ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

REDUCTION OF DENTAL ANXIETY IN CHILDREN USING VIRTUAL REALITY

M.Sc. THESIS

Fatma Betül GÜREŞ

Department of Game and Interaction Technologies

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(529191005)

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MAY 2021

ISTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

ÇOCUKLARDA DENTAL KAYGININ SANAL GERÇEKLİK İLE AZALTILMASI

YÜKSEK LİSANS TEZİ

Fatma Betül GÜREŞ
(529191005)

Oyun ve Etkileşim Teknolojileri Anabilim Dalı

Oyun ve Etkileşim Teknolojileri Programı

Tez Danışmanı: Dr. Ögr. Üyesi Gökhan İNCE

MAYIS 2021

Fatma Betül GÜREŞ, a M.Sc. student of ITU Graduate School student ID 529191005, successfully defended the thesis entitled **"REDUCTION OF DENTAL ANXIETY IN CHILDREN USING VIRTUAL REALITY",** which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor :	**Asst. Prof. Dr. Gökhan İNCE** İstanbul Technical University	.....
Jury Members :	**Prof. Dr. Leman Figen GÜL** Istanbul Technical University	.....
	Prof. Dr. Tamer TÜZÜNER Karadeniz Technical University	.....

Date of Submission : 15 May 2021
Date of Defense : 16 May 2021

To my dear father, lovely mother and the sweet memory of my grandmother,

FOREWORD

This thesis entitled “Reduction of Dental Anxiety in Children Using Virtual Reality” is written as a graduation requirement for the Master of Science program Game and Interaction Technologies at Istanbul Technical University.

The research reported in this thesis was supported by the Scientific and Technological Research Council of Turkey (TUBITAK) under the grant 119S618. I am thankful to Nada Atheer, Erenay Alpayçetin, İlkan Engin, Elif Benli, Ahmet Karagöz, Assoc. Prof. Dr. Yelda Kasımoğlu and Prof. Dr. Elif Bahar Tuna İnce for their guidance and helpful comments.

The greatest thanks go to my advisor Asst. Prof. Dr. Gökhan İnce for his absolute interest and assistance during all steps of the reseach, including the development of the application and writing of the thesis. I was able to complete this difficult journey with his encouragement, support and guidance. Additionally, I would like to thank the participants and their families, as without their assistance this research would not have been possible.

May 2021 Fatma Betül GÜREŞ

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ABBREVIATIONS

2D **:** 2 Dimensional
3D **:** 3 Dimensional
API **:** Application Programming Interface
AR **:** Augmented Reality
CPU **:** Central Processing Unit
ITU **:** Istanbul Technical University
OS **:** Operating System
SDK **:** Software Development Kit
UI **:** User Interface
UX **:** User Experience
VR **:** Virtual Reality
XR **:** Mixed Realit

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REDUCTION OF DENTAL ANXIETY IN CHILDREN USING VIRTUAL REALITY

SUMMARY

One of the main targets of dentists is to offer high quality dental care to their patients in a stress-free environment. Studies have shown that dental anxiety is linked to behavioral issues before or during treatment. Additionally, it increases the perception of pain and as a result, angry and nervous children are hesitant to go to future treatment appointments. In this research, it is aimed to reduce the dental anxiety of children with novel methods of interaction specifically prepared for dental treatments. The application is implemented using virtual reality headsets, to assess and prevent the level of stress encountered by patients during dental care and to decrease the workload of dentists.

The patient to be treated by the dentist is separated in a controlled manner from the practice area within the framework of the thesis by wearing a VR (Virtual Reality). Thanks to VR, it is assured that the patient is prepared for treatment, visually describing the instruments and equipment to be used. The patient's attention is drawn to the different contents in the VR during the procedure. These contents provide visual (video monitoring) and auditory (music listening) stimuli, as well as providing patient care information with the help of avatars (characters) and environmental components to be placed in the VR application. In addition, it aims to improve the rate of success of dental therapy in pediatric patients by reducing anxiety and apprehension of dental therapy due to the fun content of the application.

The initial design of the testing process was planned to be done on three separate groups of children. In the first group the dentist performs the procedure in the usual manner without any additional distractions for the patients. The second group patients are shown cartoons on a screen mounted on the dental unit. The third group has access to the VR application. The comparison of the group results would illustrate the efficacy of these systems. In order to test the effects of stress on dental care, the effects of VR on dental procedures that require local anesthesia are studied during these experiments. Dentist execute vital milk tooth pulp amputation and filling procedures. Due to the global health crisis known as the coronavirus COVID-19 pandemic, the testing was not possible as the initial plan described above. Only the first and third group were tested with a smaller number of participants than intended.

