBRISH et al., 2011; JORRITSMA; CNOSSEN; OOIJEN, 2014; JORRITSMA et al., 2016a; JORRITSMA et al., 2016b; MARKONIS et al., 2015) resulting in implications for the design of radiology systems.

A study presented by Esfahani, Khajouei e Baneshi (2018) assessed the importance of interaction with the user’s perspective to select usable PACS. Thus, the usability characteristics, including efficiency, learning, error and satisfaction, were used to assess the usability of each analyzed PACS. Like another more recent study, (TEIXEIRA et al., 2020), the authors evaluated the use of two alternative PACS interface devices, considering different ways of using the keyboard and mouse in clinical practice and task-oriented evaluations.

Comparing the studies mapped by Dias, Pereira e Freire (2017) and more recent studies by Esfahani, Khajouei e Baneshi (2018) in Iran and Teixeira et al. (2020) in France, there are differences in the context of health care in Brazil. Considering the peculiarities of Brazil and its SUS, especially in the case of small towns, it is essential to analyze the usability problems encountered in medical systems, such as radiology systems, in this particular context. Acquiring this knowledge can help reflect on improvements to such usability evaluation methods in this context and enhance the effectiveness of the methods employed.

1.2 Research gap

Previous studies in the literature about the usability of radiology systems do not have robust usability data from the Brazilian, considering the forms of use, cultural aspects, and the diversity of systems used in different hospitals. Furthermore, most studies abroad report usability problems without enough detail about their occurrence and relation to the clinical context.

It is essential to highlight that the set of recommendations raised by Dias, Pereira e Freire (2017) was not further detailed due to the lack of more contextual information about the problems reported in the primary studies mapped in their research. As the recommendations were based solely on the written reports of the primary studies it mapped, it did not have enough detail about the nature of the problems and their impact on the usability and clinical aspects.

1.3 Research questions

The main research question investigated in this project was "What are the organizational factors and usability issues that influence the use of radiology systems in the Brazilian context?".

The tasks in the radiological images' analysis were impacted by their complexity and the exhausting procedures used to perform them. Moreover, as health professionals in hospitals frequently perform them, it is common for these professionals to develop alternatives to streamline the performance of these tasks in their daily clinical analyses. This approach triggers several factors related to the usability of these systems and organizational factors that can impact diagnostic errors, such as stress and impatience of the professionals involved and delay in delivering results, among other possible factors.

1.4 Goals

The general objective of this study was to evaluate and analyze the organizational factors and the usability of radiology systems in the Brazilian context, to propose system design recommendations to help improve the use of such systems and help perform more reliable and less error-prone medical analyses.

Specifically, qualitative research proposes an understanding of systemic issues. Thus, interviews with health professionals will serve to understand the day-to-day of these professionals, which tasks they perform, their workload, with which systems they interact and their difficulties. At the same time, the empirical tests focus on usability problems, which will elucidate health professionals' difficulties in performing basic and more complex operations, such as image manipulation procedures, to generate diagnoses.

The arguments for these specific goals are:

a) Understand aspects related to technology, people and processes that influence the use of radiology systems;

b) Investigate organizational and interaction issues with the use of information systems in radiology by health professionals;

c) Describe the types of usability problems encountered in the use of radiology systems by health professionals in Brazil;

d) Compare the results obtained in studies in Brazil and abroad.

The study expected to contribute to the consolidation of design recommendations and evaluation of radiology systems, incorporating aspects identified and related to the context of Brazil. The scenario of previous works (DIAS; PEREIRA; FREIRE, 2017) was limited because it considered only a set of textual descriptions from the literature and not on detailed tests. So, this work will contribute with design recommendations that will assist in the construction of systems with more quality.

1.5 Work organization

This work is structured in five chapters: Introduction, Theoretical Background, Methods, Discussion, and Results. This organization has an adapted research paper format, so the two methodologies used in this study are described together in the Methods chapter and the respective results are in the Results chapter.

2 THEORETICAL BACKGROUND

This section presents the key concepts related to electronic medical records, hospital information system, radiology information system and archiving and distribution of imaging systems. The latter two are the focus of this study. This chapter also presents the usability context and related studies that have conducted usability assessments in radiology systems and the usability problems encountered.

2.1 Medical Records, Information Systems, and Archiving and Image Distribution Systems

An Information System (IS) aims to store, process and provide information to support the functions or processes of an organization. There are several types of Information System, among them Hospital Information Systems (HIS) and Radiology Information Systems (RIS).

The HIS is the hospital management system that focuses on the administrative needs of the hospital. HIS are designed to manage all aspects of a hospital's operation and provide information on the patient's health history through restricted access. They allow hospital professionals to record and consult the entire care record of each patient, and among the information are the electronic medical record, admission history, imaging exams and medical reports that will assist in diagnosis and treatment, in addition to personal and financial data (HANNAH; BALL; EDWARDS, 2006).

RIS is a management system that distributes data about diagnoses, procedures, and exams of patients over the network (DIAS; PEREIRA; FREIRE, 2017). In other words, RIS brings a proposal to automate a more agile and independent workflow, specialized and focused on radiology practices, from patient registration and registration to the final issuance of the medical report.

In the past two decades, the rapid adoption of electronic medical records has changed the landscape of how radiology departments interact with medical demands. Therefore, the integration of the radiologists' reading environment with the clinical information available in the electronic medical record has become an integral part of the interpretation workflow by both parties (BERKOWITZ; WEI; HALABI, 2018).

Medical records represent the patient's health history and record any hospital or clinic activity such as entry and exit records, results of laboratory and radiology examinations, administered drugs, and surgical procedures (BERKOWITZ; WEI; HALABI, 2018).

The radiology report is the final representation of the data by which radiologists communicate their interpretations to doctors and patients. In the report, the radiologist seeks to answer the questions that led the clinician to request the imaging exam. Traditionally, the radiology report aims to inform the health professional or patient about the information contained in the results and images regarding the patient's condition in the context of the disease. This information can be communicated through various media, including text, images, tables, and graphs (FOLIO; MACHADO; DWYER, 2018).

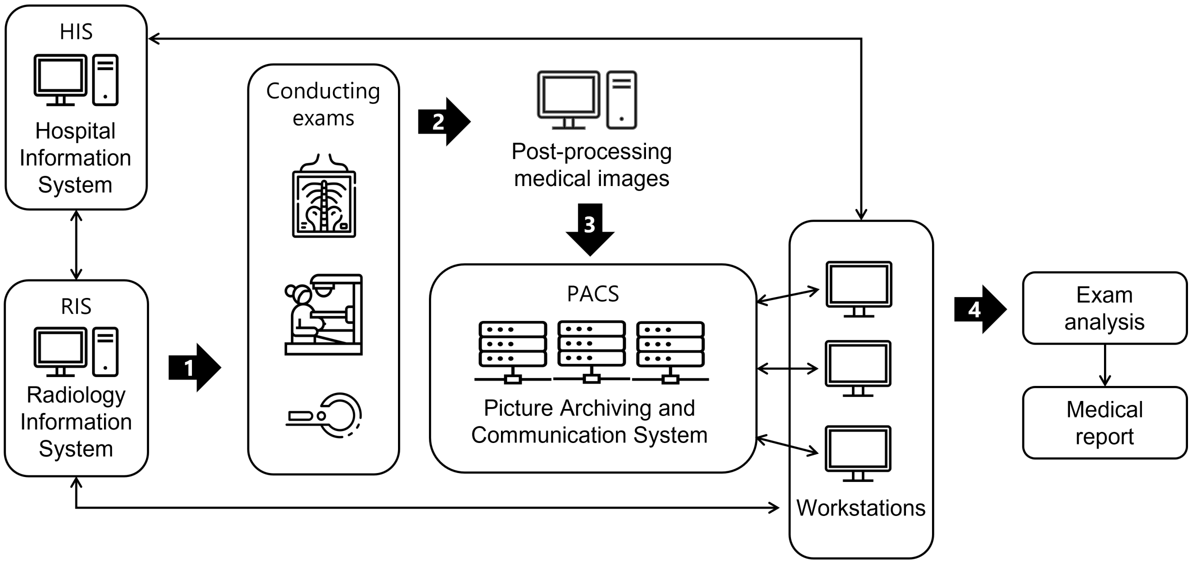
Radiology departments in hospitals have performed large-scale use of digital systems, which has generated an increasing volume of data. The best solution to manage this data and digital images is the adoption of an Picture Archiving and Distribution System (PACS) (ESFAHANI et al., 2019). According to Dias, Pereira e Freire (2017), PACS is a short- and long-term image management system which consists of archiving medical images. These images are generated by medical equipment, such as digital radiography, computed radiography, computed tomography (CT), magnetic resonance imaging (MRI) and ultrasound. PACS offers visualization of images in remote diagnostic stations, data storage for short or long term recovery and communication via local, expanded networks or public services.

PACS plays a vital role in healthcare information systems, helping to reduce costs, facilitate access to medical images, and improve workflow in the radiology department. The use of PACS improves the processing, storage, and transmission of medical images for radiologists. Also, many hospitals use this system as it helps many doctors in diagnosing (ESFAHANI et al., 2019). However, such systems involve a series of highly complex tasks for health professionals involved in their operation, and this can lead to several types of problems, such as procedural errors, delay in diagnosis, possible errors in diagnostic results, and even discomfort or stress on the part of health professionals who have used these systems for a long time.

The images generated by the radiology systems are essential assets to support diagnoses in the health area. These medical images follow the DICOM standard (Digital Imaging and Communications in Medicine), which specifies a standard model for storing medical image information (US National Electrical Manufacturers Association, 2021). This standard provides a structure that allows the exchange of various types of medical images and related information stored in a single format by PACS.

Medical images are captured and manipulated using software that integrates the PACS and RIS. Also, the software used for medical image editing tasks is usually provided by the radiology equipment manufacturer, but third-party software may be used too.

Figure 2.1 – Simplified layout of professional workflow and inter-system communication



Source: Adapted from Dias, Pereira e Freire (2017)

Figure 2.1 shows a basic flow of communication between these systems. Radiology professionals operate the radiological equipment and their systems to obtain the image. These images are archived in PACS servers. They can be visualized from computer stations located in different parts of the hospital by accessing via HIS or RIS.

2.2 Usability and Usability Evaluation

According to the ISO9241-11 standard, usability can be defined as “the extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use” (ISO, 2018b).

Preece, Sharp e Rogers (2015) define Usability as “ensuring that interactive products are easy to learn, effective to use, and enjoyable from the user’s perspective”. Usability involves optimizing people’s interactions with interactive products, which it subdivides into six measures. The measures are Effectiveness (effective to use), which determines how good the product is and how it should be done; Efficiency (efficient to use), which refers to how a product assists users in carrying out their tasks; Safety (safe to use), which involves protecting the user from dangerous conditions and undesirable situations; Utility (useful), which says how the product provides the right kind of functionality so that users can do what they need or want to do; Learnability (Easy to learn), which refers to how easy it is to learn to use a system; Memorability (easy to remember how to use), which shows how easy a product is to remember how to use once learned.

There are several methods for evaluating usability. Usability tests are considered one of the most efficient methods to uncover problems that users may find. It consists of observing users testing a system individually and allowing them to solve any problems themselves. This method is the best way to increase the quality of the user experience, and the more versions and ideas that are tested with users, the better (NIELSEN, 2012). For the analysis in this study, PACS systems and software for post-processing medical images, preferably national systems, will be evaluated. Subsequently, this evaluation will be compared with other studies in the literature related to usability that involve tests with radiology professionals. There are also inspection methods (NIELSEN, 1994b; HOLLINGSED; NOVICK, 2007; CHATTRATICHART; LINDGAARD, 2008), where an expert predicts what problems users are likely to encounter. Usability tests assess the ease of use of a system and are done with user participation, who are asked to complete specific tasks while being observed by a researcher (SEPTIANDI; SUZIANTI, 2019).

The empirical studies and tests performed with users are designed to control what they do, when they do it, and how long. This approach is used consistently and successfully to evaluate software applications where participants perform a set of tasks. This approach to assessing a software system's user interfaces involves collecting data using a combination of methods in a controlled environment, for example, observation, interviews and questionnaires, or evaluations in participants' contexts. The main objective is to determine whether a specific group of users can use an interface to perform the tasks for which they were designed. This involves, for example, making comparisons with the number and types of errors that users make between versions and recording the time it takes them to complete the task. As users perform these tasks, they can be recorded on video, just as interactions with the software can also be recorded. User satisfaction questionnaires and interviews are also used to get users' opinions on what they thought of the experience using the system. Qualitative and quantitative data collected through these different techniques are used to form conclusions about how a product meets the needs of its users (PREECE; SHARP; ROGERS, 2015).

2.3 Related Work

This section describes the related studies mapped in the literature and that will be used for comparison and discussion with the more in-depth studies done in this study involving radiology systems. The aspects worked were about usability problems, radiology tasks, and behavioral characteristics of the health professional.

Some studies, in essence, have as their theme evaluating the selection of PACS. These studies address aspects related to usability but do not delve into these aspects. As is the case of the study carried out by Esfahani, Khajouei e Baneshi (2018), which evaluated assessed the importance of interaction with the user's perspective to select usable PACS. In this scenario, the Think-Aloud protocol was used with a post-usability questionnaire to compare user interaction problems with PACS user interfaces. Thus, usability characteristics, including efficiency, learning, error, and satisfaction, were used to assess the usability of each PACS analyzed.

Esfahani, Khajouei e Baneshi (2018)'s study revealed user interaction problems on three tested PACS systems. The main finding showed that using the approach proposed in this study was adequate to increase the usability assessment from the user's perspective, who could identify many usability problems. However, the analyses presented in the results focused on the efficiency of each PACS tested, making a comparison between them, but little information on the types of usability problems encountered and their impact on clinical analyses. Still, the study brings relevant perspectives on the problems presented in each PACS. The study (ESFAHANI; KHAJOUEI; BANESHI, 2018) concluded that PACS providers should pay more attention to the usability of their products, considering all usability characteristics when selecting a PACS designated by ISO and Nielsen, to improve their design and user interface. That study brings important points of usability analysis in PACS systems. However, it does not present proposals for solutions for the software in terms of design and interface that can better use the system's better use, interactivity, and usability.

Another study (ABDEKHODA; SALIH, 2017) that aims to find out whether or not a system should be adopted, was done at the university hospital affiliated with the Tehran University of Medical Sciences in Iran. The study assesses whether the effective use of PACS systems can change the workflow to access digital images, know if response time is fast, and reduce tests and exams. The proposal is to identify factors that are decisive for the adoption of PACS by doctors. About 61% of the results showed that the expectation of performance, expectation of effort, social influences, and intention of behaviour significantly affect the adoption of PACS.

In another more recent study, Cronin, Kane e Doherty (2021) makes a qualitative analysis of the needs and experiences of hospital doctors in five countries (Ireland, UK, United Arab Emirates, USA and Australia) regarding the use and access of medical images. In this study, semi-structured interviews were carried out with 35 participants. The findings were presented under the following themes: “PACS adoption and evolution”, “locations and functions”, “tasks and resources”, “workflow”, “performance issues”, “training”, and “touchless interaction and sterility”. Among the points discussed, it addressed that PACS provides a powerful set of features but suffers from poor usability. It has very complex interfaces for an average user to explore in an effective and simplified way. However, the study is superficial concerning the topic of usability, as there are other points of interest that the author addressed.

Another topic addressed is the study by Salahuddin et al. (2020) that evaluates the behavior of health professionals in adopting an HIS concerning patient health. The study provides practical examples of how the behaviours of these professionals can result in unintended consequences with the use of HIS. The qualitative study conducted semi-structured interviews with 31 physicians in three hospitals that implemented the system. Based on the results of the interviews, a qualitative thematic analysis was carried out, resulting in the following themes: (1) carelessness, (2) alternative solutions, (3) non-compliance with the procedure and (4) copying and pasting habits.

Some studies assess topics such as practicality, agility and efficiency in radiology tasks. For example, the recent study of Teixeira et al. (2020), the authors assessed the use of two alternative PACS interface devices, considering different ways of using the keyboard and mouse in clinical practice and task-oriented exercises. Eleven senior radiologists were prospectively evaluated, using two interfaces - a graphic tablet and a portable control, tested for ten periods of work each and answered a questionnaire to assess the ergonomics of this new experience. The objective was to assess musculoskeletal discomfort using standard devices, keyboard, and mouse, as PACS interfaces with the new devices. Tasks to evaluate scrolling and image selection, zooming, making measurements and reporting were performed during this test with the new devices.

