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Critical Success Factors for Virtual Reality-based Training in Ophthalmology Domain

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Abstract

In recent years, as a result of advanced computer technology and internet resources, the interest in VR and surgical simulations has seen an increase in the healthcare domain. Virtual reality (VR), one of the modern tools that have emerged from IT, has been integrated in many hospital training programs. So far, however, there are no intensive studies with focus on investigating factors such as critical success factors (CSFs) for VR success within the healthcare context, especially in the ophthalmology domain. There are several factors that healthcare providers or designers need to consider during the implementation of VR in the healthcare domain. This paper aims to identify VR based training CSFs that motivate the ophthalmologist surgeons to adopt VR as an alternative tool for acquiring, maintaining and improving skills. This paper presents a systematic review of literature on VR based training in an ophthalmology context. In total, 59 studies published between 2006 and 2017 in 6 indexed journals were analysed. 86 CSFs were identified as significant ones for any adoption of VRT. Based on papers in different disciplines, CSFs were categorized into the 6 broad categories of HCI/VR Features, Learning Outcome, Usability, Control and Active Learning, Student and Limitation Factors, each containing one to four sub-categories. Finally, insightful practice and theory recommendations for further research have been provided for healthcare providers, researchers as well as for designers.

Keywords: Healthcare; Virtual reality (VR); Ophthalmology; Cataract

Introduction

Virtual reality (VR) is being used in several sectors and contexts, from consumer applications and manufacturers, to the airlines industry. In airlines, VR offers great value in flight simulation applications, in combination with several other forms of technologies. The use of VR in manufacturing and other industries for which the term industry 4.0 gets used now reality. It is constantly develop while this paper is written, and is poised to accelerate as benefits become increasingly clear, and as offerings, hardware and applications mature and move to the next level. Therefore, manufacturers increase their digital transformation efforts along strategic and staged paths, towards realizing industry 4.0 and the digital transformation of manufacturing.

The current trends evidence that the level of invention in VR's application in surgical training is arriving at a plateau. However, progress is still slow, and the level of adoption and stories of high success are still not well reported [1]. Implementing VR is a complex exercise, and many adopters in the healthcare field have encountered problems in different phases. For instance, many studies have been suggested that simulator training is most successful if it is integrated with a systematic training curriculum [2-6]. In addition, risky obstacles stem from the lack of non-technical skills integrated into virtual reality simulators. This is the major cause of surgical errors, and also of the lack of validity evidence for many simulators, as indicated in the literature [7-9]. Once these factors and others are integrated and fulfilled, the re-purposing and sharing of system components, and the resultant high returns on investment, will encourage healthcare providers to adopt virtual reality-based training in the ophthalmology area. The lack of a high success rate in implementing of VR calls for a better understanding of process. In order to reduce the failure rate of VR implementation, a study regarding the identification of critical success factors (CSFs) in VR implementation is crucial.

Unfortunately there has been no intensive study of CSFs for VR success within the healthcare context, unlike a number of studies reporting CSFs for other areas, such as enterprise systems [10-12]. Therefore, with a particular emphasis on ophthalmology, this paper represents a first attempt to establish common CSFs for VR-based training for ophthalmology. This paper therefore seeks to answer the following research question:

RQ: What are the critical success factors that influence the use of virtual reality-based training in the ophthalmology domain?

Taking this objective into account, the aim of this systematic literature review is to present the current status of research into VRT in ophthalmology. This study will be the first to explore the CSFs which influence the use of VRT. The study considers categories for analysing the current state and tendencies of VRT, such as the uses of VRT in the ophthalmology domain, as well as its challenges and levels of effectiveness. It will review the availability of adaptation and the personalization processes in VRT applications, as well as the use of VRT for addressing the special needs for ophthalmology residents within diverse contexts. The analysis of the different categories allows for the suggestion of trends, challenges, affordances, opportunities for further research, and a general vision towards the future.

This paper has been organized in the following way. Section 2 presents the study's background, section 3 describes its methodological design, and section 4 presents the results jointly with a discussion of findings. Section 5 follows with a discussion of trends and provides a vision towards the future. Finally, section 6 presents some conclusions.

Background

Cataracts are a well-known disease in ophthalmology filed, which

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is the leading cause of blindness and impaired vision in the world [9]. The complexity of ophthalmic surgery remains a challenge for trainers to transfer their skills to a resident level [13]. For instance, teaching cataract surgery is challenging on a technical level, due to the high skills needed for psychomotor. Subsequently, it is costly and time consuming. One of the most important and difficult steps in cataract surgery creating capsulorrhexis (opening on the anterior capsule of the lens). Capsulorhexis is another step in cataract surgery requiring specific skills in which the new cataract surgeons struggle to master [14]. Wikipedia [15] defines ophthalmology as being "the branch of medicine that deals with the anatomy, physiology and diseases of the eyeball and orbit", while an ophthalmologist is "a specialist in medical and surgical eye disease. Their credentials include a doctorate degree in medicine, followed by an additional four years of Ophthalmology residency training". After intensive training, an ophthalmologist is authorized to perform various tasks including examining eye diseases and performing surgery as needed. Ophthalmologists do not only work in the operation room, but they are also involved in academic research related to eye diseases and ophthalmology [16]. It has been reported that due to the ever-growing aged population, as well as the aging of existing surgeons, the need for ophthalmologists is expected to become greater and greater in the near future [9].

According to Singh and Strauss there are various risk factors that impede the increasing number of cataract operations around the world, including high cost of equipment maintenance, the availability and training of surgeons, the poor quality of training equipment, and inadequate members of training faculties [17]. Resnikoff et al. [18] have reported that there are 204,909 ophthalmologists providing eye care worldwide. Unfortunately, this number is too small due to the fact that the amount of global blind people has been estimated to rise to 32 million by 2020. Ophthalmologists who have the ability to perform surgery in some nations are only 15%, especially in those countries which are socialist economies. The unequal distribution of ophthalmologist abilities is notable across developed and developing nations. Therefore, two-thirds of the global ophthalmic population is assembled in just fifteen countries worldwide. It has been noted that there is an average of one ophthalmologist per each million individuals in some sub-Saharan African countries [18]. Furthermore, the disparity and fluctuation in levels of surgeon training in developing nations also augment this inequality in distribution. Inappropriate training results in maladjusted unforeseeable outcomes [19]. In addition to these obstacles, there is the situation that the use of animal parts like pig eyes do not simulate the same anatomy as human beings, but their cost and non-renewability are usually their most exciting feature. Although correct anatomy is possessed by human corpses, surgeons still face difficulties in using them due to many reasons, including the difficulty faced in obtaining them, their price, and the prominence of tissue disintegration problems [20]. Nonetheless, limitations also arise in conventional training using animals and human cadavers. Additionally, as the cases of blindness and impaired vision caused by cataracts continue to rise; new surgeons are required [9]. Despite the fact that inverse events and substandard patient-related outcomes have been linked by several risk factors which are unchangeable or unavoidable, evidence suggests that the VR-based training of surgeons has the potential to offer significant levels of skills transfer to novice ophthalmic surgeons [9]. In the ophthalmology field, Eyesi (VRmagic, Holding AG, Mannheim, Germany), PhacoVision (Melerit Medical, Linköping, Sweden), and MicrovisTouch (ImmersiveTouch, Chicago, Illinois) are three commercially-available virtual reality (VR) eye surgery simulators used currently for training [17]. Simulation can be described as being 'something that is made to look, feel, or behave like something else especially so that it can be studied or used to train people' (Merriam-Webster definition). Thomsen identified four different groups of simulation models, including animal, cadaver, inanimate, and virtual-reality models [9]. The development of a virtual reality surgical training tool has been engaged by the rapid development of electronics and computer technology. VRT has become an essential learning and practicing tool used for training and teaching skills applicable to various types of surgery. This fact shows how virtual reality simulators have remarkable potential advantages for improving the quality of surgical-skill, and should be integrated into training in order to reach ultimate goals including knowledge acquisition, skills transfer, improved patient safety, and surgical competency for ophthalmologist residents for the further years.