We have shown that the diversion approach applied with VR helps dental care of children, particularly during local anesthesia, by reducing stress levels and the child can withstand the treatment more easily than other conditions. Theoretically, focusing the attention of children would result the optimal conditions to reduce anxiety. For this reason, the best practice in this regard is VR, since it is desired to maximize the perceptual impact by offering visual, auditory and kinesthetic experiences (physical

movement). The VR aplication aims to evoke positive attitude in children by providing them a safe atmosphere and becoming a pioneer in the use of VR in the dental profession. The goal is to enable dentists to perform their procedures more effectively and safely.

ÇOCUKLARDA DENTAL KAYGININ SANAL GERÇEKLİK İLE AZALTILMASI

ÖZET

Diş hekimlerinin temel hedeflerinden biri, hastalarına stressiz bir ortamda yüksek kaliteli diş bakımı sunmaktır. Araştırmalar, dental anksiyetenin sadece tedavi öncesinde veya sırasında davranışsal sorunlar oluşturmakla kalmadığını, aynı zamanda ağrı algısını artırdığını ve bunun sonucunda korkulu ve öfkeli çocukların gelecekteki tedavi randevularına gitmekte zorlandığını göstermiştir. İlk diş hekimi ziyaretinin başarısız olması durumunda hasta psikolojisi olumsuz etkilenmektedir. Çocuk diş hekimliğinde karşılaşılan davranış biçimleri diş korkusu, anksiyete ve fobidir. Dental korku klinik ortamda bir veya daha fazla tehdit edici uyarana verilen normal bir duygusal tepkidir. Dental anksiyete, diş tedavisinde kötü bir şey olacağından endişelenme ve kontrol kaybı olarak tanımlanmaktadır. Dental fobi ise şiddetli dental anksiyete türüdür, kendini kötü hissetme ve diş hekimliğinde kullanılan aletlerden korkma ile baş gösterir.

Diş tedavileri genellikle birden fazla enjeksiyon, hızlı dönen kesme/delme aletleri ve genellikle birkaç seans süren invaziv prosedürleri içerir. Çocukların davranışları, çocuğun stresli durumlarla başa çıkma becerisine, olgunluğuna, kişiliğine, entelektüel kapasitesine, uyumluluğuna, duygu yoğunluğuna, deneyimine, ağız sağlığına, aile geçmişine, ebeveynlerin tarzına ve kültürüne göre değişir. Tüm bu hususlar çocuğun diş tedavisine uyum sağlama yeteneğini etkileyebilir. Çocuğun davranışı yönetilemediğinde, tedaviye engelleyen zorluklar oluşabilir.

Bu nedenle diş hekimi, dental anksiyeteyi en aza indirmek için anlatım, sesle kontrol, dikkat dağıtma, sözlü olmayan iletişim, pozitif teşvik gibi farmakolojik olmayan teknikler ve sedasyondan genel anesteziye kadar değişen farmakolojik teknikler kullanabilir. Geniş seçenekler arasından çocuğun bilişsel, duygusal ve sosyal gelişimine göre en uygun olanı seçmelidir.

Bu araştırmada, sanal gerçeklik (VR: Virtual Reality) kullanılarak uygulanacak diş tedavilerine özel hazırlanan yeni etkileşim yöntemleriyle çocukların dental anksiyetesinin azaltılması, hastaların diş bakımı sırasında karşılaştıkları stres düzeyinin değerlendirilmesi ve önlenmesi amaçlanmıştır. Böylece diş hekimlerinin iş yükünü azaltmak ve çocukların davranışlarını yöneterek duydukları endişeyi en aza indirgemek hedeflenmektedir.

Diş hekimi tarafından tedavi edilecek hasta, bakım sırasında VR takılarak uygulama alanından kontrollü bir şekilde ayrılacaktır. VR sayesinde hastanın tedaviye hazır olması, kullanılacak alet ve ekipmanları görsel olarak tanıtılması sağlanacaktır. İşlem sırasında hastanın dikkati uygulama içerisinde yer alan farklı içeriklere çekilecektir. Bu içerikler görsel (video izleme) ve işitsel (müzik dinleme) uyarıcıların yanı sıra sanal

gerçeklik uygulamasına yerleştirilecek avatarlar (karakterler) ve çevresel bileşenler yardımıyla hastaya uygulanacak olan tedavi bilgilerini sunmayı da amaçlamaktadır. Uygulamanın eğlenceli içeriği sayesinde çocuklarda anksiyete ve diş tedavisi endişesini azaltarak diş tedavisinin başarı oranını artırmak hedeflenmektedir.