Teixeira et al. (2020)’s study showed that 9 of the 11 participants (81.2%) reported some musculoskeletal discomfort related to using the set of interfaces, with the hands or wrists being the most frequently affected sites. Another essential point in this study was the change in posture analyzed, with the prevalence of musculoskeletal discomfort among participants being lower with alternative interface devices. Teixeira et al. (2020)'s study points out issues that were not considered in the current study. However, the study showed important value in evaluating and analyzing usability problems to have design and interface recommendations as a solution. It is plausible to consider the possibility of the system being customized and allow the use of other peripherals to improve user comfort or even to facilitate and streamline the process.

Another similar study (CHUNG; LIU, 2019) aimed to investigate how practical it would be to use technology that allows real-time interaction with radiological images without using physical devices such as a keyboard and mouse. In this case, this technology offers three modes of image interaction. The first mode is gesture recognition, which detects the user's hand gestures and translates them into commands for image manipulation. It also has the light projection mode, which detects the movements of pointing and touching on icons projected on a surface. Finally, it analyzed the capacitive detection mode, which uses a portable device to control the image review. They divided the procedures into three phases to perform the tests: a preliminary assessment, simulated clinical trials, and validation. According to Chung e Liu (2019), the results of this study revealed that the use of light projection had a 60% reduction in time compared to the control. At the same time, capacitive detection demonstrated a 71% reduction in time compared to the control mode.

The study by Kovacs et al. (2019) aimed to assess whether there are potential benefits in automating reports for radiologists. The study was divided into two stages and carried out with 13 radiologists from the team and nine radiology residents in a single institution. In the first stage, the interviewees were asked whether the automation of, for example, exam description, comparison test data, technique, and copy for medical data saved time, decreased fatigue, and increased accuracy. In the second stage, the objective was to apply a simulated exam to assess the time savings of the automation of reports and to evaluate error rates. As a result, more than 80% of respondents reported that automation improved accuracy, decreased fatigue, and saved time. As a result, the error rate also dropped.

In study (ALHAJERI; SHAH, 2019), carried out in North America, with the participation of some other countries around the world, the limitations of the current generation of PACS and solutions to improve the functionality of PACS were evaluated. An exploratory assessment of the perspectives of PACS professionals was made through four online discussion groups on LinkedIn. The first theme concerned limitations in the current generation of PACS, such as problems with image transmission, network and hardware problems, difficulties in changing specific configurations, and problems in encoded digital images. The second theme concerned solutions to improve PACS functionality, among them web-based PACS, medical image viewer, voice recognition and integration in PACS, Backup and recovery of PACS, and connection of PACS with other hospital systems. In conclusion, capturing online conversations for research provides many insights on the topic of research investigation. However, these insights are not precise regarding usability impact and lack depth and evidence of testing with actual users.

Most of these studies cite usability as an aspect to be worked on without delving into the subject. Only one study focused on evaluating the usability of radiology systems. The study in question was a systematic mapping of the literature carried out by Dias, Pereira e Freire (2017) that analyzed and compiled usability problems encountered in ten primary studies involving radiology professionals, resulting in 90 instances of problems. The qualitative analysis indicated the causes and the effects of the identified usability problems that identified 90 instances of usability problems, classified corresponding to established usability heuristics. The mapping study (DIAS; PEREIRA; FREIRE, 2017) related the problems to Nielsen and Norman's heuristics and provided implications for the most frequently occurring problems. The five heuristics with the highest number of usability problems were “Flexibility and efficiency of use”, “Consistency and standards”, “Match between system and the real world”, “Recognition rather than recall” and “Help and documentation”.

Regarding the problems related to “Flexibility and efficiency of use”, as found in seven studies (GELDERMANN et al., 2013; JORRITSMA; CNOSSEN; OOIJEN, 2014; JORRITSMA et al., 2016a; JORRITSMA et al., 2016b; DASUERAN et al., 2014; MARKONIS et al., 2015; MARKONIS et al., 2013), the article consolidated five implications for the design of radiology systems. The following implications were identified: attention to sequential steps following clinical analysis practices; direct access to critical information for clinical decision-making; making integration with other systems easier to produce clinical reports; making access to images that need simultaneous analysis more efficient; help make efficient basic image manipulations inside the system.

As for the problems related to “Consistency and standards”, the findings of six studies were consolidated (GELDERMANN et al., 2013; OLBRISH et al., 2011; JORRITSMA; CNOSSEN; OOIJEN, 2014; JORRITSMA et al., 2016a; JORRITSMA et al., 2016b; MARKONIS et al., 2015). The following implications for the design of radiology systems were identified: attention to consistency in patient identification to avoid mistaken analyses; consistent information architecture aligned with clinical terminology, and availability of important features on the interface should be consistent throughout tasks.

Regarding the heuristic “Match between system and the real world”, the compilation of results from five studies (GELDERMANN et al., 2013; JORRITSMA et al., 2016b) (MARKONIS et al., 2015; MARKONIS et al., 2013) resulted in two main implications for design that are: System rules need to allow for real-world clinical procedures, and Recognition features need to be accurate.

The main recommendation related to “Recognition rather than recall”, derived from the compilation of findings derived from five studies (JORRITSMA; CNOSSEN; OOIJEN, 2015; JORRITSMA et al., 2016a; JORRITSMA et al., 2016b; MARKONIS et al., 2015; DASUERAN et al., 2014) was to have attention to "Activation of features needs to be easily recognizable on screens".

The consolidation of issues related to “Help and documentation” from findings in four studies (GELDERMANN et al., 2013; MARKONIS et al., 2015; OLBRISH et al., 2011; MARKONIS et al., 2013) resulted in the recommendation to provide “Contextualized and task-oriented help”.

Following the same line to identify empirical studies that performed evaluations of radiology systems conducted by the systematic mapping reported before (DIAS; PEREIRA; FREIRE, 2017), we have analyzed more recent studies that performed studies with health professionals on radiology systems.

Despite having good coverage of scientific studies developed up to 2017, the study performed by Dias, Pereira e Freire (2017) was limited in the level of detail of the usability problems identified. The study proposed an initial categorization of usability problems in radiology in terms of use and clinical impact. However, it was limited due to the short descriptions of problems reported in the papers included in the mapping. To make a more detailed proposal as made in this study, more details about the usability problems and the context in which they occurred would be necessary.

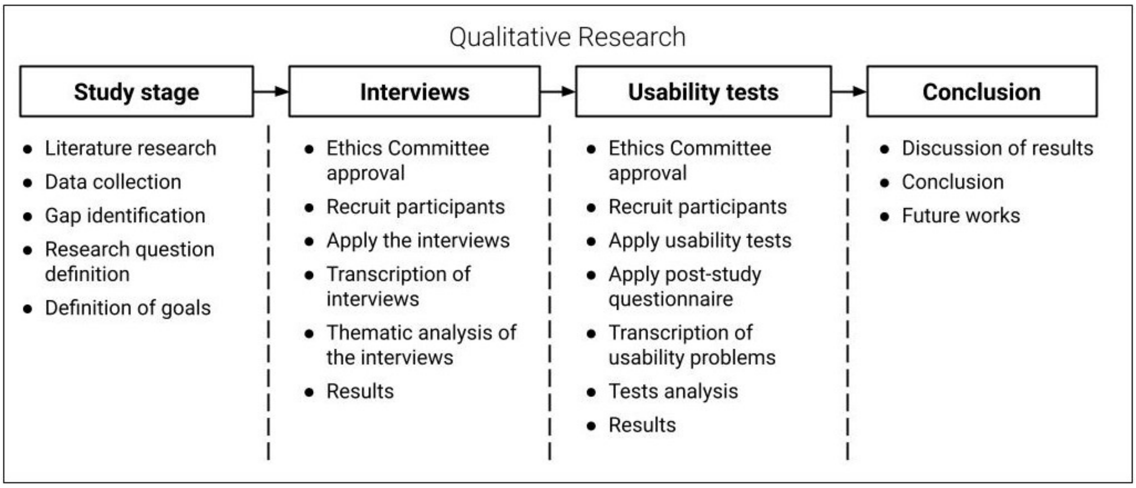
Evaluating the related studies in the literature, it is possible to notice that there are studies with PACS systems. However, each has a different objective and few studies to evaluate and identify usability problems in these systems. There is still little evidence of studies that propose solutions in terms of development and design, which motivates a more in-depth study in the Brazilian context. However, to perform such proposals to improve the design of such systems, it is necessary to have a detailed description of usability problems. Such descriptions should include how they impact users, clinical impact, users' mental models and characteristics related to the environment and settings of small and medium public hospitals in the Brazilian context. The current scientific literature does not provide evidence to support this type of proposal.

3 METHODS

This section describes the methods of data collection and analysis of interviews and usability tests in this study.

3.1 Study design

Figure 3.1 – Study design



Source: Developed by the author

As illustrated in the Figure 3.1, the study design was organized into four stages. In the first stage, the objective is to understand which aspects of technology, people and processes that influence the use of radiology systems according to the findings in the literature. At this stage it is also important to identify the gap and define the research question.

The literature review was carried out through articles researched on four scientific bases: PubMed/Medline, Science Direct, Scopus and Web of Science, including articles published between 2017 and 2021. The search followed the systematic mapping of literature that had been conducted up to 2017 by Dias, Pereira e Freire (2017). A set of terms was defined as keywords to be used in the consultations from the research questions. Chart 3.1 shows all keywords used and Appendix A presents the complete queries in each scientific base.

Chart 3.1 – Key terms used in literature search

Radiology terms
Picture Archiving Communication System
PACS
Radiology Information System
RIS
Usability terms
Usability evaluation
Usability assessment
Usability testing
Usability flaws
Usability problems
User experience
User testing

Source: Developed by the author

After the study stage, it was decided to work with two qualitative methods. First, interviews with radiology professionals. These interviews will serve to investigate organizational and interaction issues with health professionals using information systems in radiology. The objective is to know the daily life of the radiology professional, the interaction with radiology systems, routine, work processes and main difficulties encountered with the systems.

The second method consists of usability tests with users using medical image visualization and manipulation software. The purpose of usability tests is to describe the types of usability problems encountered in using radiology systems by healthcare professionals in Brazil.

After analyzing the results, the main findings will be discussed and compared with previous studies in the literature. Finally, the conclusion should consolidate a set of recommendations for the design and evaluation of radiology systems, incorporating the aspects identified and related to the Brazilian context.

3.2 Exploratory interview with radiology professionals

Qualitative research interviews aim to understand the meaning of people's experiences and discover their lived world in the face of scientific explanations. Interviews occur when the interviewee asks questions to gather personal information about a particular topic or experience. The type of interview chosen was the semi-structured interview, which is the most used in qualitative research and the health context (DEJONCKHEERE; VAUGHN, 2019).

The semi-structured interviews were carried out remotely from March to May 2021, using the videoconferencing software Google Meet, with video and voice recordings of the participant. The interviews were carried out individually, focusing on the following aspects: interaction with radiology systems, routine and work processes and main difficulties encountered with the systems. This procedure allowed a deeper understanding of the issues to be investigated later in this study.

3.2.1 Interview Participants

For the interview phase, ten radiology technicians were recruited (Table 3.1). The recruitment of participants for the interviews was done through contacts on social networks, e-mails and by indicating the participants themselves. The research protocol was approved and registered by the Research Ethics Committee of the university in January 2021 under CAAE nº 41971021.8.0000.5148.

Table 3.1 – Details of interview participants

#	Academic level	Age	Gender	State	Time*	Place
1	Radiology Technician	26	M	SP	<1	hospital
2	Radiology Technician	45	F	SP	22	clinic
3	Radiology Specialist	40	M	SP	21	clinic
4	Specialist in Tomography and MRI	31	M	PA	4	UPA**
5	Radiology Technician	32	F	RN	10	UPA**
6	Specialization in Diagnostic Imaging	28	M	SP	6	hospital
7	Technologist in Radiology	38	M	PR	17	hospital
8	Radiology Technician	31	F	SP	9	UPA**
9	Technologist in Radiology	38	M	SP	10	clinic
10	Radiology Technician	28	F	SP	2	hospital

**Working time in years* ***Emergency care unit*

Source: Developed by the author

3.2.2 Interview script

The interview script was designed to understand better radiology professionals' routine and work process and their relationship with radiology systems. It contains 18 questions, divided into initial questions to gather sociodemographic information and more specific questions that focus on the professional's work routine with radiology systems. The questions were adapted according to each interviewee's experience. For example, we adapted the questions describing the data collection and analysis tasks. Different professionals may or may not perform these tasks, so the question was adapted to explain the process adopted and who performs each task. Another example of adaptation is when asked about which systems are used to understand better, more specific questions were asked to know what each system was and if the participant knew how to identify these systems. The topics covered in the script were defined based on analyzes of studies in the literature, which showed that there are still gaps in the understanding of the usability of radiology systems. The interview script questions are in Appendix B (in Portuguese).

3.2.3 Analysis of interview data

In this step, qualitative analyzes were carried out with thematic analysis (BRAUN; CLARKE, 2006) to minimally organize and describe a set of data in detail, identifying problems, ways of using the systems and establishing categories of analysis so that they can be grouped around the topics covered. Although time-consuming, these studies generally involve many tasks that offer the possibility of immersion in the community in question, providing a rich context and allowing for a deeper understanding.

According to Braun e Clarke (2006), the application of Thematic Analysis has 6 phases. The first phase is familiarization with the data; it involves reading and rereading the data to be immersed and intimately familiar with its content. At this stage, the primary author transcribed the interviews to revisit and become familiar with the content. The author used for the transcript a free online application (oTranscribe[1]) with a word processor adapted for audio transcription.

In the second phase, the initial codes were generated. These codes identify essential data characteristics that may be relevant to answering the research question. The coding of the ten interviews generated 35 categories in the categorization instrument. Three researchers evaluated the reliability between coders using Cohen's kappa coefficient from three rounds of independent analyses to reach this result. In each round, each researcher analyzed a subset of 45 interview excerpts and assigned a code (category). In the first round, $\kappa = 0.45$ was reached, calculated with the statistical software *R*. Disagreements were verified, and the categorization instrument was updated. In the second round, $\kappa = 0.58$ was reached, still inadequate. After

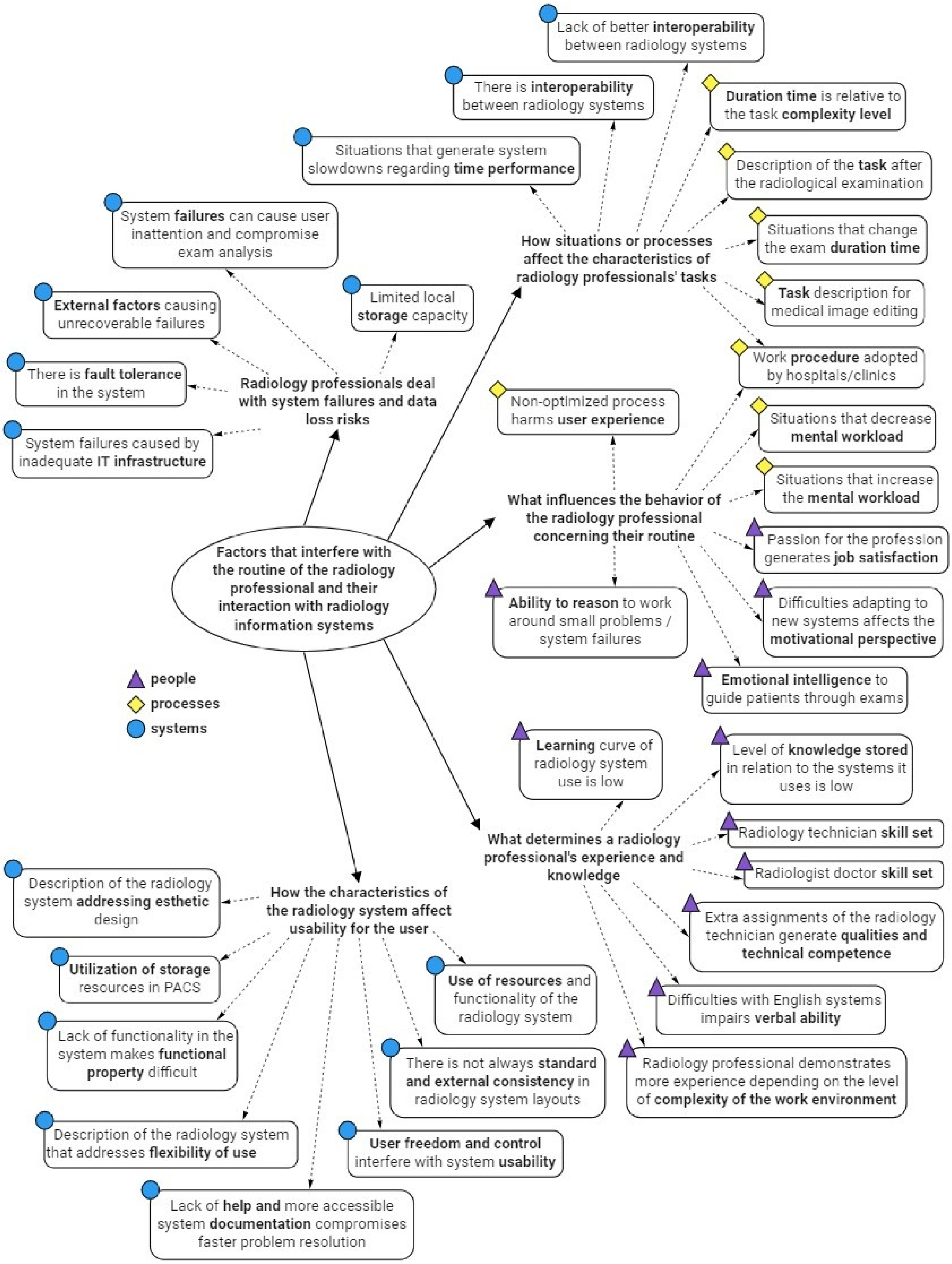
[1] https://otranscribe.com

reaching an acceptable level of reliability ($\kappa = 0.79$) (MCHUGH, 2012), a final version of the categorization instrument was used to categorize the total dataset.