There is a high interest in VRT within the ophthalmology domain. However, not a lot of work has been conducted in this area because VRT is an emergent technology. It is therefore important to establish a systematic review of the advances and real impact of its use within the ophthalmology context, describing how VRT has been used to create experienced surgeon-based training scenarios. In the ophthalmic training and learning context, where VR and simulation are notably relevant, VRT has not been fully successful [21]. Some reasons for this may be the lack of guidance, supervision, or comprehensiveness in the curriculum used for training. It is therefore significant for healthcare system management to understand what CSFs influence the use of VRT among surgeons and residents within the ophthalmology domain.

Literature in the 1980s saw the first use of the term CSFs, at a time when there was competition between organisations, and there was a need to identify reasons for why some companies were more successful than others [12]. Freund [22] defined CSFs as "those things that must be done if a company is to be successful". Important characteristics of CSFs presented by Selim, are that they are few in number, measurable and controllable [12]. Although there are plenty of research articles focusing on VRT as a different discipline, none of them address the most important issue of CSFs related to VR-based training. This study explores and then suggests some critical success factors that can assist healthcare providers, educators and designers involved in developing the VR environment. The study aims to categorize VRT CSFs, and to specify critical factors within each category, using a systematic literature review.

Review Method

In this study a systematic literature review has been conducted in order to answer research questions [23]. The variety of motivating factors is exciting when implementing a systematic literature, three of which are most applicable to this study. The first factor is the need to epitomize existing proof about technology or treatment, for instance to summarize the advantages and disadvantages of VR within the ophthalmology domain. The second factor is to determine current research gaps with the aim of proposing areas of research. The third factor is to propose a model for new research topics [24]. Therefore; the steps used by this methodology for carrying out SLR have been discussed in this section. The three main phases for a systematic review as outlined by Kitchenham are including planning the review, conducting the review and reporting on the review [25]. Therefore, the suggested procedure for a systematic review include identifying resources, study selections, data extraction, data synthesis, and report write-up [26].

Inclusion and exclusion criteria

The purpose of developing inclusion and exclusion criteria is to make sure that the researchers only use articles that are relevant to the study. For this study, the researchers considered studies that were published between 2006 and 2017 in the English language, and that focused on the use of VRT related journals and conference proceedings. The researchers included articles that firstly clearly related to VRT in ophthalmology domain, mentioning relevant key words such as VRT or simulation training in ophthalmology, secondly, that directly answered the research question, and thirdly, that indicated any CSF related to study domain. Furthermore the researchers excluded studies that were in languages other than English, that focused on VRT but not within healthcare area, that did not use VRT as their main focus, that did not answer the research questions, that were opinion pieces or viewpoints, or that were in the form of books, editorial notes, editorials, prefaces, poster sessions, panels and tutorial summaries, interviews, or news items.

Study selection process

The six stages of study selection for SLR, following Kitchenham's guidelines [25,27] has been presented in Figure 1. At the first stage set of keywords were used, such as 'virtual training' and 'surgical simulation', on six scientific databases. These included SAGE, Wiley Online Library, IEEE Explore, Springer Link, Google Scholar, and Science Direct. As a result, 698 primary studies were selected. In the second stage, duplicated studies were excluded using Mendeley, a tool used for storing citations, managing bibliographies, and compiling searches from each database. Subsequently, stages 3-4 were undertaken twice, during both the first iteration and the second one. Meanwhile, in the second iteration, a manual search was used to extend the review and, thereby, additional studies were included. This helped establish a broad perspective as recommended by Kitchenham and Charters [24].

Automatic iteration

In this iteration, the researchers started with 698 papers found on databases, and undertook stages 2, 3 and 4. During stage 2 the duplicated papers were eliminated, with 18 papers being removed, leaving 680 papers. In stage 3 the criteria of exclusion were applied only to titles, and were then applied to both abstracts and conclusions. 569 papers were excluded in this stage, leaving 111 papers. As of stage 4, in some cases it was needed to examine the full text to be able to exclude irrelevant studies, leading to 63 papers being excluded, leaving 48 papers. As a result of these exclusions in stages 3 and 4, 48 studies had been gathered by the first iteration. Alongside the automatic search, the authors conducted a manual iteration in order to determine if they had missed any relevant studies, and in order to increase the search's comprehensiveness. The authors went through all references contained

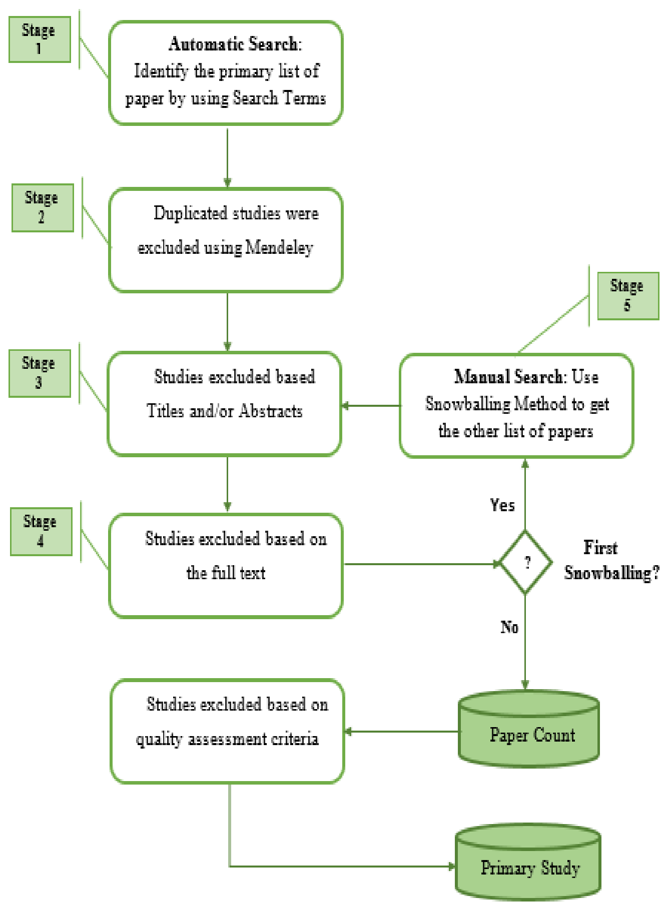

Figure 1: Research Design (Adapted from [28,29]).

in the primary studies, with 1841 articles resulting from this approach. This process is referred to as snowballing, involving pursuing references of references [27], and was implemented in both steps 3 and 4.

Manual iteration

In this round, the 1,841 references contained within 48 papers, gathered from the first iteration, were analysed at the iteration's end. Meanwhile, stages 3 and 4 were carried out again. First of all, stage 3 resulted in the exclusion of 1,794 papers based on their titles and abstracts. 44 papers remained.

Finally, 35 papers were excluded based on their full-text, leaving 11 relevant papers. Overall the systematic review identified 59 relevant papers, 48 in the first iteration, and 11 in the second iteration. Among the 59 papers found, 47 were journal papers and 7 were conference proceedings.

Quality assessment (QA)

The main purpose for using QS is to assess the quality of primary studies [24]. Therefore, in order to determine the strength of inferences, with guide recommendations for further research and analysis of findings have been included in studies, the subsequent quality criteria were used to evaluate the selected studies:

QA1: Are the critical success factors described in the paper?

QA2: Are the topics addressed in the paper, as related to our review?

QA3: Is the context of the current research, as described in the paper?

QA4: Are there recommendations for overcoming challenges evidently explained in the paper?

QA5: Are the gaps for further research clearly mentioned in the paper?