Test sürecinin planlanması esnasında çalışmanın üç ayrı çocuk grubu üzerinde yapılması hedeflenmiştir. Birinci grupta diş hekimi standart tedavi uygular. İkinci grup hastalara diş ünitesine monte edilmiş bir ekran üzerinde çizgi filmler gösterilir. Üçüncü grubun VR uygulamasına erişimi vardır. Grup sonuçlarının karşılaştırılması, bu sistemlerin etkinliğini gösterecektir. Sanal gerçekliğin lokal anestezi gerektiren diş prosedürleri üzerindeki etkileri bu deneyler sırasında incelenecektir. Diş hekimi süt dişi pulpası ampütasyonu ve dolgu işlemlerini gerçekleştirecektir. COVID-19 pandemisinden dolayı deneyler tasarlandığı şekilde üç grup halinde olmak yerinde yalnızca iki grup üzerinde ve öngörülenden daha az katılımcı ile gerçekleşmiştir.

Araştırma sonucunda VR ile yapılan işlemlerin stres düzeylerini azaltarak özellikle lokal anestezi sırasında çocukların diş bakımına yardımcı olacağı ve çocuğun tedaviye diğer koşullara göre daha kolay dayanacağı varsayılmıştır. Teorik olarak, çocukların dikkatini dağıtmak, kaygıyı azaltmak için en uygun koşulları sağlayacaktır. Görsel, işitsel ve kinestetik deneyimler (fiziksel hareket) sunarak algısal etkiyi en üst düzeye çıkarmak istendiğinden, bu bağlamda en iyi uygulamanın VR olması beklenmektedir. Geliştirilen VR uygulaması çocuklara güvenli bir ortam sağlayarak olumlu tutum uyandırmayı hedeflemektedir. Amaç, diş hekimlerinin işlemlerini daha etkin ve güvenli bir şekilde gerçekleştirmelerini sağlamaktır.

Tezin özgün değeri geliştirilen uygulama ile ilintilidir çünkü şimdiye kadar diş hekimliği alanındaki sanal gerçeklik uygulamaları çoğunlukla video izlemenin ve müzik dinlemenin ötesine geçememiştir. Ancak bu tez ile sanal gerçeklik uygulamasında yer alan sanal karakterler, animasyonlar ve diğer içerikler sayesinde çocuklara diş tedavisinin keyifli bir aktivite olarak sunulması sağlanır. Animasyon karakteri ve sanal mekan seçimi tezin etkileşim yönünü güçlendirerek çocuk hastanın kaygı ve korkusunu dikkat dağıtarak azaltmaktadır. Uygun şekilde canlandırılan karakterler çocukların hayal gücüne hitap eden 3 boyutlu sahneler içerisine yerleştirilmiştir. Tez kapsamında çocuk diş hekimliğinde ileri farmakolojik yöntemlerin kullanımının azalması nedeniyle çocuk diş hastalarının ağız sağlığı bakımını artırmak ve sağlık giderlerinin maliyetini düşürmek mümkündür.

Tezin en önemli bulgusu, geliştirilen sistemin her iki taraf için de (çocuk hastalar ve diş hekimleri) faydalı olduğunu kanıtlamış olmasıdır. Toplanan veriler, sanal gerçeklik uygulamasının çocuklar üzerinde hem fiziksel (yaşamsal belirtilerin ölçümünde iyileşme- kan basıncı) hem de psikolojik (uygulanan psikolojik / psikometrik ölçeklerdeki iyileşme) üzerindeki yatıştırıcı etkisini göstermektedir. Ek olarak, VR Grubuna uygulanan anketteki sonuçlar, deney grubuna dahil olan neredeyse tüm çocukların bir sonraki diş hekimliği randevularında VR kullanmaya istekli olduklarını göstermektedir. Bu veriler, çocukların VR teknolojisine yönelik olumlu eğilimlerini doğrulamaktadır. Benzer şekilde, sanal gerçeklik uygulamasının diş hekimleri için faydalı yönleri, daha kısa tedavi süresi ve yüksek sistem kullanılabilirlik skorlarında ortaya çıkmıştır. Son olarak her işlemde aynı açıklamaları tekrarlamak zorunda olmadıkları için bu sistemin diş hekimlerine kolaylık sağladığı görülmüştür.