The third step involved analyzing the categories and grouping the data to identify broader patterns (themes). In the next phase, candidate themes were analyzed against the dataset to determine whether they tell a compelling story about the data and answer the research question. In this phase, themes are refined, which sometimes involves splitting, combining, or discarding. Then, each theme was named and defined through a detailed analysis, elaborating the scope and focus of each one. Figure 3.2 shows the final result of this analysis in the format of a thematic map, which included the assignment of categorization units in the form of codes (out of a total of 35 codes/categories), organized into five main thematic axes (themes), which are: System features affect usability for users; Situations or processes affect the characteristics of user tasks; User behaviour about their routine; User experience and knowledge; and System crashes and data loss risks.

The final phase involved weaving together the analytical narrative and data extracts and contextualizing an analysis concerning the existing literature. A more detailed description of the identified participants' themes, categories and contributions is presented in Chapter 4.

Figure 3.2 – Thematic Map



Source: Developed by the author

3.3 Usability evaluation of a radiology system

This study specifically analyzed DICOM image post-processing tasks, evaluating the usability aspects of a radiology system by health professionals from Brazil. This research component did not aim to fix the interfaces of the systems but to learn more about users and their interactions and to help provide empirical evidence for the proposal of recommendations for the design of radiology systems and to contrast with previous results in the literature.

A previous study (SILVA; PEREIRA; FREIRE, 2022b) carried out with the collaboration of the author had the same purpose as the current study. However, the previous study had few details of the nature of the problems due to limitations in the design of the usability evaluation. Therefore, a further study was carried out with usability tests with a full recording of the sessions.

The usability tests led to significant results regarding user behaviour and difficulties in using the software. The method counted on content and thematic analysis to divide problems into categories according to how they affect the interaction. Data analysis was qualitative, where the unstructured data found were transformed into texts and other artefacts in a detailed description of the situation or problem, considering the essential aspects (LAZAR; FENG; HOCHHEISER, 2017).

These tests were carried out remotely from November 2021 to March 2022, using Google Meet and Zoom software, with video and audio recording of participant audio, and also the computer screen later used to document all important and valuable information.

3.3.1 Evaluated system

As previously described, usability tests were performed remotely. Unfortunately, the issues related to COVID-19 in that period did not allow them to be performed in hospitals. Thus, the system chosen to carry out the usability tests was DICOM image manipulation software. This type of software is more accessible. However, information security and patient data issues did not allow the use of the same software that the participants used in their respective work environments.

Some national systems, such as PIXEON, Medilab and I-MEDSYS, were available, but they are complete solutions that include PACS and RIS systems and do not have trial versions that could be used detached from the full equipment. In a previous study (ARANDA, 2018;

SILVA; PEREIRA; FREIRE, 2022b), Fujifilm's Console Advance and Konica Minolta's Regius Console CS2 systems were tested and evaluated for the same purpose as this current study.

The software used for this study was the JiveX DICOM Viewer (Figure 3.3), free software for non-commercial use for viewing images in DICOM format. None of the participants had previously used the software. In this software, it is possible to manipulate the image using several standard tools in software used by radiology professionals. The software, some sets of example images, and the user manual for this software are available for download on the Visus website[2].

Figure 3.3 – JiveX DICOM Viewer

Source: Screenshot of JiveX DICOM Viewer software

The DICOM images used in the tests are publicly available through the TCIA[3] service (The Cancer Imaging Archive), which de-identifies and hosts an extensive archive of medical cancer images accessible for public download at <https://www.cancerimagingarchive.net/about-the-cancer-image-archive-tcia>. These medical images are downloaded using a spe-

[2] https://www.visus.com/en/downloads/jivex-dicom-viewer.html
[3] https://www.cancerimagingarchive.net

cific software called NBIA Data Retriever[4]. In addition, image queries can be made at <https://public.cancerimagingarchive.net/nbia-search>.

3.3.2 Usability evaluation participants

Four male and two female radiology technicians were recruited (Table 3.2). The recruitment of participants for usability tests was done through contacts on social networks, e-mails, and by indication from the participants themselves. The research protocol was approved and registered by the university's Research Ethics Committee with protocol CAAE Nº 49170921.6.0000.5148 in August 2021.

Table 3.2 – Details of usability test participants

#	Academic level	Gender	State	Work in years	Workplace
1	PhD	M	Pará	4	UPA*
2	BSc degree	F	Paraná	6	Hospital
3	Specialization	M	São Paulo	17	Hospital
4	Specialization	M	São Paulo	9	UPA*
5	BSc degree	F	São Paulo	10	Clinic
6	Specialization	M	São Paulo	5	Hospital

**Emergency care unit*

Source: Developed by the author

Participants were from different regions of Brazil and had different characteristics, such as workplace and working experience. Three participants had a specialization, two had BSc degrees, and one held a PhD. Three worked in the hospital, two at UPA (Unidade de Pronto Atendimento, which translated means "Emergency Care Unit"), an emergency care unit, and the other worked in a clinic. The average experience time was eight years, the most experienced participant had seventeen years, and the least experienced participant had four years.

The level of knowledge and experience with computer use, most are said to be acceptable on a scale between low, acceptable and advanced levels. Likewise, most say they are acceptable with their level of experience with radiology systems.

[4] https://wiki.cancerimagingarchive.net/display/NBIA/Downloading+TCIA+Images

3.3.3 Evaluation procedure

The method used was a moderated usability test performed individually and remotely. First, the researcher explained how the test would work and gave a general tour of the software installed so that the participant had at least an overview. Afterwards, the participant remotely accessed the primary researcher's computer, which contained the software and images used during the test, through the Google Remote Desktop service. Then the participants were given the tasks to perform while moderated by the researcher.

The scenario of the tasks chosen was X-ray exams, which is more common among the participants. The user would have to manipulate the x-ray images in the software according to the tasks pre-defined by the researcher. The tasks to be performed were:

a) Select layout;
b) Adjust the position (rotation);
c) Adjust the size (zoom);
d) Execute windowing (darken, lighten, highlighting);
e) Describe the side or name of the incident; Open four images in 2x2 layout;
f) Export file;
g) Print X-ray exam.

The duration of each task was relative, but it had a limit when the researcher understood that the participant would not be able to perform the task or would take longer than necessary. Thus, the researcher intervened to assist or complete that task. In addition, during all tasks, the researcher always reminded the participant to think aloud, which allowed the researcher, later with the video recording, to review, analyze and better understand the cognitive process and the possible difficulties of the participants with the system. The think-aloud technique focuses on user cognition when interacting with the system (ESFAHANI; KHAJOUEI; BANESHI, 2018). These tests studied and evaluated aspects are cognitive learning, interaction and usability problems with information systems and other radiology software elements.

Each test lasted about 60 minutes. After completing the tasks, two satisfaction and usability questionnaires were applied to assess the participants' post-task impressions. One of the questionnaires is a demographic survey developed by the author himself, which includes, for example, the participant's education, age, position held, time of experience with the use of the computer, and the system. The other questionnaire is the PSSUQ - Post-Study System Usability

Questionnaire (LEWIS, 1995), an instrument based on a script of post-test questions with 19 items that assess user satisfaction with the usability of a system. In this case, the researcher used an adapted version of this research in European Portuguese (ROSA et al., 2015). These questionnaires are available in Portuguese in Appendix C.

3.3.4 Analysis of usability evaluation data

This section describes the analysis methods of the usability tests performed in this study. It relies on content and thematic analysis techniques to divide problems into categories according to how they affect interaction. Data analysis is qualitative, where the unstructured data found will be transformed into texts and other artefacts in a detailed description of the situation or problem, considering the essential aspects (LAZAR; FENG; HOCHHEISER, 2017). Usability problems identified in the content analysis were organized using a thematic analysis (BRAUN; CLARKE, 2006).

The primary researcher transcribed problems detected during the recorded tasks, recording the usability problems identified in these recordings. Transcriptions and coding were organized into a spreadsheet in Google Sheets. For categorization and organization into themes, we used the paper Petrie e Power (2012) as a reference. After describing each problem, the researcher also assigned a severity rating to the issue based on the impact of the user's task. This rating was adapted based on the Nielsen severity rating scale (NIELSEN, 1994b), described as follows:

a) **Cosmetic problem**: does not need to be fixed unless there is extra time available in the project (annoying but does not impact the task);

b) **Minor usability issue**: the fix should have low priority (little impact on tasks, users can recover quickly);

c) **Serious usability issue**: important to fix, therefore should be given high priority (severe impact on tasks, recovery may occur, but with substantial effort);

d) **Usability catastrophe**: imperative to fix this before the product can be released (severe impact may prevent users from completing their tasks).

Open coding was performed after identifying the problems and generating the initial codes to categorize the problems found after each round of open coding, the version of the categorization instrument was analyzed by the primary researcher's supervisors until disagreements were solved. The next step in thematic analysis involves identifying themes for the categories identified in the categorization round. The themes were the same used in Petrie e Power (2012) work. Finally, at the end of the stage, the themes, categories and usability problems identified during the process were presented.

The measures taken included: usability problems; the seriousness of these problems; what will be the impact with clinical alignment; what percentages will be achieved for each task; what difficulties will be encountered in performing the tasks; and if there was discomfort or stress in the system of use.

4 RESULTS

This chapter presents the results obtained in the thematic analysis of the interviews and usability tests with radiology professionals in this research.

4.1 Interviews with radiology professionals

The results are related to the aspects addressed in the interviews that describe the work routine of radiology professionals, cognitive learning, interaction and usability problems with information systems and other radiology software elements. The interviews had participants from different regions of Brazil, one from the north, one from the northeast, seven from the southeast and two from the south of the country.

The results presented in this section were published as a full paper at the $18_{t}h$ Brazilian Symposium on Information Systems (SBSI) (SILVA; PEREIRA; FREIRE, 2022a).

This thematic analysis revealed five themes that interfere with the routine of the radiology professional and the radiological context:

a) How the characteristics of the radiology system affect usability for the user;
b) How situations or processes affect the characteristics of radiology professionals' tasks;
c) What influences the behavior of the radiology professional concerning their routine;
d) What determines a radiology professional's experience and knowledge;
e) How radiology professionals deal with system failures and data loss risks.

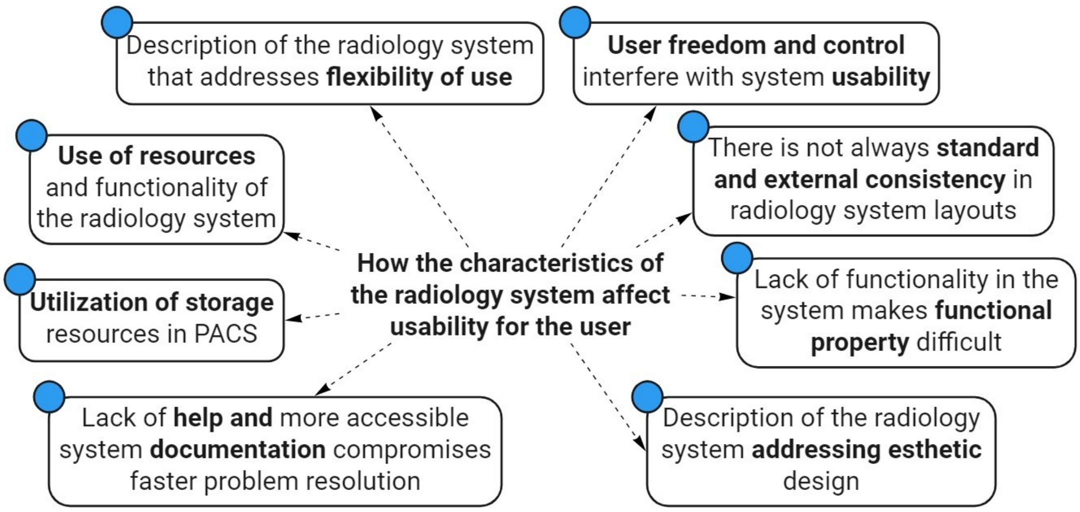
The results of the analysis are based on Nielsen's heuristics (NIELSEN, 2020) for reference to usability issues, on ISOs 25010 and 9241-11 (ISO, 2011; ISO, 2018a) for software quality issues and usability standards, and in books and articles (WAGNER; HOLLENBECK, 2020; PARLANGELI et al., 2020; MCSHANE; GLINOW, 2018; OLIVEIRA, 2013) that address organizational behaviour, processes and cognitive psychology. A spreadsheet with categorization details is available at this link <https://bit.ly/plan-interviews-analysis>. For a better understanding, the next subsections describe each theme in more detail. It is important to note that the categories are related to three elements that make up the concept of Information Systems: **people** (in purple triangle), **processes** (represented by yellow diamond) and **systems** (in blue circle), illustrated in Figures 4.1 to 4.5.

The following sections present an analysis on the themes identified in the analysis.

4.1.1 System features affect usability for users

One of the factors found in the interviews shows how the system's characteristics can affect the work of the radiology professional in terms of usability. Figure 4.1 illustrates the categories that describe these characteristics. The context-related categories of "systems" are represented by blue circle.

Figure 4.1 – System characteristics affect usability for users



Source: Theme component of Figure 3.2

During the interviews, we found that the **lack of functionality in the system makes functional property difficult**. This issue occurs when the system does not provide solutions or resources for a particular task or problem, which impairs achieving user-specified tasks and goals. An example of this can be seen in the following excerpt described by participant 2:

> "... difficulty printing some exams where the layout does not allow it and I have to keep rotating the image. This is lacking, but it is because we do not have the tool in this equipment that I work with, but it exists."

The description of the **use of system resources and functionality** made by the interviewees was essential to understand their use, determining the degree to which the resources used, when performing their functions, meet the requirements. Some interviewees talked about having **freedom and control**, which also interferes with the system's usability, as it must be able to be used by users to achieve a better experience with effectiveness, efficiency and satisfaction in some contexts of its use.