Therefore, 59 selected studies were assessed by the five QA criteria, in order to fulfil the authors' confidence in the trustworthiness of a specific identified study. This six QA schema were inspired by Nidhra et al. and Balaid et al. [28-30]. Three values, specifically high, medium and low, were all included in the schema. Therefore these scores determined the quality of each particular study. A score of two was given to those studies that fulfilled a criterion. Giving a score of two detailed that a study partially filled a criterion. Finally, a study was given a score of zero if it did not fulfil the criterion. Greater scores were given to those studies that scored equal or more than seven, while a medium score was given to studies if they scored six. A low score was considered to be on below six. The outcomes of applying the quality assessment criteria have been detailed in Appendix A.

Data analysis

Figure 2 presents the process conducted to attain this study's results. An initial list of 200 factors which motivated residents to use VR was identified, based on concepts and terms provided by the studies paper. Duplicated factors were excluded. Then the factors that have a same meaning were merged as well, after definitions and descriptions from the extracted publications were reviewed. For example, 'realistic tissue mechanics' was one factor that peaked the physician's intention to use VR, as examined in Mednick et al.'s work [31]. Based on the definition the authors proposed for realistic tissue mechanics, "the extent to fantastic preparation for a real patient" for which surgeons can utilise VR as a real operation, was a factor that the authors merged with 'realism'. These techniques reduced the list of appropriate factors from a total of 200, to 86 conceptually different factors. In order to make more sense of the factors, the researchers moved onto the next stage of grouping them into significant clusters. Therefore, the researchers went through different sources in different disciplines such information systems and IT, in order to obtain the right category label for each set of factors. As with the first round, the researchers categorised the factors into clusters, and then sent the first draft to judges in order to ensure the content made sense to them. Overall the researchers identified six main categories, including HCI/VR Features, Learning Outcome, Usability, Control and Active Learning, Student and Limitation Factors. The first categories were based on Lee et al. [32]. However, the last one was based on an article by Bacca et al. [33]. Also, in order to make more sense to the factors, the researchers then sought to create sub-categories for each of the six main categories, as based on literature from various disciplines. Furthermore, both the categories and sub-categories were further sent for inter-judge agreement, as the second round. Finally, after satisfaction and validation had been fulfilled the taxonomy was ready for publishing. As a result, Figure 3 presents this section's findings.

Results

In this section, some significant statistics result and tables regarding the extracted studies have been presented. With respect to the source, the extracted factors and citation statuses are also provided and described. The detailed results have been presented in the subsequent sections.

Citation status

Taking into account the citation rates, it can be determined that the primary studies are high quality. This is an effective way of determining the quality of extracted articles. Therefore, Figure 4 presents the overall citations of the included papers. The numbers of citations were extracted from Google Scholar.

As can be seen from Figure 4 around 56 included studies have been cited by other sources. Overall, the 1-to-10 citation group contained the most articles. Meanwhile the groups with 30-40 and 40-50 times had the lowest numbers, with only three and two selected studies respectively. Additionally, the groups with 10-20 citations, and those with 50 or more citations, had similar numbers of studies, between 12 and 11 respectively. Six studies were cited between 20 and 30 times. On the other hand, only four studies have not been cited by any other sources, due to the fact that most of them were just published one or two years before. The researchers roughly gave an overall view of the selected quality papers and the authors did not compare them. The outcomes of the citation number have been given in Appendix B.

Categories of taxonomy

This paper has investigated the CSFs that have motivated ophthalmologists to use VRT through a systematic review approach. The result of the authors' systematic review has been depicted in (Figure 3). After arriving at 86 distinguishable CSFs determined as being the main reasons which influence surgeons to adopt VR as a learning and training tool in their workplaces, this paper classified them into six main categories. These include HCI/VR features, usability, learning outcomes, student, control and active learning, and limitation factors. The following section offers a detailed explanation of each category and their related factors.

HCI/VR feature factors

HCI/VR feature factors describe technology features that could affect skill transfer to surgical novices, and ultimate training outcomes

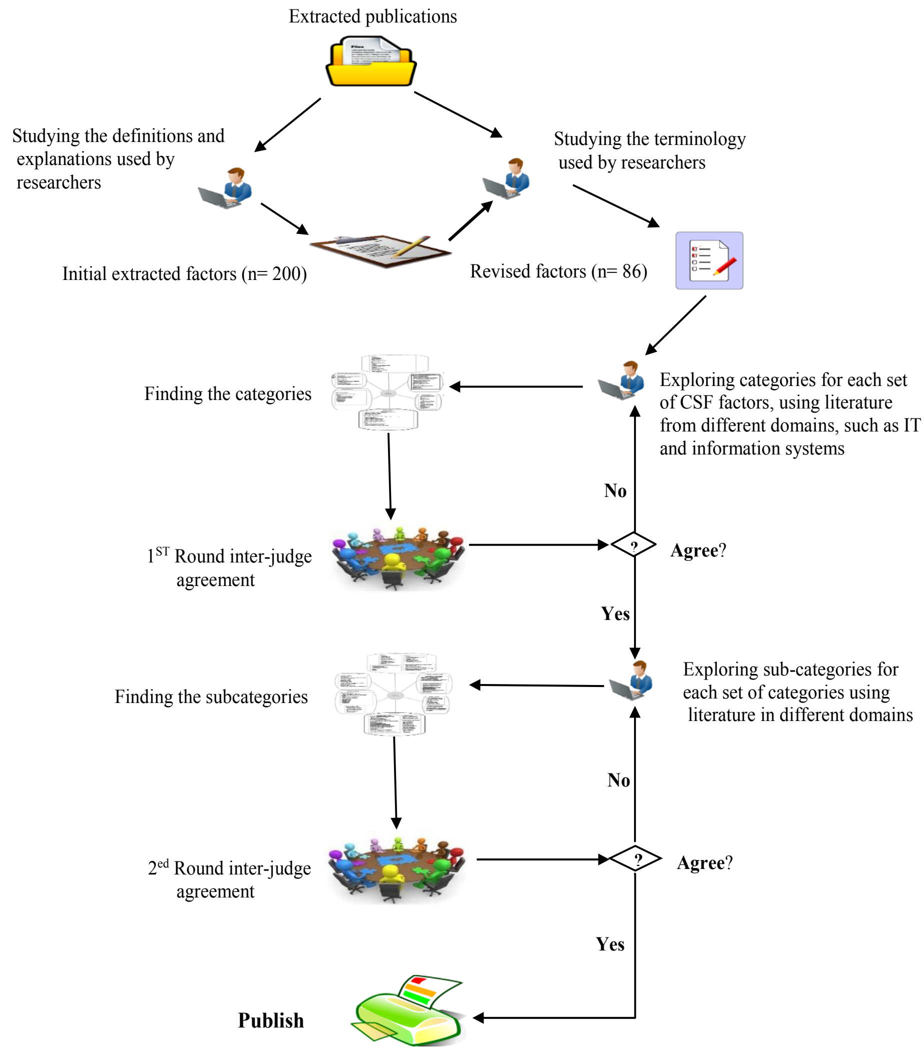

Figure 2: The Data Analysis Process (Adapted from [29]).

[32]. They are further arranged into four sub-categories. The first sub-category is realism, or the degree of realism of scenarios depicted in the VR domain, such as visual realism and haptic realism. The second sub-category is control, which refers to the user's ability to control activity events in the VR environment, such as the 2-hand and 2-feet surgical technique, and movement patterns. The third sub-category is software, using visualization model, or a haptic model. The fourth sub-category is hardware, including visual hardware, sensory and motor information. The sample determination for each factor from the extracted studies have been illustrated in Table 1, in order to provide valuable insights into how each CSF affects VRT use. As Table 1 shows, the 22 HCI/VR feature factors motivate resident cataract surgeons to use VR as a training or assessment tool. Realism factors, such as haptic feedback, devices and realism, are critical to VRT success which is the most cited factors from literature. To a lesser extent, the 2-hand and 2-feet surgical technique, anatomical similarity and the greater economy of motion, could be also be critical success factors that influence the surgeon's intention to use.

Usability factors

The usability determinants the inspire ophthalmologist to use VRT are related two aspects, specifically quality and accessibility. The first aspect is evaluated through perceived usefulness, which covers items such as the ability to work more quickly, ability to increase productivity, the item's importance, relevance, usefulness and efficiency at work, and its value [37]. However the second one is assessed through the perceived ease of use, covering such items as convenience, controllability, ease, and unburdening [32]. This category is composed of two sub-categories. The first is perceived usefulness, for instance cost reductions and teaching several surgeries. The second is perceived ease of use, for instance low stress environment and reduced complexity. Sample conclusions for each factor, extracted from studies, have been presented in (Table 2). This table highlights the 13 usability-related factors that impact resident trainees' use of VRT, validity, cost reduction, and provide formative feedback which are cited as the most important critical success factor. To a smaller extent a safe learning environment, reliability, efficacy, low stress environment and reduced complexity, as all indicated in literature, could also encourage surgical doctors to utilize VRT.

Learning outcome factors

The learning outcomes factors which affect the use of VR as a training tool for surgical ophthalmology, are those related to action

Factors	Sample of Conclusion
A physics-based computer model	"A physics-based computer model, which utilizes the best existing data along with HMS test data to produce high-fidelity simulation of eye geometry, tissue properties, cutting,...• A visualization model, which will use data, including high-definition video of cataract surgeries, to create high-resolution, real-time visual images of eyes,..• A haptic model, which will simulate the feel experienced by the surgeon during actual surgeries to deliver a realistic force feedback response." [34]
A visualization model	
A haptics model	
Graphics	"Through the combination of human--computer interfaces, graphics, artificial intelligence, high-end computing, and networking, current virtual-reality systems allow the user to become immersed in and interact with an artificial environment…"[2]
Artificial intelligence	
Networking	
Human-computer interfaces	
Computers,	"Computers, visual hardware (e.g., microscopes, visual image generators), haptics devices (haptics refers to the science of touch in real and virtual environments), surgical equipment, and operator/mentor stations ". [34]
Visual hardware	
Haptics devices	
Surgical equipment	
Operator/mentor stations	
Surgical instruments	"functional features, such as sensory and motor information processing........we may conclude that instrument and anatomical similarity, as well as movement pat- terns, are important factors for skill transfer, corresponding to functional features of the tasks..." [9]
Movement patterns	
Sensory	
Motor information	
User interface and guidance	"The surgical platform consists of interactive user interface and guidance which reduces the complexity" [20]
The 2-hand and 2-feet surgical technique	"Thus, simulating the phacoemulsification cataract 2-hand and 2-feet surgical technique described in this paper. We believed that simulation training using 4 extremities was key in our clinical experience as well as in the difference in surgical performance between the 2 resident groups" [4]
Greater economy of motion	"One study of 16 surgical trainees indicated that those who underwent virtual reality training were showed greater economy of motion when performing the surgery on patients compared with those who did not have the training " [35]
Visual and haptic user interface	"Advanced virtual reality involves visual and haptic computer--user interface, most often derived from the use of external props" [2]
Haptic feedback	"The combination of graphical interface with haptic device which consists of tactile feedback is able to provide precise representation on human physiology" [36]
Realism	"It is important to note that successful skills transfer depends on both the realism of the simulation and the training curriculum used to support the simulator." [17]

Table 1: HCI/VR Feature factors.

and performance which result from learners [32]. Performance achievement such as improved ophthalmologic surgical performance and OR performance, and perceived learning effectiveness such as improved patient safety and the reduced rate of complication are sub-categories of the learning outcome factor category. Table 3 illustrates the sample conclusion for each factor. As Table 3 presents, of the nine learning outcome factors that influence ophthalmologic surgery personnel's intention to use VRT as alternative tool for acquiring skills, improved ophthalmologic surgical, phacoemulsification performance and patient safety, time savings and reduced rate of complications are the most frequently cited success factors by researchers. To a lesser degree improved OR performance and capsulorhexis wet-laboratory performance, improved surgical competency and reduced the rate of errant capsulorhexis are considered by the literature to also be CSFs as well (Table 3).

Student factors

As the name proposes, student factors affect surgical novices personnel intentions to use VRT, are those which impact the learning outcomes which include communication skills, learning styles, problem solving styles, attitudes toward technology, cognitive needs, computer anxiety, and experience of technology [32]. Student factors can be further divided into student characteristics, which include the extent of pre-learning, inherent learning style. Table 4 presents sample conclusions for each factor from the extracted studies. Table 4 shows that among the four student success factors that impact surgical novice personnel's intentions to use, the inherent learning styles and opportunities for reinforcement are frequently studied in this category have identified as CSFs. To a lesser degree, the literature recommends that the type and nature of feedback, and the extent of pre-learning, could be other CSFs that influence novice surgeons to use VR as device for acquiring and measuring skills. Although the student factor receives less attention, its role could be significant in transferring skills to resident trainees during training sessions [7].

Control and active learning factors

The control and active learning factors are those related to learner control, referring to instructional designs. Here, decisions regarding learning path or events of instruction could be made by learners. Many items could be covered by learner control, such as learning pace, sequencing, content of instruction, and amount of practice in a learning environment [32]. This category is composed of one sub-category, specifically learner control which includes skill transfer, accelerated surgical training and learning, and shorter learning curves. The Table 5 shows the example conclusion for each factor from the primary studies. As Table 5 presents, of the 13 success Control and Active Learning factor affecting ophthalmologists to adopt VRT, training tools, assessment skills , skills transfer, accelerated surgical training and learning, shorter learning curves have been most CSFs studied in the literature. To a lesser extent, literature suggests that simulator design and functionality, and allowing repeated practice can also encourage resident trainees to use VRT as selected way for enhancing their skills

Limitation factors

The sixth category, limitation factors, is composed of three sub-categories, including overall structure and content such as a lack of an integrated comprehensive training curriculum and unknown training amount, overall technical skills such as excess realism and complexity levels, and non-technical skills such as decision making, communication and team work. Table 6 shows sample conclusions for each factor from the extracted studies. As Table 6 highlights, of the 18 limitation factors which impact the surgical novice's personal intentions to not use VRT, the lack of an integrated comprehensive training curriculums and non-technical skills, such as decision-making, communication, teamwork and leadership, are the most frequently CSFs cited. This was followed by a lack of guidance and supervision. To a lesser degree, the literature suggests that a lack of teacher's effective feedback, unknown training amounts, high costs, and excessive realism and complexity, could all greatly impact a surgical novice's personal intentions to not use VR as a training tool within their career.