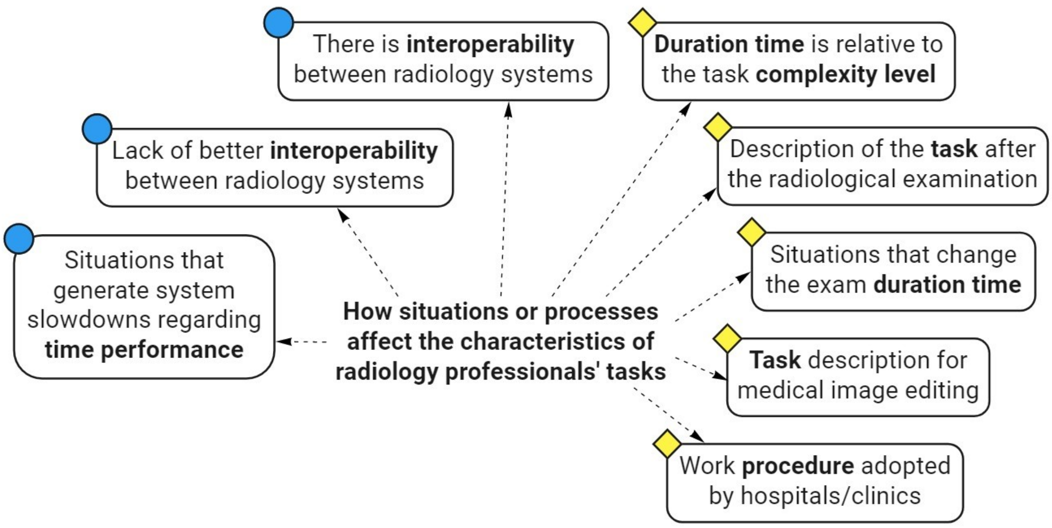
The researcher also noticed during the interviews the **flexibility of use, aesthetic design, and pattern and external consistency**. The first shows that shortcuts speed up the interaction for the more experienced user but are hidden from novice users. On the other hand, aesthetic design is vital to keep the content, and visual design focused on the essentials, where the visual elements of the radiology systems interface support the primary user goals. Moreover, pattern and external consistency indicate that users should not have to ask themselves if different words, situations or actions mean the same thing. That meant that the system did not maintain consistency, which can increase users' cognitive load, forcing them to learn something new, especially in contexts where users who work in different clinics use different systems concurrently. Participant 3 describes some of these characteristics:

> "Each one (user) has their scheme to do this (task), so each one has its method, there are of course the easiest to move and the hardest to move too, according to each manufacturer."

4.1.2 Situations or processes affect the characteristics of user tasks

It is noticeable that the tasks of radiology professionals are based on the processes adopted by hospitals and clinics. Thus, several situations can occur that affect the characteristics of these tasks. Figure 4.2 illustrates the categories that determine these situations, which can be related both to the context of "systems" (categories represented by blue circle) and to the context of "processes" (categories represented by yellow diamond).

Figure 4.2 – Situations or processes affect the characteristics of user tasks



Source: Theme component of Figure 3.2

Regarding the system, the lack of **interoperability between systems** and the slow performance affect the tasks of these professionals. Moreover, as part of the process, the interviewees describe the **complexity level of the task**, the **duration time** of the task and how the

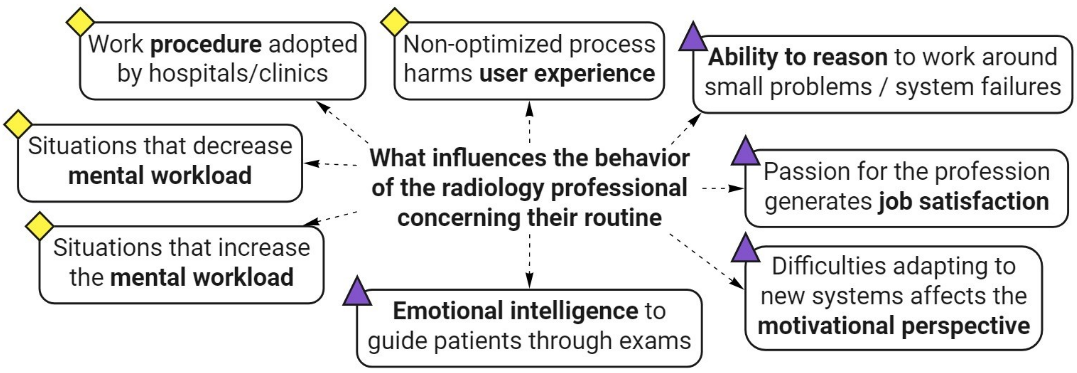
procedures are adopted by hospitals and clinics can be understood as situations that affect tasks. Participant 2 exemplifies one of these characteristics:

> "... you have a simple exam, which will be quick, you have to prepare it, put it to process and execute, something from 5 to 10 minutes, on the other hand you have, for example, a contrasted exam that will take half an hour to 40 minutes with patients in the room."

4.1.3 User behavior about their routine

The results involving user behaviour had aspects related to the context of "processes" (in yellow diamond) and the context of "people" (in purple triangle), as shown in Figure 4.3.

Figure 4.3 – User behavior in relation to their routine



Source: Theme component of Figure 3.2

Some processes decrease or increase the **mental workload** about the cognitive effort required of the professional. The **user's emotional perspective** suggests that there is an adjustment of the characteristics of the jobs to the needs and interests of the people who perform them, providing the opportunity for **job satisfaction**. Radiology professionals can know how to lead patients during exams as **emotional intelligence**, especially older or debilitated patients. These professionals often need to think inductively and deductively to find solutions and solve specific problems. One of these approaches is exemplified by participant 6:

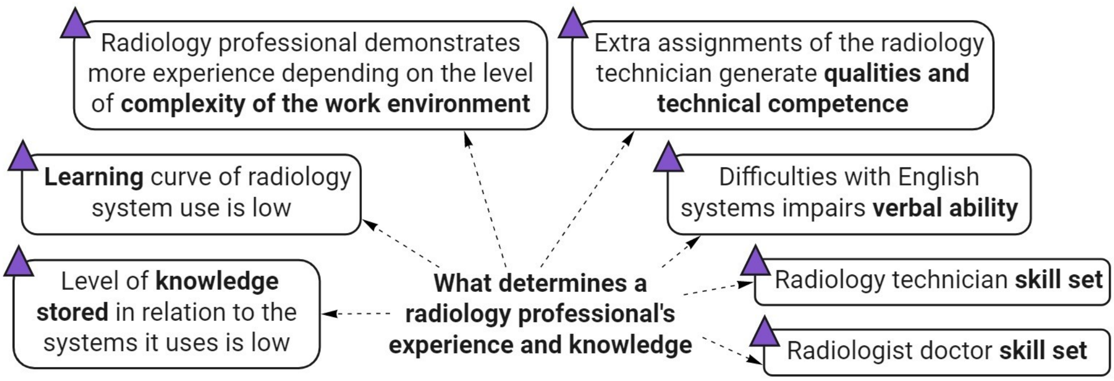
> "... if your password and username don't allow it, you have to ask a normally older colleague at home to solve the problem... to avoid this problem and send it to the right patient folder, ensuring that this image goes to the right patient."

4.1.4 User's knowledge and experience

Currently, the radiology professional is not limited to just performing exams. The experience and search for knowledge bring new demands and obligations to the user. Figure 4.4

illustrates the categories that describe radiology professionals concerning knowledge and experience with their work. Here the categories are related to the context of "people" (in purple triangle).

Figure 4.4 – User experience and knowledge



Source: Theme component of Figure 3.2

Participant 3 comments on the evolution of the radiology technician in relation to his ability and **stored knowledge** to analyze the exams. However, the report is still an exclusive task of the radiologist.

> "...I found it interesting, it's the image analysis part. ... maybe some other interviewee will comment more on this as well. ... we already do the analysis, but not the report."

The **complexity of the work environment** is also an essential factor that drives the professional experience. Participant 3 reports his experience in different work environments that helped to gain experience.

> "I spent seven years in the hospital, where I gained a lot of experience. Mainly direct contact with the emergency room, ICU, surgical center... I left the hospital and ended up migrating to the clinic through an invitation from a radiologist and I am there until today."

Participants 4 and 9 describe the **difficulties with systems in English**, with the significant presence of systems developed outside Brazil and without localization:

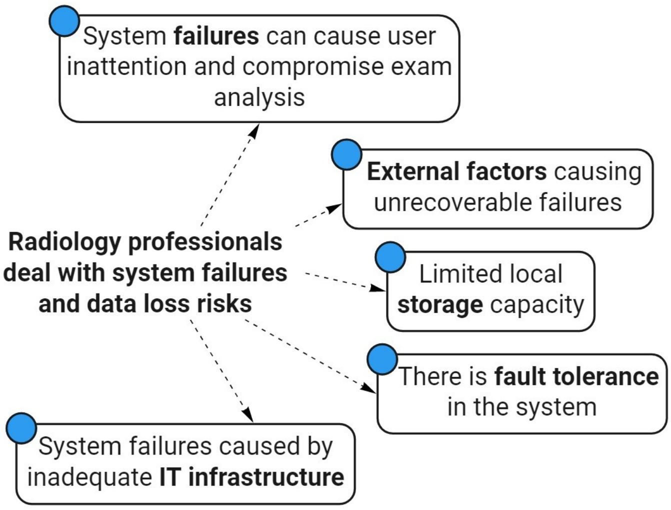
> "... I think my biggest difficulty was in the language, but it just gets easier later on because you're exercising some types of messages and other types of information in English, so it's a little easier to handle of these tomography and resonance platforms for example. (Participant 4)"

> "In the beginning, it takes us a little longer to adapt because there is a lot in English, these interfaces and equipment, so a lot of things end up being in English, mainly in CT, MRI, so I think that was the more difficult. (Participant 9)"

4.1.5 System crashes and data loss risks

In addition to dealing with patients and a series of procedures, the radiology professional also deals with situations that can lead to data loss (Figure 4.5). For example, **system failures or external factors** such as power outages may occur. Having **IT support and infrastructure** makes a big difference.

Figure 4.5 – System failures and data loss risks



Source: Theme component of Figure 3.2

The following situations were described during the interviews:

> "The only problem that ever occurred was identifying the cassette, taking the exam and when it came time to reveal the image in the system, nothing came out. Moreover, in this case 2 or 3 times it has happened. And then I would not be able to tell you what kind of problem that would be. (Participant 1)"
>
> "...it was network problems, not system-specific. The system responds well to what we expect. (Participant 2)"
>
> "... doing the exam sometimes in that rush to make images and suddenly there is a problem like this loading you put and lose the image and you have to redo it. (Participant 5)"

In this study, the risks to patients did not have significant findings or were minimized by the participants. The researcher considered that eventual system failures could compromise and generate minimal risk to the patient. The risks may be more significant at other times, such as inattentive failures during medical records and/or examinations. Participant 6 describes a situation in which a failure in the system can cause user inattention, and the test results may be impaired:

> "Another problem is also when they delete the exam for some reason. If you delete an exam from the *worklist*, sometimes because you clicked on the wrong patient to delete or canceled patient A, patient B will take the exam. Then, when you cancel the exam of patient A, you end up canceling the exam of B, ... you will send the images and they will fall into a folder in sections ... there will be a mix and there will be some information such as the patient's name and everything else. "

4.2 Usability evaluations

This section presents the results obtained in analysing usability tests carried out with six radiology professionals for this research. It is important to note that the software used in the usability test had no integration with a PACS and RIS system. So, we only consider the process of editing the radiology image done by the radiology technician.

The results presented in this section were submitted to the 21st Brazilian Symposium on Human Factors in Computing Systems (IHC), Innovative Ideias and Emerging Results track (SILVA; PEREIRA; FREIRE, 2022c).

The study found 64 problem instances, with an average of 10 problems per user. Problems were separated into 20 problem categories organized into four themes: Visual Presentation, Content, Information Architecture, and Interactivity (Table 4.1), as defined by Petrie e Power (2012).

Table 4.1 – Problem categories organized into themes (continuation)

Code	Category	Occurrences	Some examples
Visual Presentation			
visu1	Unclear or confusing layout	6	Toolbar for windowing task has different options that accomplish the same goal (U4-P5)
visu2	Text/interactive element is not clear/distinguished enough to identify its functionality	10	The user did not realize that there is another interactive element to describe the side and the radiological incidence that inserts only the text without the indicative arrow (U2-P2)
visu3	Interactive elements with different functionality have similar icons	3	The icon of the "reset" element is confused with the icon of the "rotate image" element (U4-P2)

Table 4.1 – *Problem categories organized into themes (continuation)*

Code	**Category**	**Occurrences**	**Some examples**
visu4	It takes time to find the desired interactive element	7	It took a long time for the user to find the text tool that allows describing the side and radiological incidence (U3-P4)
Content			
cont1	Layout with too much content confuses the user	2	Mouse action drop-down menu presents many unnecessary options (U6-P4)
cont2	Content is not clear enough	7	Radiology image viewing software content is not available in other languages (U2-P7)
cont3	Duplicate or contradictory content	1	The "reset" interactive element exists in two places, but performs different actions (U5-P9)
cont4	Undefined terms	1	The interactive element represented by the floppy disk icon does not make it clear what the user is saving (U5-P10)
Information Architecture			
arch1	There is not enough structure for the content	3	The actions performed with the mouse can be changed, but require several steps that hinder the user (U5-P11)
arch2	Purpose of the structure is unclear	4	There are two options to display more than one radiology exam image on the screen with different objectives that confuse the user (U5-P8)
Interactivity			
inte1	Lack of information on how to proceed and why things are happening	2	In the radiology image viewer, the user does not know how he activated and how to close the full-screen mode (U3-P8)
inte2	Excessive effort required by the user	2	If the user makes a mistake in a procedure, it is necessary to reset and redo everything again (U4-P9)
inte3	System does not allow user to revert wrongly performed action	5	If there is any misfit in the radiology image during the editing process, the user cannot revert to the previous action (U5-P2)

Table 4.1 – *Problem categories organized into themes (conclusion)*

Code	Category	Occurrences	Some examples
inte4	Software does not generate feedback on user actions	3	The software does not provide visual feedback when switching between one radiology image and another (U4-P1)
inte5	Illogical interaction sequence	7	Opening the same radiology image in the layout with more than one image preview (U3-P10)
inte6	Result of the action performed does not meet the user's expectation	11	The "ESC" key, by default, coincides with the action to exit full-screen mode, which does not occur in this radiology image viewer (U6-P8)
inte7	Expected interactive functionality is absent	3	The option to undo the last action is missing in this radiology image viewer (U1-P3)
inte8	Security issues not highlighted	1	Software allows opening images of different patients in the same work window and does not have a division to identify these images (U4-P11)
inte9	Missing error/warning messages	4	When resetting the radiology image to the initial state, the software does not ask if the user wants to proceed with the action (U1-P3)
inte10	Delay to perform a task	4	The user took a long time to perform a task because he could not use the tool properly (U5-P5)

Source: Adapted from Petrie e Power (2012)

Visual Presentation details how the software is presented visually to the user. Four categories reveal that users had difficulties interacting with the layout because it did not present greater clarity and organization of its functionalities, and the presentation of some icons confused users. Consequently, several times, some users took time to find the interactive elements to perform the tasks.

There are four categories under the **Content** theme, where the problems are: parts of the layout display much content, often with an unclear context, sometimes duplicated, or with terms that are not very well defined to make its functionality clear to the user.

The **Information Architecture** theme shows the system has structural problems that imply the user's task. Here we have two categories that describe situations that could be facilitated for the user to perform the task without much effort, as is the case of actions that he can perform with the mouse. Moreover, the other category shows how it is not apparent to the user how to use multi-layout to display images.

The **Interactivity** theme is the one that most presents problem situations. There are ten categories to describe each situation. It is worth highlighting four categories: "Lack of information on how to proceed and why things are happening", "System does not allow the user to revert wrongly performed action", "Illogical interaction sequence", and "Result of the action performed does not meet the user's expectation". In the tests, it was clear that most users had difficulties. For example, when entering the full screen, the user did not know what happened and did not know how to go back. Also, whenever he performed a wrong action, he could not undo it. At other times the user's action did not have the result he expected. These situations ended up causing the user to go through unnecessary steps to solve or fulfil the task.

4.2.1 Violated Nielsen's heuristics and severity scale

In addition to categorization, each problem was analyzed by assigning a related violated heuristic as defined by Nielsen (2020). Of Nielsen's ten heuristics, the study presented a violation in seven of these heuristics, as shown in Table 4.2.