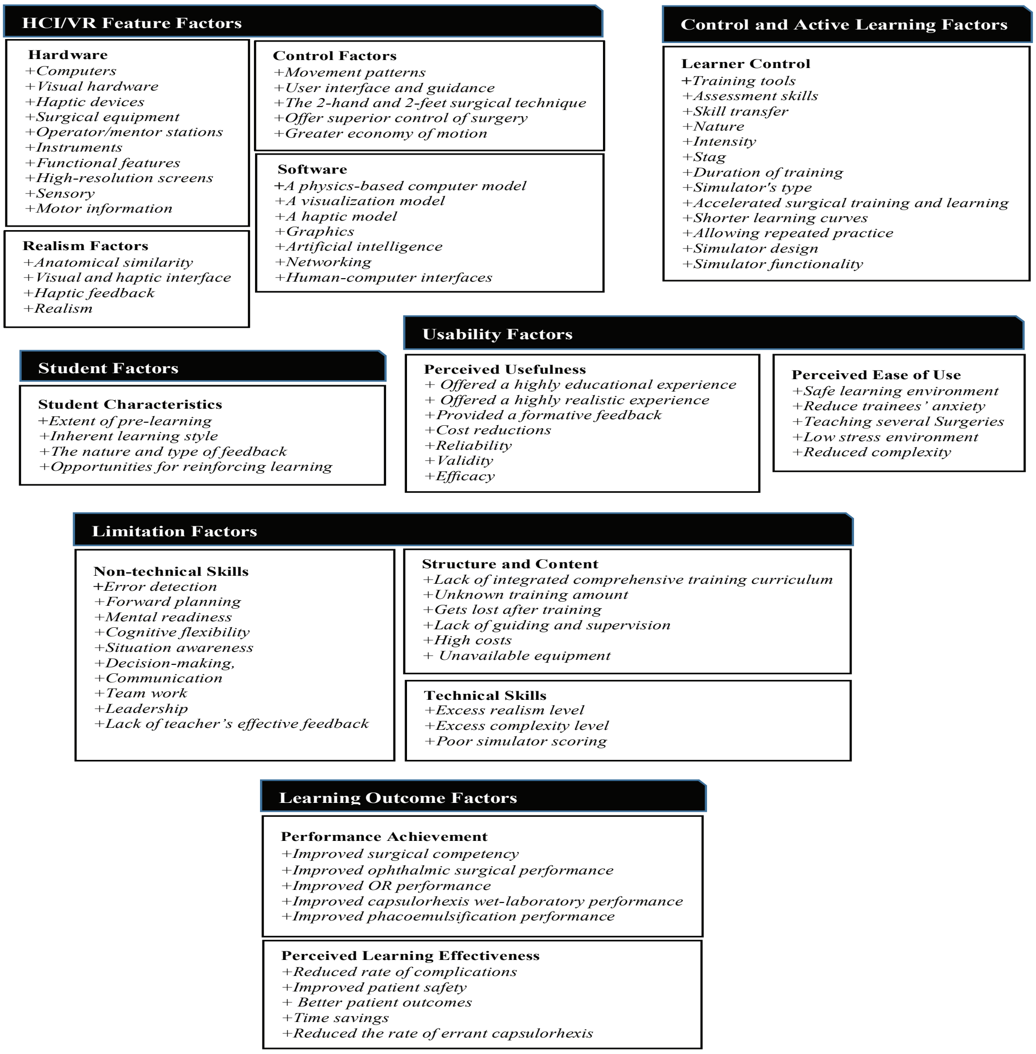

Figure 3: The Critical Success Factors of Virtual Reality- Based Training.

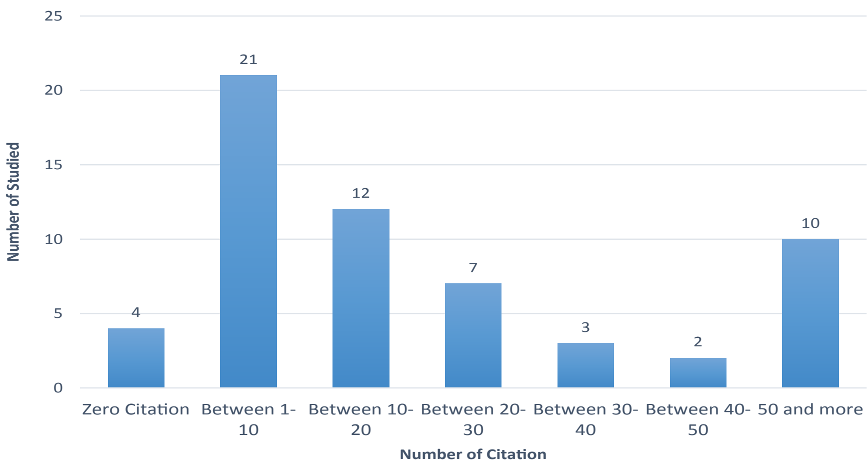

Figure 4: Citation Counts.

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Factor	Sample of Conclusion
Offered a highly educational experience Offered a highly realistic experience	"Simulators are capable of providing a highly educational and realistic experience…" [38].
Provided a formative feedback	"There are several benefits of using virtual-reality simulators in surgical …., including the fact it is less time intensive for educators as the simulator also provides formative feedback."[39]
Cost reductions	"Skills transfer there may be improved patient safety and procedure efficiency, associated with cost savings." [7]
Validity Efficacy Reliability	"Using simulation models without knowledge of reliability, validity, and efficacy may compromise patient safety… " [1]
Safe learning environment	"Involved training in real-time environments. Simulation training provides the benefit of creating a safe learning environment with no risk to patient safety." [38]
Reduced trainees' anxiety	"…can help to prepare and determine residents' readiness to perform on live cases and thus serve to reduce trainees' anxiety." [5]
Teaching several surgeries	"Simulators have been designed to teach direct ophthalmoscopy, laser trabeculoplasty, goniotomy, retrobulbar anaesthesia, laser retinopexy, and vitreoretinal surgery." [40]
Low stress Environment	"…Simulation allows learners to acquire skills in a controlled low-stress environment" [40]
Reduced complexity	"The surgical platform consists of interactive user interface and guidance which reduces the complexity of getting used to the training tool." [20]

Table 2: Usability factors.

Factors	Sample of Conclusion
Improved surgical competency	"For cataract surgery, surgical competency improves significant" [9]
Improved OR performance	"Eyesi results in improved resident performance of CCC in the operating room" [41]
Improved ophthalmic surgical performance	"The EyeSi is a valid part-task training platform that may help develop novice surgeon dexterity to expert surgeon levels" [3]
Improved capsulorhexis wet-laboratory performance	"The simulator improves wet-lab capsulorhexis performance" [42]
Improved phacoemulsification performance	"Using this simulator, trainees can practice standardized phacoemulsification techniques and abstract tasks repeatedly with instant objective feedback of performance" [43],
Reduced rate of complications	"The study also showed that the simulator group had a significantly lower rate of complications in the cases" [44]
Improved patient safety Patient outcomes	"…benefits for training programs and trainers, and, most importantly, improved patient safety and outcomes" [45]
Time saving	"This yielded a maximum possible operating room time savings of $103 763 for a 9-person residency using the simulator for 10 years under our most optimistic scenario." [46, p.1616]
Reduced the rate of errant capsulorhexis	"Eyesi reduces the rate of errant capsulorhexes." [41]

Table 3: Learning outcome factors.

Factors	Sample Conclusions
The extent of pre-learning Inherent learning style The nature and type of feedback Opportunities for reinforcing learning	"Many factors determine whether skills can be transferred successfully, including the extent of pre-learning, inherent learning style, the nature and type of feedback, as well as opportunities for reinforcement of learning." [7]

Table 4: Student factors.

Factors	Sample Conclusion
Training tool	"Surgical simulators have been widely used for training in neurosurgery, gastroentrology, laparoscopic surgery, orthopedics, and ophthalmology" [47]
Assessment skills	"Surgical training using simulators have been adopted by many surgical specialties to provide training in a controlled environment and also to provide objective assessment of skills." [42]
Skill transfer	"Skill transfer is also an essential component for trained surgeons to maintain, update, and acquire new skills." [6]
Nature Intensity Stage Duration of training Simulator's type	"Exactly how simulation-based training should be integrated into the training curricula in a cost-effective manner for different specialties, exploration of other important dimensions of skills transfer including the nature, intensity, stage and duration of training, and the type of simulator device required to deliver the greatest transfer effect". [7]
Accelerated surgical training and learning	"To deliver a virtual reality program that accelerates and augments surgical training and provides maximal skills transfer in the most timely and cost-efficient manner" [48]
Shorter learning curves	"Moreover, utilization of VES simulators training has shown to be associated with improvements in wet-lab performance of capsulorrhexis, shorter learning curves, shorter phaco and median" [49]
Allowing repeated practice	"Expert surgeons showed a greater initial facility with all microsurgical tasks. With repeated practice, novice surgeons showed sequential improvement in all performance scores" [3]
Simulator design Simulator functionality	"Many factors determine whether skills can be transferred successfully, including those that relate to simulator design and functionality, the way that simulators are used as a training tool" [7]

Table 5: Control and active learning factors.