Table 4.2 – Violated Nielsen heuristics

Heuristic	**Occurrences**
Visibility of System Status	3
Match Between System and the Real World	13
User Control and Freedom	8
Consistency and Standards	14
Recognition Rather than Recall	4
Flexibility and Efficiency of Use	8
Aesthetic and Minimalist Design	14

Source: Developed by the author

A severity scale based on Nielsen (1994a), Rubin e Chisnell (2008) was also applied. The Table 4.3 shows the number of occurrences corresponding to each severity level.

Table 4.3 – Nielsen and Rubbin Severity Scale

Rating	Severity	Occurrences
1	Cosmetic problem only	19
2	Minor usability problem	15
3	Major usability problem	12
4	Usability catastrophe	18

Source: Developed by the author

For more details, a complete table with all categorized problem situations with the violated heuristics and severity rating can be accessed in link <https://bit.ly/tab-usability-tests>. Moreover, in Section 4.3, details of the analysis of this data obtained in the usability tests are presented.

4.2.2 Post study questionnaire

After carrying out the usability test, participants received a link to a post-study questionnaire to assess satisfaction with the usability of the software. The PSSUQ questionnaire brought some interesting insights. Overall, all participants say they are satisfied with the system they used in the test. Most (83%) understood that the system had a pleasant interface, was easy to understand and learn. However, only two participants understood that they could complete the tasks efficiently. Only one participant said that the information the system presented was clear. Moreover, none of the participants agreed that the system indicated an error and helped resolve it.

4.3 Usability Problems Encountered

This section describes each category obtained by analyzing the usability test data. Each subsection represents a category illustrating how the issue affected the user.

4.3.1 Unclear or confusing layout

User interface content and visual design need to be clear, easy to read or view and focus on the essentials for the user (NIELSEN, 2020). Unnecessary or excess elements distract the user from the information he needs. Ideally, prioritize important content and features. Problems related to this category had six occurrences.

In the usability test of the JiveX DICOM Viewer software carried out with users, we observed that users took time to find the tools and resources to perform the tasks. The toolbar on the right side contained all possible options, as shown in Example 1 in Figure 4.6. The visual would be more evident if it had only the essential tools with the option to expand when necessary. Thus, the user's search for the right tool would be minimized, for example, having only the default zoom tool instead of displaying all zoom options. Example 2 shows the print window, where the software replicates the image manipulation tools needlessly rather than focusing only on print features.

Figure 4.6 – Unclear or confusing layout

(a) Example 1 (b) Example 2

Source: Screenshot of JiveX DICOM Viewer software

Two other Nielsen heuristics affected in this category are: "Consistency and standards" which is the ability to learn while maintaining both types of consistency: internal and external; and "Recognition rather than recall", which allows people to recognize information in the interface, rather than having to remember.

In this category, as a severity scale, there were two of level 1, two of level 2 and two of level 3. Highlighting the two situations of level 3, which was necessary after a specific time during the task, the researcher intervened to give tips so that the user could find the most suitable tools for the respective tasks.

4.3.2 Text or interactive element is not clear enough to identify its functionality

The design must speak the user's language. It is necessary to ensure that the user understands the meaning without looking for a definition or remembering what it means (NIELSEN, 2020).

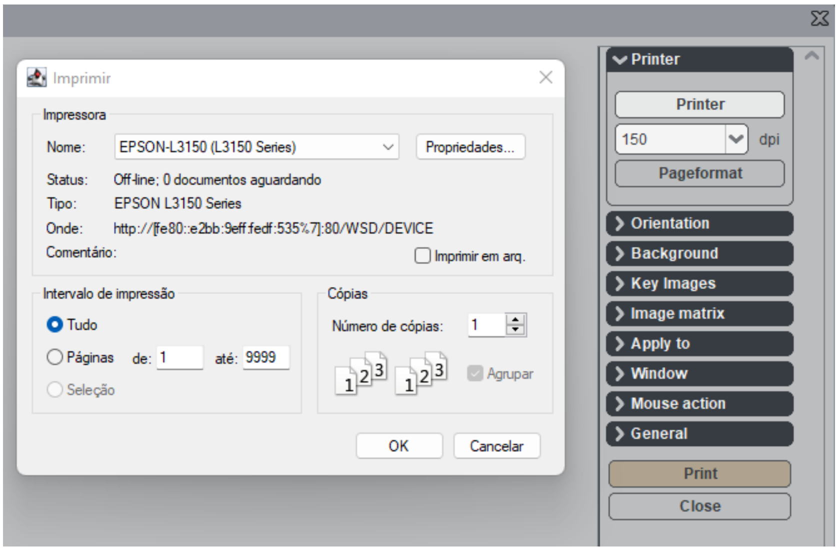
During the tests, several users used a text tool to write the incidence on the exam image. There are two tools with the same purpose, but one of these tools includes an arrow, and some users tried to remove the arrow without success. Others took a while to realize that the other tool did not include the arrow. Figure 4.7 shows the detail of each tool.

Figure 4.7 – Interactive element is not distinguished enough to identify its functionality

Source: Screenshot of JiveX DICOM Viewer software

The tool icons describe the tool's action when positioning the mouse over the tool icon, but the difficulty with the English language prevents the user from identifying the action. Another example is the print window with a button "Printer" and another "Print" (Figure 4.8. As the "Printer" button appears at the very beginning, the user goes straight to it and clicks a standard window of the Windows operating system with the title "Print" suggests to the user that it is clicking OK and that is it.

Figure 4.8 – User difficulty with the English language



Source: Screenshot of JiveX DICOM Viewer software

We had ten hits for this category that violated the following Nielsen heuristics: "Aesthetic and minimalist design", "Match between system and real world", "Recognition rather than recall", and "Consistency and standards". Regarding severity, we had one of level 1, three of level 2, one of level, and four of level 4. In all problem instances with a severity level of 4, users could not complete the task satisfactorily.

4.3.3 Interactive elements with different functionality have similar icons

In this example, three users confused the icon representation of an interactive element with another element, as shown in Figure 4.9. The task in question was to rotate the image, but in the toolbar, the interactive element "Reset" has an icon similar to the representation of the standard rotate icon in other software. The violated heuristic is about consistency and standards, which says it must follow established industry conventions, whether internal or external (NIELSEN, 2020).

Analyzing the problem according to the task, we can denote the severity of level 2 or 4 depending on the situation. During the tests, it happened in two ways. In the first one, no image editing had been performed, and the rotation task would be the first action. In this case, nothing would happen so that it would have severity 2. However, if any other task was performed before the rotation task, confuse the rotation button with the reset. The result is equivalent to severity 4.

Figure 4.9 – Interactive elements with different functionality have similar icons

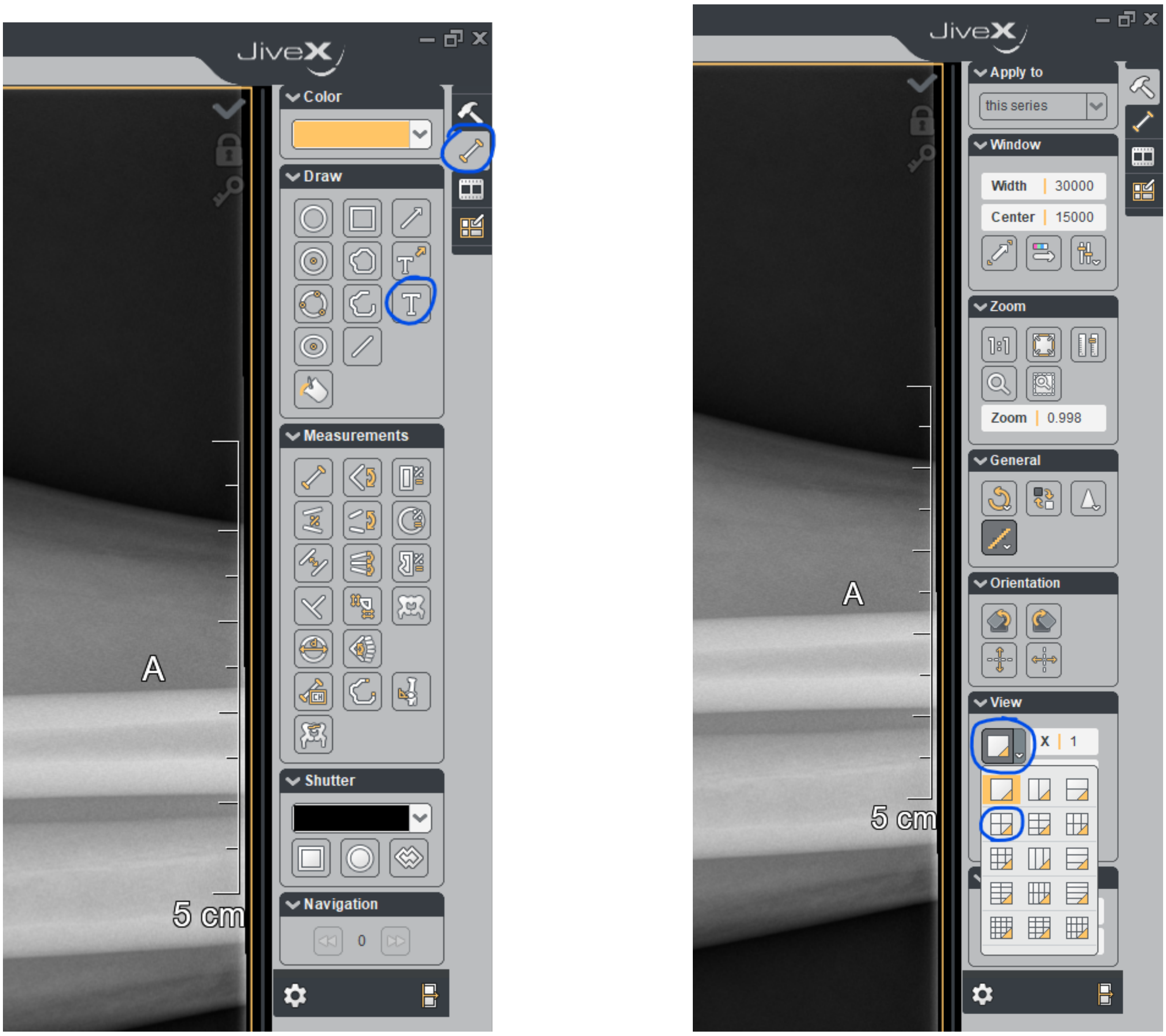
Source: Screenshot of JiveX DICOM Viewer software

4.3.4 It takes time to find the desired interactive element

As the category name describes, four users who participated in the tests in specific tasks took a long time to find the desired interactive element. We had seven hits for this category, and the most affected Nielsen heuristic was "Aesthetic and minimalist design". The "Flexibility and efficiency of use" heuristic appeared in one case. Regarding severity, most were level 1 and only one level 4, where the user needed the researcher's intervention to find the appropriate tool.

In Figure 4.10, we have two examples illustrating this category. In Example 1, we have the tool's location to write the incidence in the exam image. Notice that accessing it requires first using the second icon on the extreme right of the toolbar. Moreover, in Example 2, to choose the 2x2 layout, it is necessary to expand the interactive element in the "View" set of the toolbar.

Figure 4.10 – It takes time to find the desired interactive element



(a) Example 1 (b) Example 2

Source: Screenshot of JiveX DICOM Viewer software

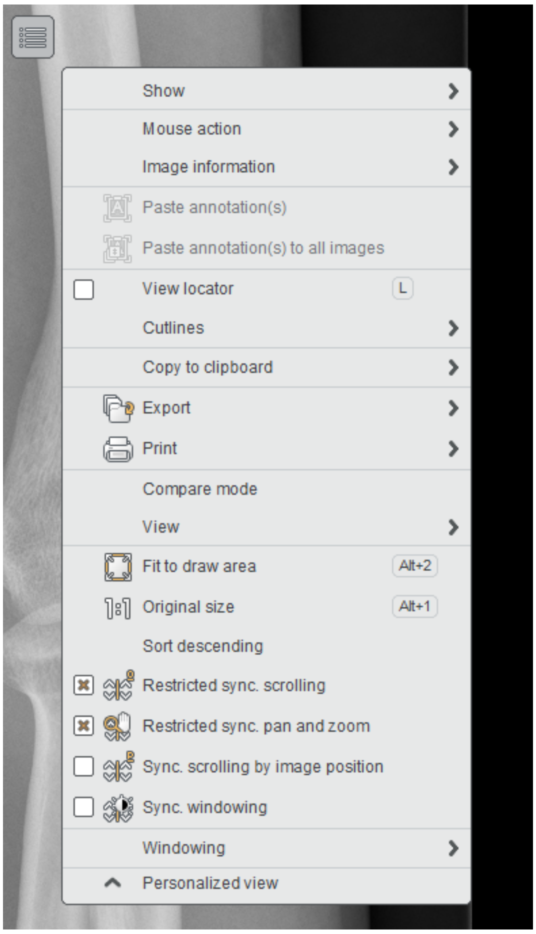
4.3.5 Layout with too much content confuses the user

We had two problem situations in this category that violate the "Aesthetic and minimalist design" heuristic. According to Nielsen (2020), it is crucial to prioritize only necessary elements to avoid distracting users from essential information.

The examples illustrated in Figure 4.11 show that the drop-down menu presents too much information. Another example is in the print window, which does not focus only on the necessary features of the print, as already shown in Figure 4.6 (b).

The severity in these two cases was applied as level 1, as it is understood that the problem can be easily circumvented.

Figure 4.11 – Layout with too much content confuses the user



Source: Screenshot of JiveX DICOM Viewer software

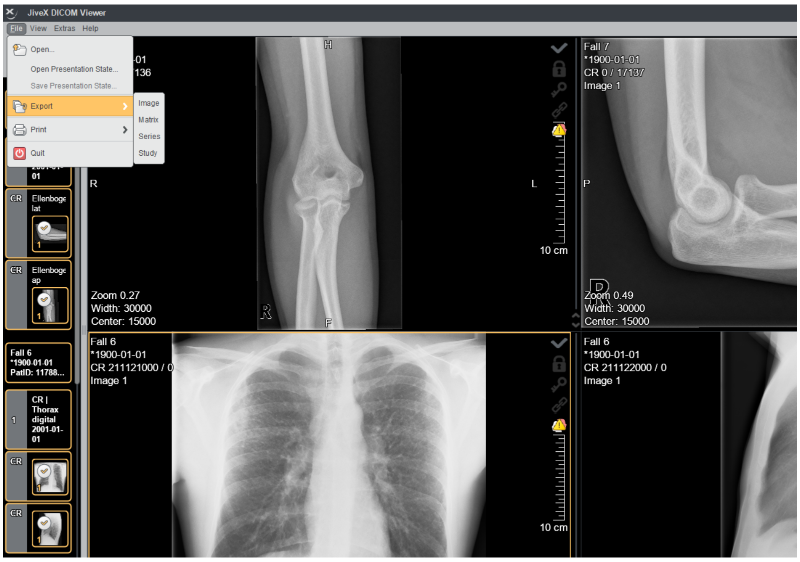
4.3.6 Content is not clear enough

We had seven problem situations in this category, and we understand that five violated the heuristic "Match between system and the real world". The leading cause is users' difficulty with the English language.

For the example, let us use the problem situation that violated the "Consistency and standards" heuristic. Figure 4.12 shows four options for exporting exam images, and the task was to export four exams. The user chose the option he understood to be exporting all exams but ended up exporting only one.

In terms of severity applied, we had two level 4, two level 3, one level 2, and two level 1. The severity is applied according to each problem situation. We understand that level 4 situations are influenced because the user could not clearly identify the interactive elements or understand their functionality.

Figure 4.12 – Content is not clear enough

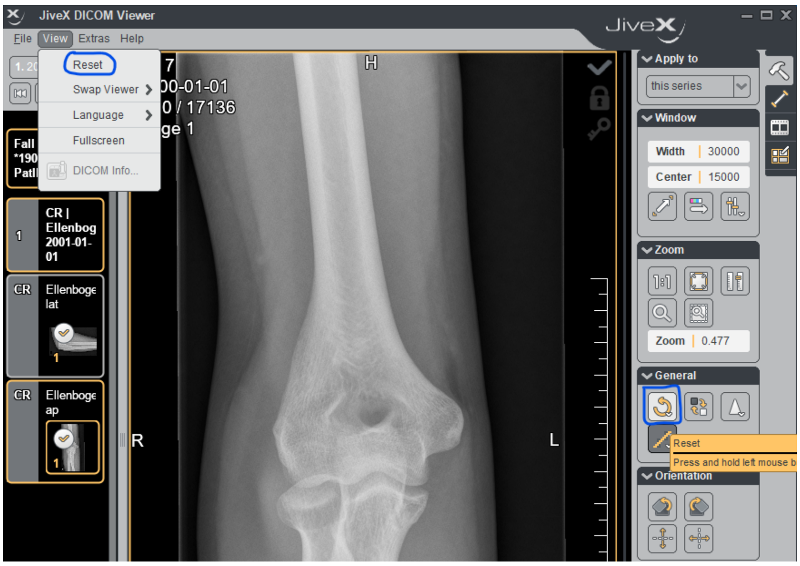


Source: Screenshot of JiveX DICOM Viewer software

4.3.7 Duplicate or contradictory content

This category had one problem instance that appeared out of a user's need after performing a task. The user wanted to close all images and found the solution in the "Reset" option in the "View" menu. However, there is another "Reset" in the toolbar, but its action is different. The Figure 4.13 shows the location of the "Reset" option.

Figure 4.13 – Duplicate or contradictory content



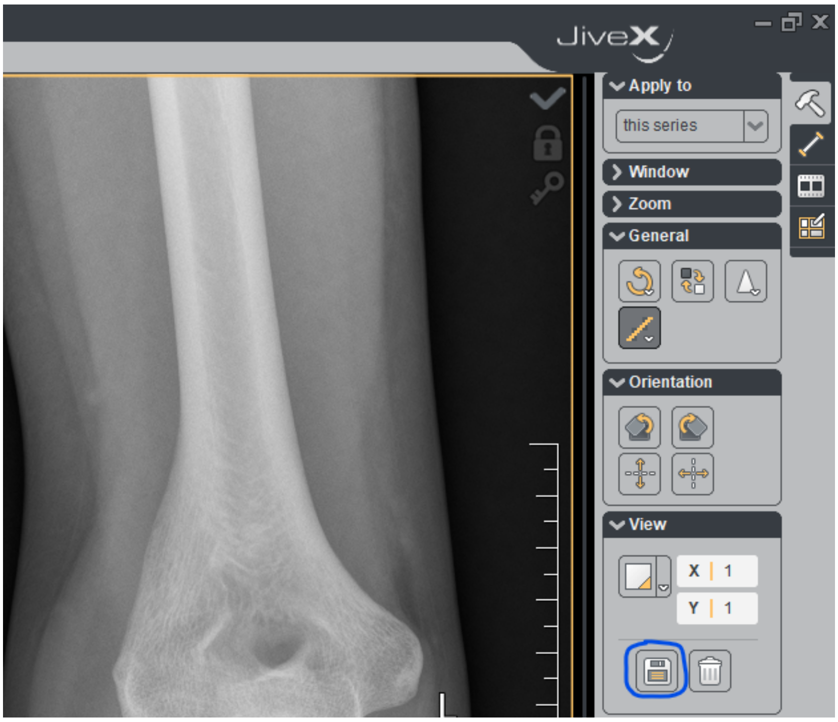
Source: Screenshot of JiveX DICOM Viewer software

In this case, the Nielsen heuristic was "Match between system and the real world", and we applied a severity level of 4, as the expected action does not match reality, compromising the user's work.

4.3.8 Undefined terms

This category had only one problem occurrence. The interactive element analyzed is the "Save" button which is located in the "View" of the toolbar on the right side (Figure 4.14). The task was to save the exam images, and the user understood that the icon representation, being a floppy disk, would save the images. However, the action of this interactive element was to save a customised layout.

Figure 4.14 – Undefined terms



Source: Screenshot of JiveX DICOM Viewer software

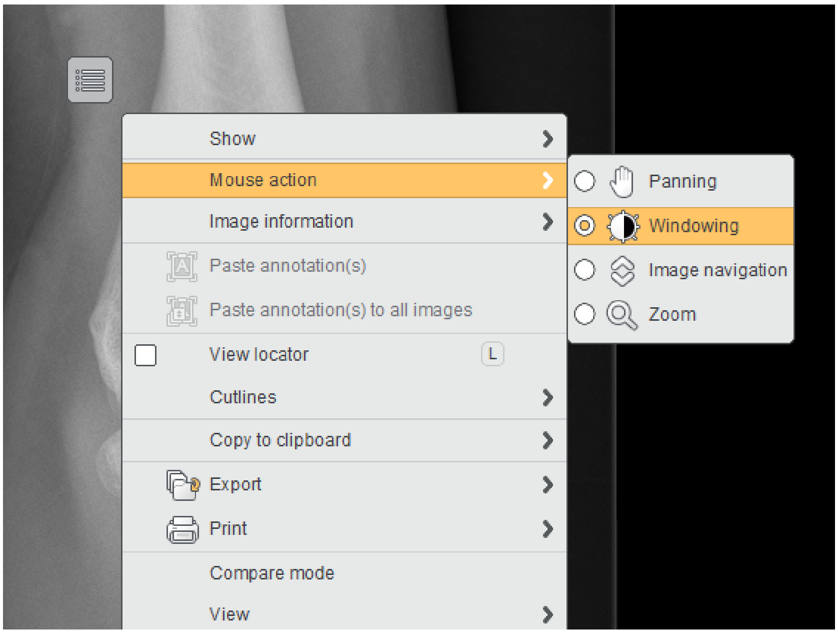
The affected Nielsen heuristic was "Match between system and the real world", and the severity level 4 was applied because the user was confused, thinking he was saving the image, took a while to understand what was happening and needed the help of the researcher to manage to complete the task.

4.3.9 There is not enough structure for the content

This category describes how the system proposes using specific resources and having the user perform several steps. Thus, three problem occurrences were detected. Each of the issues affected a different heuristic, which is “Visibility of system status”, “Flexibility and efficiency of use” and “Aesthetic and minimalist design”.

To illustrate an example, the user has chosen to use mouse actions to perform the windowing task. However, for this to work, it is necessary to change the type of mouse action in the drop-down menu, as shown in Figure 4.15. So every time the user needed to do an action on the exam image, he would have to change the mouse action; otherwise, he would make a mistake, having to reset the image and redo the whole process. During the task, the user found it strange because when executing the task, the action was zoomed because it was configured that way. As a result, the user could not understand the situation and did not complete the task satisfactorily.

Figure 4.15 – There is not enough structure for the content



Source: Screenshot of JiveX DICOM Viewer software

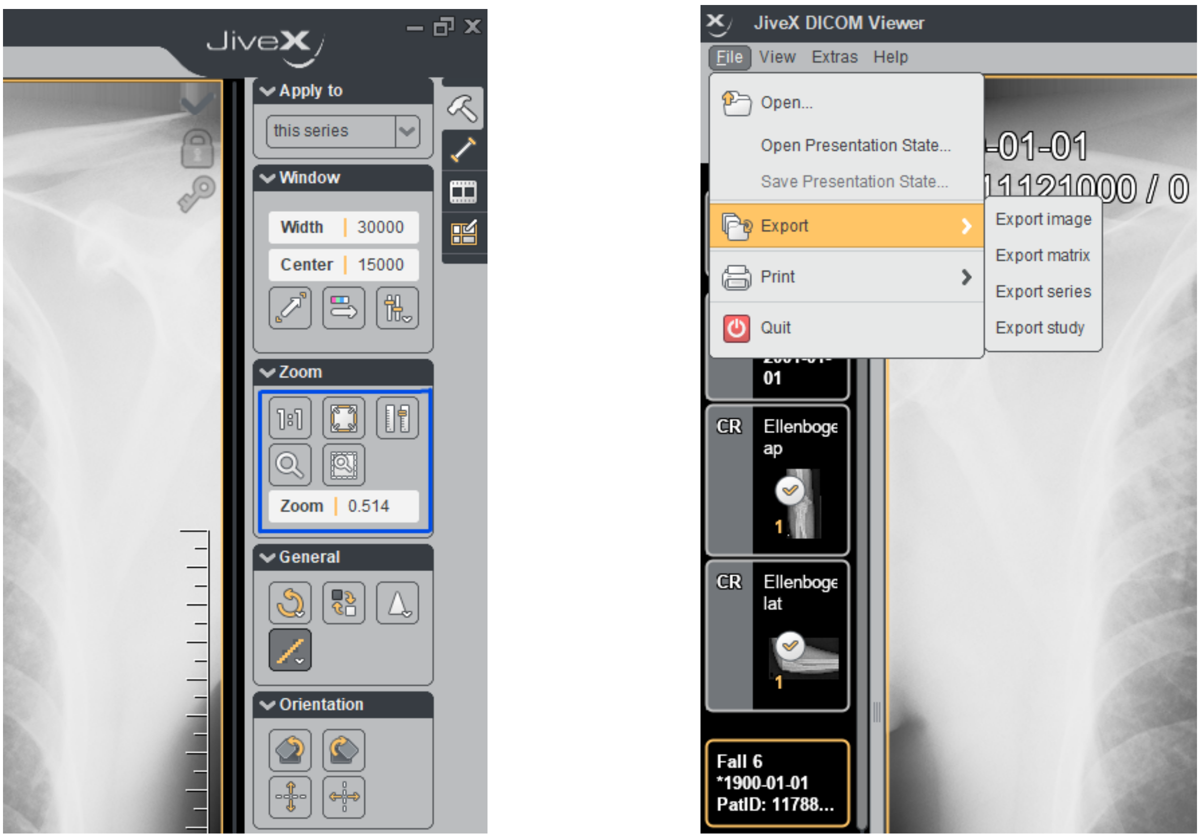
For this example, a severity level of 4 was applied due to the user’s situation. In the other occurrences of problems, we had milder severity of levels 1 and 2.

4.3.10 Purpose of the structure is unclear

Improving the ability to learn by keeping the types of consistency (internal and external) helps the user to understand and perform tasks. In this category, we had four problem occurrences that affect this "Consistency and patterns" heuristic and another two: "Match between system and the real world" and "Visibility of system status".

In Figure 4.16 (a), we have the example where the zoom tool, like other tools, has several options and is not always clear enough for the user to identify its functionalities. Another example illustrated in Figure 4.16 (b) is the options for exporting exams, and the result did not match what the user expected.

Figure 4.16 – Purpose of the structure is unclear



(a) Example 1 (b) Example 2

Source: Screenshot of JiveX DICOM Viewer software

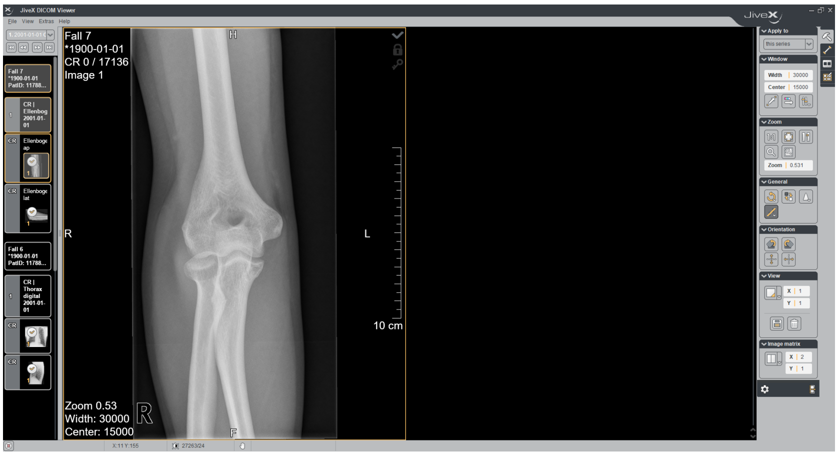
The severity level applied to the occurrences were 3 and 4, as the users could not complete the respective tasks satisfactorily.

4.3.11 Lack of information on how to proceed and why things are happening

This category describes situations where the user had difficulty understanding the action he was performing or did not know how to react in unexpected situations. Two problem situations occurred during the medical image manipulation tasks that affected Nielsen's "Aesthetic and minimalist design" heuristic.

The situations occurred with the same user, one in which the user had difficulties understanding the change of the action performed by the mouse and the other situation in which he entered the image comparison mode without knowing where he clicked (Figure 4.17). The severity level applied were levels 2 and 3, respectively.

Figure 4.17 – Lack of information on how to proceed and why things are happening



Source: Screenshot of JiveX DICOM Viewer software

4.3.12 Excessive effort required by the user

In this category, we had two problem occurrences that describe how the user is unnecessarily required to perform specific tasks. One of the cases was simpler, with severity level 1 and affected the "Flexibility and efficiency of use" heuristic.

In the other case, the user mistakenly changed the contrast of the exam image, so he had to reset the image and redo the whole process since the system does not have a command that undoes the last action done. In this case, the severity level applied was level 3 and affected the 'User control and freedom" heuristic.

4.3.13 System does not allow user to revert wrongly performed action

The context of this category is what drives the previous category. The problem is that the system does not allow the user to reverse his wrongly performed action.

We had five problem situations that violated the “User Control and Freedom” heuristic. However, they had different levels of severity according to each situation: three level 4, one level 3 and one level 2.

4.3.14 Software does not generate feedback on user actions

The system must keep the user informed about what is happening during the execution of a task (NIELSEN, 2020). This category describes the lack of feedback from the software. For example, during a specific task, the user was trying to switch between two x-ray exams, but the user could not tell if he was switching between one and the other.

There were three issues where the user did not have visual feedback. Each occurrence violated a different heuristic: “Match between the system and the real world”. “Consistency and standards” and “Visibility of system status”. Regarding severity, levels 1, 2 and 3 were applied according to each situation.

4.3.15 Illogical interaction sequence

As the category name says, the software has some interactions that do not make sense to the user. Seven problem situations were found for this category that violated four heuristics: “Flexibility and efficiency of use”, “Visibility of system status”, “User control and freedom” and “Match between system and the real world”. In the severity scale, we had, according to each problem situation, three level 1, two level 2 and two level 3.

For example, it makes no sense for the system not to have an option to undo the last action performed by the user. The action to enter full screen triggered by two clicks on the exam image is also irrelevant. Having actions such as clicking on an exam and having the system replacing another, without the user’s intention, in a layout with more than one image on the screen caused confusion.

4.3.16 Result of the action performed does not meet the user’s expectation

This category describes when the result of the action performed by the user is unexpected. Eleven problem situations were found in the tests with the radiology software that did not correspond to what the user expected. We had six violations of the “Consistency and standards” heuristic, the others violated the “Flexibility and efficiency of use”, “Match between the system and the real world” and “User control and freedom” heuristics.

Some examples mentioned above also fall into this category. For example, the user tried to zoom in on the exam with the mouse and the result ended up changing the contrast in the image. In another case, they exported four exams and the result only exports one. By mistake, the user enters in fullscreen and tries to exit by pressing the “ESC” key, which does not work.

In the severity scale, we apply levels 1, 2 and 4 according to each situation. Severity level 4 was applied in six occurrences, which denotes attention to these situations.