Factor	Sample of Conclusion
Lack of an integrated comprehensive training curriculum	"As Gallagher stated, 'their power can only be truly realized if they are integrated into a validated comprehensive curriculum.' [50]
Unknown training amount	"However, the amount of training on a cataract surgery VRS before reaching proficiency remains uncertain." [51]
Get lost after training	"Also, the constant training in with this equipment may cause the physician or student to forget the procedures and protocols developed to guarantee the safety and comfort of the examined patient". [52]
Lack of guidance and supervision	"One factor that is, however, likely to be critical in whichever model emerges as most effective, is the involvement of a senior trainer offering guided supervision". [20]
Lack of teachers' effective feedback	"While one barrier to giving immediate feedback may be a teacher's reluctance to criticize or upset a trainee, most residents state that they would like more feedback directly after performing a procedure". [35]
High cost Unavailable equipment	"Residency programs rely heavily on their existing surgical techniques and equipment because of obstacles such as high cost, ……and equipment availability associated with new innovations in surgical ophthalmology". [6]
Excess realism level Excess complexity level	"The quality level of the simulation must be controlled and adapted for each person, since the excess of realism and complexity can confuse the examiner when learning basic skills, as shown by medical students". [52]
Visual cognition Error detection, Mental readiness Anticipation Forward planning Cognitive flexibility Situation awareness	"A variety of cognitive skills linked to success in surgery have been identified, including visual cognition, error detection, anticipation, forward planning, mental readiness, and cognitive flexibility". [8]
Decision-making Communication Leadership	"In reality, a wider array of skills is fundamental to safe practice, including decision-making, communication, and leadership." [9]

Teamwork	"Benjamin reports that team working, leadership, insight, dexterity, decision making, prioritizing and empathy are all important and should be assessed." [43]
Poor simulator scoring	"Simulator scoring rendered unacceptably poor discrimination for both the hydro-manoeuvres and the phacoemulsification divide-and-conquer module." [42]

Table 6: Limitation factors

Discussion

Trends

The distribution of the extracted papers per year have been illustrated in Figure 5, which shows that over the last 10 years, the number of published papers covering VRT have increased. In particular, since 2007 the articles regarding VR in the ophthalmology domain have increased considerably, with a 2013 peak of 13 studies and two stables situations from 2009 to 2010 and 2015 to 2016 with 4 articles. However, the trend hit the bottom three times in 2007, 2011 and 2015, with 1, 2 and 3 extracted studies respectively. The researchers may explain that VRT has attracted the attentions of physicians, healthcare providers and academics researchers during that time. The increase in the number of studies since 2007 might have consistently depict VRT's success, including that of the ophthalmology's domain as well, and it might be a good indicator that VRT has been definitely adopted by ophthalmologist as an alternative learning and training tool.

On the other hand, the distribution of studies authored in different continents have been depicted in Figure 6 North America and Europe are the most dominant continents, with 46% and 42% of authors affiliated with Europe and North American universities, respectively. Therefore almost all factors indicated in this paper have been extracted from Europe and North America. The next most productive paper source has been Asia, with 7% of the studies, followed by Australia and South American with 2% and 3% of the papers, respectively. Asia stands up behind Europe and North America, in terms of research which has been recently conducted. Whereas it can be seen that Asian countries have increasingly began attempts to design VRT for two reasons. Firstly, they are seeking to reduce costs. It can be seen that cost is one limitation factor facing project managers in healthcare. While Liu and Hutnik has reported that because of some barriers such as the high cost and availability of equipment, ophthalmology residents fully rely on existing surgical methods and devices [6]. In the second place, the number of ophthalmologists in developing nations is too small when compared with those in developed states [17]. Due to this fact; Asian nations have tried to design new training tools to speedily generate new expert surgeons in fast and cost-efficient manner.

There is a lack of meta-analyses and literature surveys on CSF, regarding the use of VRT in a variety of disciplines. With regards to the use of VRT in ophthalmology, it has been found in the literature that the big picture of CSF has not been examined in ophthalmology domain by any studies until now. Henderson et al. for example, conducted research into VRT in ophthalmology by undertaking meta-analysis through 19 papers. They retested the effect of non-technical skills factors that could impact resident student' intentions to adopt VR as an unconventional training tool [8].

Furthermore, Henderson et al. conducted a literature review on the evaluation of the Virtual Mentor Cataract Training Program. Their review was comprised of 19 papers, and they identified 10 factors regarding the major cause of surgical errors [8]. More importantly, Dawe et al. carried out an intensive literature review regarding the factors that influence the use of VRT through about 59 papers and came up with about 15 factors that directly or indirectly influence the use of VR [7]. Given that the more comprehensive the source of systematic review, the richer the result, this paper's authors decided to carry out a systematic review in order to update the topic and to provide literature with a more inclusive "big picture" of critical success factors that motivate ophthalmology surgeons to use VR as a training or assessment tool in their workplace.

The taxonomy proposed in this study can be also viewed in terms of comparing external variables and internal variables for using VRT. It is very clear that the majority of users decide to use VR in their workplace for internal variables, which can have a positive effect on them, such as skill transfer, accelerating surgical training and learning, and improving ophthalmic surgical performance.

There are two types of CSF, as a result of internal reasons. In first type, VR is used in ophthalmic surgery as an alternative training device, with a higher utility that provides better learning's conditions such as a safer learning environment, reduced trainee anxiety, teaching several surgeries, and a low stress environment. The second type happens when VR is utilized as an assessment tool that can predict and measure resident' skills. Such internal reasons typically make the ophthalmology resident decide to use VR to improve patient safety and outcomes, or to reduce the rate of complication.

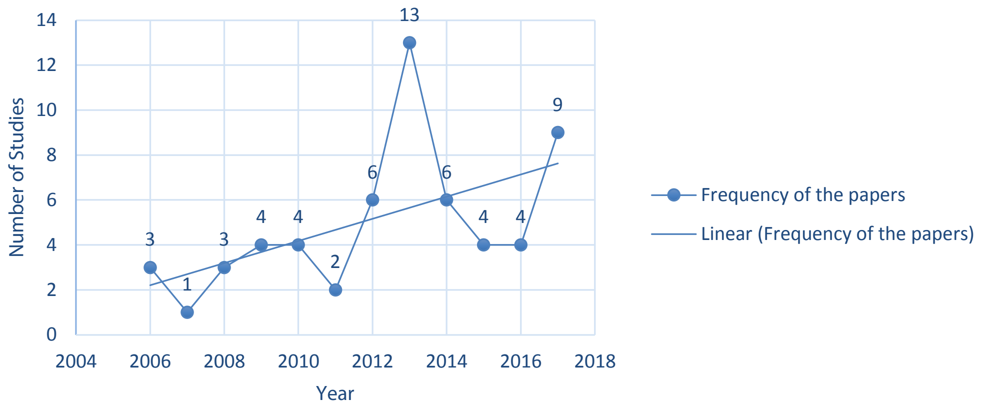

Figure 5: Frequency of Research Papers by Year.

In some other cases, the ophthalmologist may not decide to take risks in order to select VR as a training tool due to external factors, such as a lack of an integrated comprehensive training curriculum with VR, an excess realism and complexity levels, a lack of guidance and supervision, a lack of teacher support and feedback, greater costs, and less focus on cognitive skills.

Recommendations

Recommendations for practice

Learning outcomes, HCI/VR features, control and active learning, usability, student factors and limitations, all have practical implications on accepting VRT as a way to acquire, improve, maintain and measure skills, as such factors could at best lead to a learning environment that is tolerable for the ophthalmology resident, such as a safe learning environment, reduced trainees' anxiety, reduced complexity, and transferable skills. Figure 7 and Figure 8 present the distribution of the frequently-cited learning outcome, HCI/VR feature, control and active learning, and the usability, student and limitation CSFs which impact the surgical novice's use of VRT. These are the ones that have been studied by at least four publications, within the researcher's systematic review source.