4.3.17 Expected interactive functionality is absent

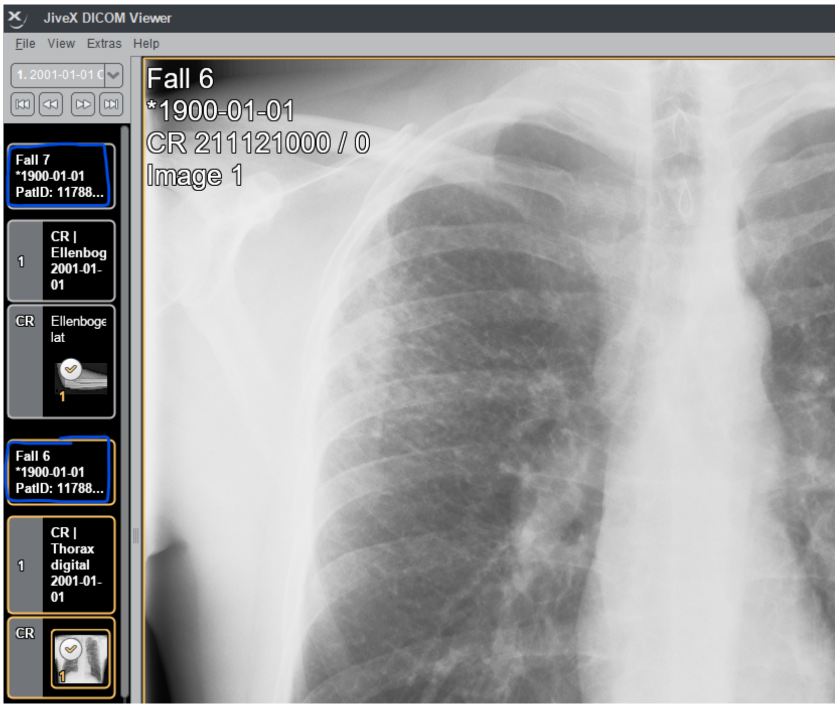
In this category, we found three problems related to the lack of features standard in other radiology systems. For example, two users tried to use the keyboard command "CTRL + Z" to undo the last action, but it did not work because this functionality was missing in the software in question. Other hotkeys that are also present in similar software were not available. The occurrences violated the “User control and freedom” and “Consistency and standards” heuristics. The applied severities were rated 1, 3 and 4 according to each problem situation.

4.3.18 Security issues not highlighted

We had an occurrence that refers to this category. What happened was the fact that the system allows the user to open exams of different patients in the same work environment and does not make this division clear (Figure 4.18).

The problem violates the “Consistency and Patterns” heuristic with severity level 4 because it can confuse the user and cause clinical problems.

Figure 4.18 – Security issues not highlighted



Source: Screenshot of JiveX DICOM Viewer software

4.3.19 Missing error/warning messages

Keeping the user informed about what is happening or communicating to the user what the system's state is is critical to ensuring good communication between system and user (NIELSEN, 2020).

We had four problem situations encountered. For example, the situation that we understand and does not occur is that the system could generate an error warning that would be the permission to open exams for different patients in the same work environment. This situation violates the "Visibility of system status" heuristic, and we apply a severity level of 3. Another example is when the user uses the "reset" button, at least the system should notice if the user would like to clear all changes made to the exam.

According to each situation, the other violated heuristics were: "Consistency and patterns" and "Match between the system and the real world". We also had situations where levels 2 and 4 of severity were applied to the severity scale.

4.3.20 Delay to perform a task

This category describes the time spent by the user to perform a task. We had four issues where users took a long time to perform a specific task and almost all situations could not complete the task, which induces a level 4 severity.

Regarding the violated heuristics, we had: “Consistency and standards”, “User control and freedom” and “Match between the system and the real world”.

For example, we can mention the task of placing four images in a 2x2 layout, where one of the users was unable to drag the images to each quadrant. Another task that another user had difficulty completing was zooming, as the user was confused by the zoom options and also with the actions performed by the mouse.

5 DISCUSSION

This chapter discusses the specific questions of interviews and usability testing, relating them to the findings of related work, and comparing the results. The limitations of the research and how each situation was worked is also discussed.

5.1 Lessons learned with the interviews with health professionals

The interviews with radiology professionals brought up aspects related to the context of Information Systems, divided into “people”, “processes” and “system”.

The first factor to be highlighted is the situations or processes that affect the tasks of radiology professionals. The tasks are determined according to the procedure adopted by the hospital or clinic. The duration of each task depends on the level of complexity of this task. However, some situations can change the duration of the task. For example, more debilitated patients or children take longer to perform the exams or even patients with several exams. On the part of the system, interoperability is a factor that interferes, as there may be communication failures, or at least there is no integrated system requiring data collection by the radiology technicians themselves. Another factor is the slowness of some systems when opening multiple medical images.

The next factor concerns the behaviour, experience and knowledge of radiology professionals. The interviews provided information about the motivational perspectives, skills, quality and technical competence of those working in radiology. The radiology professional is linked to the processes adopted by hospitals or clinics, often not optimized and impair the professional’s experience. Work situations can increase or decrease the workload, which can be determined by the type of exam or the volume of exams depending on the day and time. Usually, the radiology technician does not have much technical knowledge of the system he uses, and his or her duties are basically to perform the exam. Some radiology technicians can carry out extra duties such as analyzing exams, but only the radiologist is the one who can make the report.

The other factors are linked to the use and characteristics of radiology systems. Therefore, the description of the radiology system’s characteristics was essential to understand if the professional knows the system, the pros and cons, and how this affects the usability of the user. Other highlights are the failure situations and data loss risks mentioned by the participants. For example, there is a certain intolerance of faults, and external factors, such as power outages and lack of infrastructure, affect the workflow.

5.1.1 Comparison of the interviews with the related work

The systematic mapping presented by Dias, Pereira e Freire (2017), for example, helps to understand several aspects of the system's usability, such as information access management; ease and integration between systems; help, support and access to documentation; and consistency and information architecture standards aligned with clinical terminology for task execution. For example, one of the most violated heuristics, with 30 cases, was "Flexibility and efficiency of use", which is cited as an example that users needed to take unnecessary measures to complete tasks or even situations where the user had to repeat commands several times. In addition, the system often does not offer the necessary support and does not present usability factors that improve the performance of radiology professionals' tasks. In the current study, there are situations where the user needs to work around minor system issues to perform tasks, such as asking the IT department to request a password reset. This or other findings can be related to the categories of the themes "How the characteristics of the radiology system affect the usability for the user" (Figure 4.1) and "How situations or processes affect the characteristics of tasks of radiology professionals " (Figure 4.2), presented in the current study.

Integration and availability are two characteristics in the process of choosing a technology. PACS system technology allows it to be customizable and easily integrated with other systems such as RIS or HIS. The analysis of discussions on PACS systems presented by Alhajeri e Shah (2019) explained the limitations of PACS functionalities. The results show problems with data backup, archiving and recovery, difficulties transmitting images, and lack of proper tools. In line with the present study, we can highlight the categories "Using PACS storage resources", "Lack of functionality in the system makes functional property difficult", "Lack of better interoperability between radiology systems", and "System failures caused by inadequate IT infrastructure". For example, one of the participants reported that he had already worked with the PACS, which did not let him retake the exam and that it is much work to get around this situation. Other examples are local storage problems and the lack of interoperability between systems.

The behaviour of the radiology professional in relation to cognitive psychology requires attention and needs the system to be consistent and safe in some situations. Therefore, it is possible to align this study with the study presented by Salahuddin et al. (2020), which demonstrates that the unsafe use of HIS influences the behaviour of the health professional. The "Carelessness" theme emphasizes that the user being attentive and checking everything is essential to avoid mistakes. This issue is because the system does not have the resources to check for errors. In the same way, the present study brings the findings corresponding to the categories "There is fault tolerance in the system", "Ability to reason to circumvent small problems/failures in the system" and especially the category "System failures can cause User inattention and analysis of impairment scans" that show that user attention is required during specific tasks. For example, one of the participants reported that there is a recurring error where the system duplicates patient exams.

Implementing technologies such as PACS in the health area changes the workflow of professionals who use this system. According to Abdekhoda e Salih (2017), to decide on a PACS, end users' attitudes towards the use and application of this system must be recognized. In the present study, the categories describe the experience of the radiology professional in using radiology systems, what the processes are like, and what are the characteristics of these systems. This would complement the study by Abdekhoda e Salih (2017) to understand what it takes to hire a PACS.

In another study (KOVACS et al., 2019), a study was proposed to evaluate the automation of exam reports and determine whether this practice reduces working time and what the error rates are. However, the current study did not present arguments related to automation. However, in the categories mapped from the interviews with radiology professionals, some aspects speak, for example, the duration time concerning the complexity of the task and of situations that change the duration of an exam. These points may be necessary when evaluating possible ways to automate processes in the radiology environment.

5.1.2 Specific findings related to the Brazilian scenario

This study brings as a novelty concerning the literature the aspects involving the characteristics of radiology professionals, their work routine, how they deal with problem situations and their difficulties. Person-related categories help to understand user dynamics better when interacting with information systems. They describe knowledge, job satisfaction, skills, qualities, technical competence, and emotional intelligence. The categories that describe the processes are also essential to understanding what decreases or increases the mental workload and how radiology professionals perform the procedures and tasks. In mapping the interviews, it was possible to observe that the work routine, the characteristics of the systems and the interaction of radiology professionals with the systems are conditioned to the hospital or clinic process.

The system is centred on the process and not on the user. Participants could not expose their difficulties using the system in terms of usability. The reports point to the need to get used to the characteristics of the systems, even if they need to memorize actions and use actions in languages they do not understand.

Especially in Brazil, users showed difficulties with systems in English. This becomes a barrier for the user to adapt to the system. Discussing this topic, we ask ourselves why hospitals and clinics do not invest in radiology systems that are in Portuguese. Are there quality systems in Portuguese? Moreover, do the big brands make their systems available in the country's language? These questions can be investigated in future work that meets the needs of countries like Brazil.

5.2 Lessons learned from the usability evaluation

The usability evaluation results with a radiology system mapped problems of different severity that can affect the tasks of radiology professionals, analysis processes and patient exam results. These results showed that several situations could have simple solutions that need better design during system modelling. This study brought four essential aspects: the visual presentation of the system, the content, the information architecture and the interactivity with the system.

In the visual presentation, it was shown that the layout of the radiology system is overloaded with elements that confuse the user. For example, some elements are impossible to identify their functionality, and others have similar icons with different functionality. Furthermore, users took a long time to find some elements, either because they were hidden or because it was difficult to identify just visually by the icon representation.

In addition to visual aspects, content also had a significant impact. Some situations hindered users in carrying out the tasks. The drop-down menu, for example, has much unnecessary information. Options for exporting exams are unclear. There is duplicate or contradictory content, such as the option to reset changes made to the exam. It also happened to have a term poorly defined or out of context. In this case, the save button was represented by the floppy disk icon, which was to save a custom layout.

Information architecture is essential to maintain a coherent and objective structure. Unfortunately, this does not occur in some situations on this system. For example, the system uses the same mouse actions for each interactive element but needs to keep switching between them in the drop-down menu. This requires several steps and disrupts the workflow. Another situation is that some system structures are not clear. For example, it has two options that seem to serve the same thing (to put more than one image on the screen).

Interactivity is the main factor that appears in usability tests, and the system has several problems of this type. First, the system does not clarify what is happening. For example, the user does not know that he needs to change mouse actions to perform tasks. It requires too much effort when the user makes a mistake, and he/she has to reset and do it all over again. It does not even allow it to undo the last action performed. The system does not generate user feedback, such as the option to crop the medical image, which does not allow it to resize it. Some iteration sequences have no logic, for example, if the user double-clicks on the image, it activates the full-screen mode, and there is no need for it. Some actions do not meet the user's expectations, and some features are missing. For example, the "ESC" key does not work on exiting full-screen mode. Some security issues appear, and errors/warning messages are missing. For example, if the user is going to reset the changes he made, it is expected that a dialogue box will appear asking if he wants to continue with the operation. Furthermore, many of these problems make the user take time to perform the tasks.

5.2.1 Comparison of the usability evaluation with related work

The systematic mapping of the literature carried out by Dias, Pereira e Freire (2017) shows the violated heuristics without delving into the context. The "Correspondence between the system and the real world" heuristic; "Consistency and standards"; and "Flexibility and efficiency of use" had significant relevance. These heuristics also appear with many occurrences in the current study. A good example is the category "(inte6) Result of the performed action does not meet the user's expectations" which has ten occurrences as shown in the 4.1 table.

Esfahani, Khajouei e Baneshi (2018)'s study brings usability problems evaluated in three PACS systems. Some features, such as a zoom tool and icon representation, presented in the tasks applied in this study also appear in the current study and have similar results. For example, both studies revealed problems with tools with similar icons and different functions or the icon's representation with functionality not identifiable.

Cronin, Kane e Doherty (2021) performed a qualitative study with an analysis of the needs and experience of clinicians using PACS. The study presents findings that describe factors like tasks and resources; workflow; performance issues; and training. In addition, the author addresses the situations where usability problems may occur but does not go into detail. In contrast, the usability tests of the current study delve deeper into the topic of tasks and features. While the study by Cronin, Kane e Doherty (2021) presents reports from the participants, the present study reports the situations as they emerged in an actual simulated test, with the problems highlighted and contextualised.

The present study revealed that users had difficulty completing some tasks during usability testing. Unfortunately, no study in the literature delves into this aspect. However, some studies promote alternatives to using different devices to perform some of these tasks, for example, applying zooming or windowing on medical exam images. The study by Teixeira et al. (2020) evaluated the use of devices other than keyboard and mouse and had a different focus. However, it is possible to assess whether using these different devices can improve efficiency in some tasks. For example, usability tests from the current study show that users had difficulties using some tools. Considering a tablet, we have more straightforward and more intuitive gesture actions when zooming in on a medical image. The same fact occurs if applied to a touchscreen monitor. Another example is dragging medical images onto a layout that allows more than one image to be displayed on the screen. People are used to interacting with gestures, and it might be an option to model mouse actions based on interactive gestures.

The study conducted by Alhajeri e Shah (2019) is more related to PACS systems. However, the present study may indicate integration aspects with PACS and RIS systems. Although there was no such integration in the tests, it is still possible to discuss some aspects. The example of the category “(inte8) Security issues not highlighted" reveals that the software allows opening images of different patients in the same work area without separating. We can imagine the seriousness of this situation. In this case, even not testing the integrity with PACS and RIS, we could indicate in which situations it needs attention and which aspects are essential for better integration. For example, in situations requiring user attention, always show a notification that describes the status of the operation and asks if the user wants to continue.

Finally, the specific aspect in Brazil is that many radiology equipment and software are unavailable in Portuguese, especially regarding tomography and magnetic resonance imaging systems. This is an important aspect, as many visual presentation and content problems that appeared in the tests compromise most users, as they do not know English.

5.3 Research limitations

This research had some limitations, and this section describes which threats to its validity need to be analyzed, how we tried to mitigate them, what we could not mitigate and how this could be addressed in future work.

Initially, we intended to recruit radiology technicians and physicians for the interviews. However, we were at the peak of the COVID-19 pandemic, and the work demand of these professionals was beyond normal, especially doctors. As we interviewed only one physician, we decided to limit the data from the interviews to radiology technicians for more consistent and homogeneous data. Another threat to validity was the lack of *in loco* observation of the interviewees. This limitation was also due to the restrictions imposed by the COVID-19 pandemic. However, the interview script included details to describe the environments and procedures to mitigate this threat.

The study also aimed to cover a range of radiology systems in the Brazilian market, which could not be controlled without careful sampling. To mitigate this threat, we sought to include professionals from hospitals and clinics from different contexts and Brazilian regions. Thus, statistical significance typical of quantitative studies was not sought, but representativeness due to the diversity of participants, characteristic of qualitative studies.

The usability tests with users had to be carried out remotely because, at that time, hospital and clinical environments were still restricted due to care about COVID-19. So, as it was impossible to carry out the tests in person, it was necessary to adapt them so that they could be carried out at a distance, and we had some limitations for this. First, it was not possible to access medical systems over the internet; second, for ethical and security reasons in hospitals and clinics, it could not expose access to patient data in a public way.

For this usability test scenario, the way we found to carry out the usability tests was to provide a commercial software for public and free use. We also provided the medical images from a public and free image bank. This software works with the process of refining the exam images before being sent to the PACS. It allows the doctor to analyze and write the report. Another limitation is that we did not have a PACS system or a HIS or RIS system available to integrate. With this, we mitigate usability testing tasks, specifically for radiology technicians. As most of the participants had experience only with x-ray exams, we chose to work only with this scenario since MRI and CT exams are more complex. However, it was impossible to mitigate tasks such as collecting patient data from the RIS and sending the exam to PACS. The software also does not have a patient registration module.

Despite the limitations, the present study presented important contributions to understanding usability and organisational issues related to the use of radiology systems by health professionals. Other limitations can be addressed in future work. For example, future studies could include physicians in both interviews and usability tests would already complement the study. In addition, conducting tests in person to include tasks related to using other integrated systems such as RIS and PACS will contribute to the current data.

5.4 Recommendations

From the interviews and the usability evaluation, we derived a set of recommendations for the design and evaluation of radiology systems, which will help construct better quality systems, incorporating the aspects identified and related to the Brazilian context. It is a set of 19 recommendations divided into recommendations for medical imaging visualization and manipulation software, recommendations based on cognitive aspects, and recommendations according to the experience of the radiology professional.

Elements of the medical image viewing and editing software that need to be improved according to this study's analysis:

a) Provide visual, audible, or dialog box feedback in situations requiring user attention. For example, suppose the user changes to a medical exam image and decides to save, close the unsaved image, or even reset (reset command) to the original image. In that case, the system should display a message asking if the user wants to proceed with that action. This recommendation is intended to keep the user informed of what is happening and keep the workflow safe;

b) The system must have "undo", "redo", or "cancel" functions for erroneously performed actions during radiological analyses. Unexpected actions or errors in execution always happen, so it is critical to provide the user with an emergency exit;

c) Maintain consistency and visual standards of icons and follow conventions established in the context of radiology. This will help to minimize users' cognitive load during radiological analysis;

d) The mouse actions that perform the zooming or windowing tasks are generally the same. These actions should only be activated when the user clicks on the zoom or window tools. By default, clicking and dragging the mouse over the exam image is to move the image on the screen. The mouse wheel, by default, should have the zoom effect. The system must follow conventions established in the context of radiology and allow the user to customize keyboard shortcuts, mouse actions, touch gestures, and combinations of these shortcuts. This will improve the workflow and make the functionality more suitable for inexperienced and experienced users;

e) Keep the content and visuals focused on the essentials. The features most radiology technicians use should be available for quick access and easy to find. This makes the interfaces cleaner and without irrelevant or rarely needed information, improving user workflow and decreasing relative visibility;

f) The print window needs to be clear and display only print features;

g) The layout option that displays more than one image on the screen must have a clear division between the patient exams in case the user opens exams from different patients. Also, only use the option "drag and drop" to organize the images into the quadrants. This will assure the user that the images will not be switched with just one click;

h) With multiple images displayed on the same screen, the system should allow the user to act on the image without having to select the image first. Because the mouse is over the image, the system already understands that the action must be performed on that image. This prevents the user from mistakenly making a mistake, in case he needs to and forgets to select the image first;

i) Contextual help for interactive elements should be minimally explanatory but simple and short. This will help to reduce the information the user needs to remember. If possible, include a link to a video explaining how to use that tool. For example, if the user does not know how to use the image cropping tool, the video shows how it works;

j) Provide quick solutions for errors eventually generated by the system. Then, if any errors occur, display the error message without technical jargon, using the traditional visual of the error message, and provide the user with quick and simple solutions to resolve the issue;

k) Provide organized and easy-to-read documentation. Documentation needs to be in an easily accessible place, for example, in the “Help” menu. For the Brazilian context, the documentation must have a Portuguese version.

To ensure that the above recommendations are applied, the false consensus effect (BUDIU, 2017) must be considered. This concept refers to the developer’s tendency to assume that users behave like theirs when using the system. Therefore:

l) It is recommended to test the system with the real users who will use the system.

Another aspect addressed in this study is users’ cognitive load. User attention is a precious resource and should be allocated as needed for the task (WHITENTON, 2013). To minimize cognitive load, there are three fundamentals:

m) **Avoid visual clutter:** Excessive use of visual elements or irrelevant elements impair usability for the user;

n) **Build on existing mental models:** Using existing models of other systems and standardizing labels and layouts, reduces the learning the user has to do when using new resources or systems;

o) **Offload tasks:** Do not overload the design with too much textual information. Look for alternatives to present the same context with more precise and intuitive elements.

The following recommendations are based on interviews with radiology professionals, in the context of experience using radiology systems:

p) Propose user management and password control that allows the user to exchange and recover passwords without significant difficulties. Propose security methods, such as two-factor authentication or token use;

q) Integration between RIS, HIS and PACS systems needs to be consistent and secure. Address issues of patient and exam data duplication when transferring between these systems;

r) Propose an automatic backup system to minimize data loss affected by external factors such as power outages;

s) Ensure that the radiology system has a standard and consistency of its functionalities. That is, the user must be able to perform a task on system A the same way he can on system B.

6 CONCLUSION

Thus, this study investigated the organizational factors and usability issues that influenced health professionals' use of radiology systems in the Brazilian context.

Radiological image analysis is impacted by the complexity of its tasks involved and by the entire exhaustive procedure used to perform these tasks. Thus, it also investigated how often health professionals in hospitals and clinics performed these tasks and whether they developed alternatives to speed up the performance of these tasks. This study triggered several factors related to the usability of radiology systems and organizational factors that impacted diagnostic errors, the stress and impatience of the professionals involved, on the delay in delivering results, among other factors that were possible to analyze.

This study employed two qualitative methods. The first was developed in an exploratory way with a thematic analysis of semi-structured interviews with ten radiology professionals. The interviews were conducted remotely with video and audio recordings of the participants. It aimed to know the routine of the radiology professional, the interaction with the radiology systems, the work processes and the main difficulties encountered with the systems.

The main findings of the interviews were divided into five themes: (1) How the characteristics of the radiology system affect usability for the user; (2) How situations or processes affect the characteristics of radiology professionals' tasks; (3) What influences the behavior of the radiology professional concerning their routine; (4) What determines a radiology professional's experience and knowledge; (5) Radiology professionals deal with system failures and data loss risks. The themes are related to the Information Systems context were highlighted in three pillars: "people", "processes" and "system". The discussions addressed situations or processes that affect the tasks of radiology professionals, where these professionals are linked to the procedures adopted by hospitals or clinics. They also addressed these professionals' experience, knowledge and difficulties in radiology systems. The discussions addressed situations or processes that affect the tasks of radiology professionals, where these professionals are linked to the procedures adopted by hospitals or clinics. They also addressed these professionals' experience, knowledge and difficulties in radiology systems. A comparison with related works was made, reporting how the findings complement the previous works and what is new and specific in Brazil, in this case, the difficulty with systems in English.

The second method employed was moderate usability testing with six radiology technical professionals using DICOM image post-processing software. The tests were performed with remote access to the software by the participants. In addition, the participants' screens and audio were recorded using the Think-Aloud method to improve the capture of interactions and the development of tasks. The objective of this method was to map usability problems in radiology systems.

Key usability testing findings resulted in 64 usability questions, organized into 20 categories that provided essential insights into usability practices and recommendations in complex medical systems used in radiology practice. The categories were organized into 4 themes: "Visual presentation", "Content", "Information architecture" and "Interactivity". The themes portrayed how the tested software was visually presented to the user, how the contents were organized, if the system presented structural problems and if the interactions involved the tasks, resulting in usability problems. The study argued that usability factors in radiology systems need attention, even if the tests were done in non-commercial software, but which present the essential tools for the tasks performed by radiology technicians. The results were significant to denote which usability aspects violate Nielsen's usability heuristics, which severity level is applied and how these problems can interfere with the clinical process. Discussions were mapped onto usability issues of different severity that affected participants' tasks. Finally, the findings in the usability tests were compared with previous studies, describing how this study deepened the usability aspects. As with the interviews, the difficulty with the system in English is that it occurs specifically in Brazil.

Finally, the study contributes with recommendations (Section 5.4) for the project design and evaluation of radiology systems, incorporating usability aspects identified and related to the Brazilian context. Furthermore, these recommendations incorporate the scenario of previous works (DIAS; PEREIRA; FREIRE, 2017) which was limited by considering only a set of textual descriptions of the literature and not in detailed tests. Thus, the design recommendations will help to build future systems with better quality.

For future work, we want to conduct studies with a more significant number of professionals, including radiologist doctors and compare the severity of usability and patient safety based on the "rating" made by medical professionals. Also include tests with other integrated radiology systems such as RIS/HIS. In addition, the severity scale should encourage user-centric development processes with a focus on security, facilitating the design of user-friendly interfaces, making systems more secure, and providing methods to measure and validate user performance before deployment.

The present work resulted in the following scientific publications, including articles published, submitted and in the process of submission:

a) Fábio Aparecido Candido da Silva, Marluce Rodrigues Pereira, and André Pimenta Freire. 2022. Understanding Interaction and Organizational Issues in Radiology Information Systems: a Qualitative Study with Health Professionals. In XVIII Brazilian Symposium on Information Systems (SBSI). Association for Computing Machinery, New York, NY, USA, Article 46, 1–8. https://doi.org/10.1145/3535511.3535557 (PUBLISHED);

b) Fábio Aparecido Candido da Silva, Marluce Rodrigues Pereira, and André Pimenta Freire. 2022. Usability Problems Found in Complex Medical Systems: a Study with Radiology Professionals. In IHC 2022 - Ideias Inovadoras e Resultados Emergentes. (SUBMITTED);

c) Fábio Aparecido Candido da Silva, Marluce Rodrigues Pereira, and André Pimenta Freire. 2022. Usability of Radiology and Image Archiving Systems: a Study with Health Professionals in an Interior Brazilian Town. In International Journal of Business Information Systems. (ACCEPTED FOR PUBLICATION).

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APPENDIX A – Complete queries

Table 1 – Search strings

Scientific Bases	String
Pubmed/Medline	picture archiving communication system[Title] OR PACS[Title] OR radiology information system[Title] AND usability evaluation[Title] OR usability assessment[Title] OR usability testing[Title] OR usability flaws[Title] OR usability problems[Title] OR user experience[Title] OR user testing[Title] AND ("2017/01/01"[PubDate] : "2021/05/01"[PubDate])
Science Direct	TITLE-ABSTR-KEY(picture archiving communication system) OR TITLE-ABSTR-KEY(PACS) OR TITLE-ABSTR-KEY(radiology information system) OR TITLE-ABSTR-KEY(RIS) AND TITLE-ABSTR-KEY(usability evaluation) OR TITLE-ABSTR-KEY(usability assessment) OR TITLE-ABSTR-KEY (usability testing) OR TITLE-ABSTR-KEY(usability flaws) OR TITLE-ABSTR-KEY(usability problems) OR TITLE-ABSTR-KEY(user experience OR user testing)
Scopus	(TITLE-ABS-KEY (picture archiving communication system) OR TITLE-ABS-KEY (pacs) OR TITLE-ABS-KEY (ris) OR TITLE-ABS-KEY (radiology information system) AND TITLE-ABS-KEY (usability evaluation) OR TITLE-ABS-KEY (usability assessment) OR TITLE-ABS-KEY (usability testing) OR TITLE-ABS-KEY (usability flaws) OR TITLE-ABS-KEY (usability problems) OR TITLE-ABS-KEY (user experience) OR TITLE-ABS-KEY (user testing)) AND DOCTYPE (ar OR re) AND SUBJAREA (mult OR medi OR nurs OR vete OR dent OR heal) AND PUBYEAR > 2017
Web of Science	Título: (picture archiving communication system) OR Identificadores de autor: (PACS) OR Título: (radiology information system) OR Identificadores de autor: (RIS) AND Título: (usability evaluation) OR Identificadores de autor: (usability assessment) OR Identificadores de autor: (usability testing) OR Identificadores de autor: (usability flaws) OR Identificadores de autor: (usability problems) OR Identificadores de autor: (user experience) OR Identificadores de autor: (user testing) Tempo estipulado: 2017–2021. Índices: SCI-EXPANDED, SSCI, A & HCI, CPCI-S, CPCI-SSH, ESCI.

Source: Developed by the author

APPENDIX B – Interview Script

Table 2 – Interview Script

0	First, thank you for taking the time to participate in this interview! I will not assess you in any way, but I will learn from you about how you work and behave during your more specific tasks. With that, I hope to improve my project for people like you. There are no right or wrong answers to any questions I will be asking in this study. I am simply interested in understanding how you do things related to radiology tasks. I will conduct this study primarily as a discussion and ask you questions to better understand what you do. This interview will be recorded so I can go back and review things later and ensure we haven't missed anything. I will not use your name with the recordings or the results. Video files will only be used internally and never shared anywhere with anyone. Is it OK for you? Do you have any questions right now? [Ask the person to turn off smartphone notifications]
1	How old are you?
2	What is your academic background and profession?
3	What is your professional performance today?
4	How long have you been in your current occupation?
5	Tell me about your experience with radiology.
6	Does it work with collection, analysis or both?
7	Tell us about the work shift routine in the radiology sector.
8	How many times a day, on average, do you process the completion and analysis of an exam?
9	How long does an examination process take?
10	How long does an analysis and report generation process take?
11	How do you consider the workload in performing radiology analyses? (Whether it's exhausting or not) (Why)
12	What tools and systems (if you know the brand) do you currently use to carry out the tasks and in what context?
13	Could/Would you tell me what the collection tasks are like and how they are done in the system?
14	Could/Would you tell me how the analysis tasks are done and how the system supports it?
15	Are there difficulties using the system? (Remember to put if you use more than one, and for those who use more than one, what differences do you notice)
16	Tell me specifically which system usage difficulties are most common.
17	Tell me about a specific case where the system has (significantly) disrupted work and if this had any consequences.
18	Could you tell me if the systems used are made in Brazil or imported? Is the influence of different standards or procedures from the Brazilian ones on imported systems?

Source: Developed by the author

APPENDIX C – Questionnaires

Table 3 – Demographic Survey

1	How old are you?	(18 to 25); (26 to 35); (36 to 45); (above 45)
2	What is your academic background?	(Graduate); (Specialization); (Master's degree); (PhD)
3	What is your role?	(Radiology Technician); (Radiologist)
4	How long have you been in the position?	(less than 5 years); (5 to 10 years); (more than 10 years)
5	What is your level of computer experience?	(Low); (Acceptable); (Advanced)
6	What is your level of experience using the systems?	(Low); (Acceptable); (Advanced)

Source: Developed by the author

Table 4 – Post-Study System Usability Questionnaire (PSSUQ)

1	EN	Overall, I am satisfied with how easy it is to use this system.
	PT	Em geral, estou satisfeito com a facilidade de utilização deste sistema.
2	EN	It was simples to use this system.
	PT	Este sistema foi simpes de utilizar.
3	EN	I could effectively complete the tasks and scenarios using this system.
	PT	Consegui completar as tarefas e os cenários utilizando este sistema.
4	EN	I was able to complete the tasks and scenarios quickly using this system.
	PT	Consegui completar rapidamente as tarefas e cenários utilizandoo este sistema.
5	EN	I was able to efficiently complete the tasks and scenarios using this system.
	PT	Consegui completar as tarefas e cenários com eficiência utilizando este sistema.
6	EN	I felt comfortable using this system.
	PT	Senti-me confortável a utilizar este sistema.
7	EN	It was easy to learn to use this system.
	PT	Foi fácil aprender a utilizar este sistema.
8	EN	I believe I could become productive quickly using this system.
	PT	Acredito que me tornaria rapidamente produtivo se utilizasse este sistema.
9	EN	The system gave error messages that clearly told me how to fix problems.
	PT	O sistema deu mensagens de erros que me indicaram claramente como resolver os problemas.
10	EN	Whenever I made a mistake using the system, I could recover easily and quickly.
	PT	Sempre que cometi um erro durante a utilização do sistema, consegui recuperar de forma fácil e rápida.
11	EN	The information (such as on-line help, on-screen messages and other documentation) provided with this system was clear.
	PT	A informação fornecida pelo sistema (como ajuda online, mensagens no ecrã ou outra documentação) foi clara.
12	EN	It was easy to find the information I needed.
	PT	Foi fácil encontrar a informação que precisava.
13	EN	The information provided for the system was easy to understand.
	PT	A informação fornecida pelo sistema foi fácil de entender.
14	EN	The information was effective in helping me complete the tasks and scenarios.
	PT	A informação foi eficaz para me ajudar a completar as tarefas e os cenários.
15	EN	The organization of information on the system screens was clear.
	PT	A organização da informação que o sistema transmitiu foi clara.
16	EN	The interface of this system was pleasant.
	PT	A interface do sistema foi agradável.
17	EN	I liked using this interface of this system.
	PT	Gostei de utilizar a interface deste sistema.
18	EN	This system has all the functions and capabilities I expect it to have.
	PT	Este sistema tem todas as funcionalidades e capacidades que eu esperava.
19	EN	Overall, I am satisfied with this system.
	PT	Em geral, estou satisfeito com este sistema.

Label: EN: English | PT: Portuguese

Source: Adapted from Rosa et al. (2015)