Here, Figure 7 and Figure 8 show the percentage and number of publications for more frequently cited CSFs. 28 CSFs have been presented as features for any VR-based training environments. These include nine related learning outcomes, three related HCI/VR features, five control and active learning features, five usability features, and six limitations. Among these CSFs, training tool factor is the most often cited one, with 56 citations. This is followed by validity, assessment skills and providing formative feedback, within 27, 26 and 19 studies, respectively. The 59 studies suggested those are the highest cited CSFs. To a lesser extent, 16 and 17 studies indicated improved patient safety and shorter learning curves respectively, while improved ophthalmic surgical, improved phacoemulsification performance and cost reductions are similarly indicated by 14 research papers, as presented in Figure 7. Time savings and haptic feedback have equal indications, with 13 times for each one. All these factors were cited by 13 studies or more, as CSFs affect VRT to be adapted. On the other hand, as according to Figures 7 and 8, some of them have less than 13 citations. These include accelerated surgical training and learning, the lack of an integrated comprehensive training curriculum, reduced rates of complications, skill transfer, realism, a lack of guidance and supervision, haptic devices, non-technical skills such as decision-making, communication, teamwork, leadership, safe learning environment, reliability and lack of

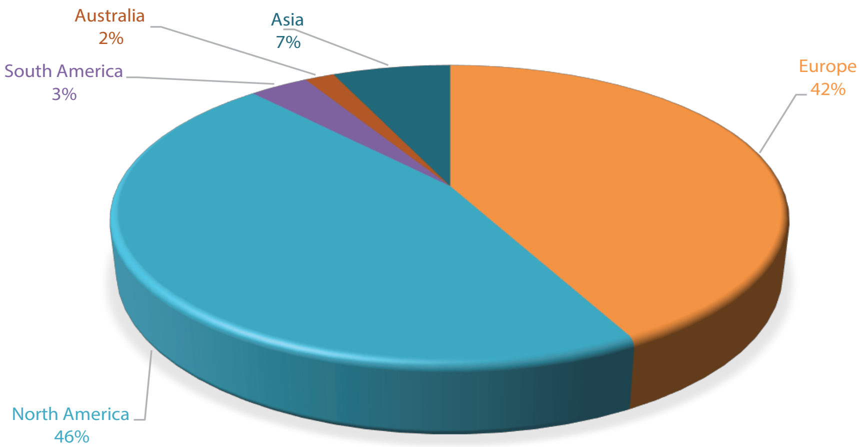

Figure 6. Frequency of Papers Produced per Continent.

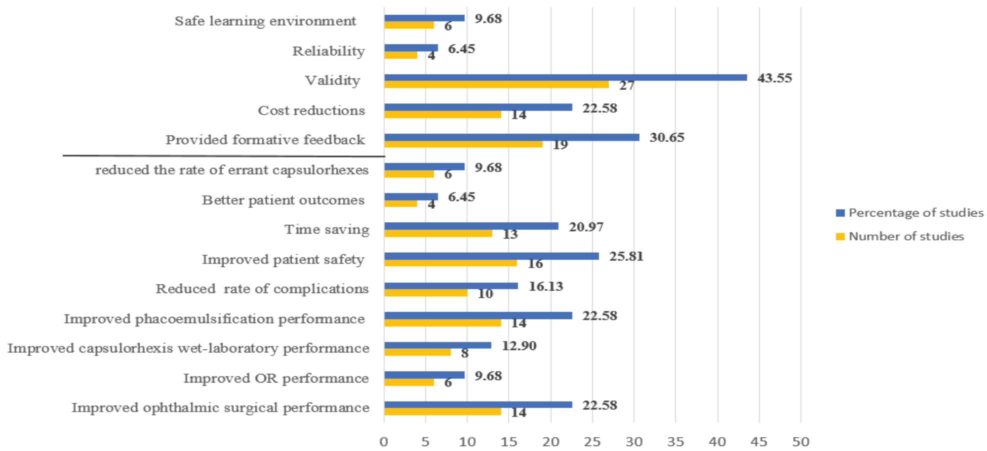

Figure 7: Percentage of Publications for the more Frequently Cited Learning Outcome and Usability Factors.

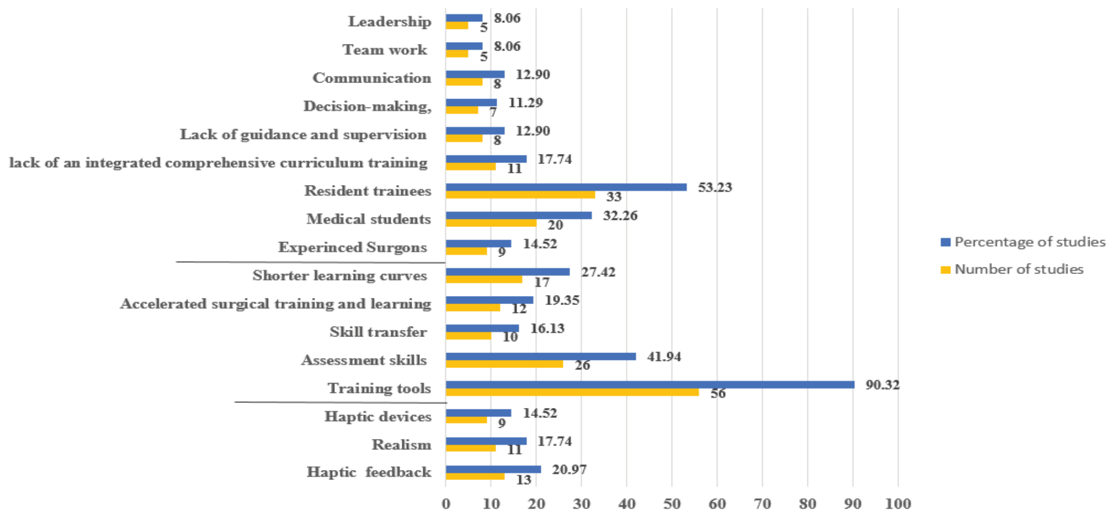

Figure 8: Percentage of Publications for the more Frequently Cited control and Active Learning, HCI/VR Feature, and Limitation Factors.

teacher's effective feedback. These could still have an extreme impact on the process of adopting VR as a training tool.

Although the student factor includes, the extent of pre-learning, inherent learning style, the nature and type of feedback, and opportunities for reinforcing learning, have all not been included in Figures 7 and 8. However they can still play an essential role in adopting VRT. It has been reported that this factor could successfully help to transfer skills to novices [7]. Therefore, this paper's authors have suggested giving more attention to this factor, while avoiding any adoption's failure of VRT during the implementation process.

This study looked into the CSFs of VRT within the ophthalmology domain, because of the practical relevance of this issue for training new surgeons. In light of the insights from this study, the researchers would like to pose several recommendations to designers and healthcare providers. The author's recommendations can help ophthalmologists in two ways. Firstly, the authors can recommend ways of improving VRT to be excellent tool for transferring skills to residents. In addition, several CSFs are affecting VRT's adoption within surgical performance, so understanding and overcoming these factors is significant for such healthcare providers. Secondly, these recommendations can assist with identifying which comprehensive training curriculums are more likely to be integrated with VR.

As the first issue, this paper seeks to offer insights for healthcare providers and designers that determine the reasons ophthalmologist apply to use VRT in a learning way, in terms of how high valued skills can be transferred, and how challenges can be overcome in order to eliminate the surgical risks. In the following paragraphs, the authors will introduce some frequently-cited limitations factors and provide a number of suggested strategies can be employed to motivate the ophthalmologist's intention to use VRT during the learning stage. Lack of a comprehensive training curriculum [7], guidance and supervision, and non-technical skills [8] have all been cited as external keys that may impede surgeons from using VR as a device to enhance their learning experiences. Therefore, overcoming these factors can significantly contribute to maintaining the use of VRT.

At the first, in order to overcome the lack of an integrated comprehensive training curriculum, the literature has proposed a number of strategies. Firstly, a cataract surgical training curriculum should consist of 3 parts. These include the pre-patient training program of theoretical education wet-lab training, virtual-reality, and training to proficiency, along with supervised practice on patients which involves supervised training on 25 patients, and the follow-up training program for surgeons operating independently-including virtual-reality training to a proficiency level and continued supervised practice on patients [39]. Secondly, Lorch and Kloek have suggested that surgical teaching guidelines regarding pre-procedure teaching can be used within the field of ophthalmology, to maximize a resident's skill acquisition within a constructive learning environment. These guidelines can apply to pre-procedure teaching, including knowing your learner, using simulation, and setting preoperative learning goals and expectations, the intra-procedure which involves creating a safe learning environment, communicating during the procedure and introducing a procedure in a stepwise manner, and post procedure which gives immediate feedback, considers a video review of procedures, and keeps a competency checklist [35]. The above described strategies cover some critical limitation factors such as a lack of guidance and supervision, and a lack of teacher's effective feedback. On one hand, a lack of guidance and supervision has been cited by eight studies. This paper's authors believe this factor should get much attention by researchers, in order to avoid any failure for adapting VR as a training tool from users. The consultant's supervision with the structured debriefing and the involvement of expert are the key feature, and can significantly offer help regarding skills transfer to resident trainees [21]. It has been broadly recognised that the simulator has been presented as being high-quality technology. Thereby, its use may result in medical students becoming discouraged and making many complaints, when they have not been supervised by the expert or have not given any detailed instruction how to use the technology in the right way [52]. On the other hand, the feedback provided was highly prominent within 19 research articles in the Usability category. This is proof that missing this kind of critical factor can have an extreme effect on the training process and can definitely bring risk to the OR and especially to the patient. Hull and his team have reported that feedback is a critical factor for non-technical skills [53]. This is why many residents mentioned they need more feedback, especially after performing any procedure. This is the result of a lack of feedback from teachers [35]. Therefore, by combining two strategies together, residents may probably reach required dexterity.

At the second goal, to overcome cognitive or non-technical skills, the literature has proposed a number of strategies. These include situation awareness (gathering information, understanding information, and projecting and anticipating future states), decision making (considering options, selecting and communication options, and implementing and reviewing decisions), communication and teamwork (exchanging information, establishing a shared understanding, and coordinating team activities , and leadership (Setting and maintaining standards, coping with pressure, and supporting others) [54]. Further work is needed to integrate all limitations into the VR environment. There is perhaps a need to borrow other tools or techniques, for example ontology, to ideally enhance the VRT environment.

On the other hand, this paper's authors have only found one study which reported that the virtual mentor for cataract training purposes can virtually allow the trainees to perform decision-making as non-technical skills. Another study regarding the comprehensive training curriculum has indicated that CITC (Capsulorhexis Intensive Training Curriculum) on the Eyesi, reduces the rate of errant capsulorhexes. However, they were not confident that CITC is the main reason because there are many factors that could influence the reduction of such an ability of expert to guide resident when he or she needs it most [41].

Lastly, the haptic feedback factor has recently been attracted researchers' attention. This paper's authors can see from Figure 8 that haptic feedback was cited by 13 studies as CSF. Sikder and his colleagues stated that MicrovisTouch is the only available simulator that has incorporated haptic feedback with full virtual experiences, compared to other simulators like Eyesi which uses the physical eye and head. The authors further stated that the majority of participating ophthalmologists have approved such integration that could bring more realistic operation experiences. Therefore, designers should take into their account these key features [44]. Meanwhile, visual realism and haptic realism are essential parts of any real environment simulation [55].

By enhancing these factors, the researchers believe that ophthalmologists will be reinforced by advanced training, the learning curve will be shortened, and they will be delegated to ideally and safely perform eye surgery with low costs and reduced complication rates.

Recommendations for Theory

In general, the current study adapts the categories and sub-categories used in a robust acceptance model TAM [32,56]. Therefore, the current study makes critical recommendations for future studies by creating a new model of CSFs for VR based training [57-60]. Proposed taxonomy in this paper provides a good starting point for both software designers and researchers interested in following up on one or more of the identified CSFs discussed in this paper [61-64]. The proposed taxonomy can be used to design a theoretical framework or model and can further predict behavioural intention to use VR based training prior to actual implementation. Moreover, this study contributes to the efforts to systematic literature review relating CSFs VR based learning in ophthalmology context. This is the first study in this domain. Most significantly, this study could benefit healthcare's management staff in their future plans to adopt VRT technologies and could benefit designers in order to either design or redesign current simulators [65-68].

Conclusions and Limitations

VR-based training has been and will continue to be adopted by many healthcare providers. Therefore, a variety of CSFs must be carefully estimated before any implementing such technology. Creating a VR environment for a training purpose involves a very complicated process of establishing and developing an integrated information technology system [63-65]. This paper, in line with the systematic literature review, has identified six VRT critical success factor (CSF) categories that can guide healthcare mangers, designers and educators to effectively adopt VR technologies within the ophthalmology domain [69-72].

The specified six VRT CSF categories have been based on the number of citations of selected papers, and also on the authors' perceptions. The first category is control and active learning, involving training tools, assessment skills, skill transfer, accelerated surgical training and learning, and shorter learning curves. The second is the HCI/VR feature which involves haptic feedback, realism, and haptic devices. The third is learning outcome, which involves improved ophthalmic surgical performance, improved OR performance, improved capsulorhexis wet-laboratory performance, improved phacoemulsification performance, reduced rate of complications, improved patient safety, better patient outcomes, time saving and reduced the rate of errant capsulorhexes [73-75]. The fourth is usability factors, which includes provided formative feedback, cost reductions, validity, reliability, and a safe learning environment. The fifth is the student factor, which contains the extent of pre-learning, inherent learning style the nature and type of feedback and opportunities for reinforcing learning and the sixth is limitation, including lack of integrated comprehensive curriculum training, lack of guidance and supervision, decision-making, communications, teamwork, and leadership. The six CSF categories impact the decision to adopt VR technology within the ophthalmology domain. Therefore this paper has presented a novel taxonomy for realising and maximising VRT benefits though a critical factor approach. The paper argues that VRT benefits are realised when the simulators have been redesigned, integrated and implemented within the indicated CSFs [76,77].

In this paper, as mentioned above researchers have identified many CSFs and categorised into six categories. Although the CSFs is not limited to what they have been reported in this paper, the proposed CSFs is important to give some guideline to adopt VR for learning or training purpose in domain of ophthalmology (in particular) and healthcare (in general).

Taking one of category such as Contents and Structure this factor obviously so important to ensure the successful of VR. Development of contents for VR involving capturing domain knowledge from subject matter experts (SME) including ophthalmologist doctors, nurse and medical student. Making tacit knowledge explicit from these SME is challenging. Further, lack of guidance and supervision factor is so critical as well. The recent high quality technology that has been embedded in VR such as excess realism level and new immersive technology make VR environment so big and complex. Therefore, it is so significant to make sure that how user, like medical student can navigate virtual environment without getting lost inside it. Indeed, addressing issues related to CSFs such as contents and structure, can be essential in ophthalmology domain in order to minimise any risks to patients or getting failure adoption from health committee [78,79].

Many limitations were encountered while performing this study. Firstly, the researchers faced challenges with regards to downloading more papers, due to limited open access to papers in some journals. The lack of an intensive study of CSFs for reported VR success was the second limitation the researchers struggled to deal with, particularly during the systematic literature review process, in terms of attaining more critical factors to support this study. Thirdly, factors extracted were limited to articles published between 2006 and 2017. Lastly, the proposed factors are mostly captured in the context of VR applications reported in domain ophthalmology. Therefore, it is not possible for the researchers to claim the comprehensiveness of the proposed CSFs.

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Nevertheless, this study is a first attempt to highlight the importance of identifying CSFs for VR applications, mainly for learning purposes in healthcare, such as ophthalmology. Therefore, further research can be done and this can open more avenues for research into CSFs for VR based learning success in particular and VR applications success in general.

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