Bu tez ile geliştirilen VR uygulamasının dünya çapında ağız ve diş sağlığı alanında ekonomimize katkı sağlayacak potansiyel bir ürüne dönüşmesi ve ulusal ve uluslararası diş hekimliği kliniklerinde kullanıma açılması beklenmektedir. Mobil uygulama mağazalarından (Google Play ve App Store) kolayca indirilerek uygun fiyatlı sanal gerçeklik gözlükleri üzerinde çalıştırılacak bir uygulamanın geliştirilmesi, yaygın kullanımı sağlamakta önemli bir adımdır.

Sistemin daha da geliştirilebilmesi için, bakış seçme özelliği geliştirilebilir ve uygulamanın başlangıcına oyun mekaniğini öğretmek amaçlı eğitici bir bölüm eklenebilir. Dahası, bakış seçme teknolojisi (kafa hareketleri ile seçim) yerine, göze dayalı seçim olanakları (göz hareketleri ile seçim), günümüzde pahalı olan ancak yakın gelecekte erişilebilir hale gelebilecek göz takibi teknolojisi barındıran özel sanal gerçeklik gözlükleri kullanılarak araştırılabilir. Böylelikle çocuk hasta, diş tedavisi sırasında gerektiği gibi kafasını sabit tutarken gözleri ile girdi verebildiği için yüksek etkileşimli görevleri gerçekleştirebilir.

Ayrıca bu programın kullanımı diş hekimleriyle sınırlı kalmayacak şekilde çalışmanın kapsamını genişletmek mümkündür. Diğer tıbbi alanlardan başlayarak yeni kullanım alanları keşfedilebilir. Örneğin aşılardan korkan bir çocuk, korkunun üstesinden gelmek ve kolayca aşı olmak için uygulamanın başka bir genişletilmiş versiyonunu kullanabilir. Farklı tıp alanlarından doktorlarla görüştükten sonra bu kullanım şekli genişletilebilir. Sanal gerçekliğin diş hekimliği gibi alanlarda kullanımı hala deneyseldir, ancak bu alanda araştırmacılar, uzmanlar, bilim adamları ve endüstri liderlerinin yardımıyla gelişmeler görülecektir.

1. INTRODUCTION

The first dentist visit has a critical importance, as it may have a negative effect on the psychology causing the dental treatment session to be unsuccessful. The forms of negative behavior encountered in pediatric dentistry are dental fear, anxiety and phobia. It is a normal emotional response to one or more threatening stimuli in clinical life in dental fear medicine. Dental anxiety is to worry that something bad will happen during the dental treatment, often losing control of oneself. Dental phobia, on the other hand, is the severe type of dental anxiety, which is characterized by feeling bad and being afraid of objects used in dentistry (needle, filling device) [1]. "Dental fear and anxiety" are used to express negative feelings about dentistry in children and young adults. Regardless of the degree of fear and underlying reason, these incompatible behaviors delay, disrupt and even prevent dental treatments.

Considering the prevalence studies conducted between 1982 and 2006, it has been reported that approximately 9% of children in the normal population in Australia, Canada, Europe and the United States have dental fear and anxiety [1]. In other studies, conducted on the subject, the frequency of dental fear, anxiety and behavior management problems in children from various countries was 74% in Brazil [2], 30.6% in Singapore [3], 27.02% in Croatia [4], 25.6% in Turkey [5], 23.1% in Sweden [6], 22.2% in Finland [7], Taiwan 20.6% [8]. In recent studies conducted in low and middle-income countries, the ratios vary between 6% and 29% [9], [10], [11], [12].
Dental treatments often involve multiple injections, rapidly rotating cutting/piercing instruments, and invasive procedures that usually take several sessions. The behavior of the pediatric dental patient varies according to his/her ability to cope with stressful situations, maturity, personality, intellectual capacity, compatibility, emotionality, experience, oral health, family background, parents' style and culture. All of these aspects can affect the child's ability to adapt to dental treatment and present difficulties to the treating physician. When the child's behavior cannot be managed, the clinical and preventive care needs cannot be met [13].

For this reason, the dentist can use non-pharmacological techniques such as tell-show, voice control, distraction, modeling, non-verbal communication, positive encouragement, and pharmacological techniques ranging from sedation and general anesthesia in order and minimize dental anxiety in the child and to provide high quality dental services to the child patient. The dentist should choose the most suitable one according to the cognitive, emotional and social development of the child from a wide range of options [13].

Advances have been made in the management of dental treatment-related pain and anxiety. Various pharmacological (e.g., sedation, general anesthesia) and non-pharmacological (e.g., tell-show, demonstrate, motivation, distraction) strategies have been proposed to help pediatric patients adapt to dental stress factors [14]. Distraction is psychologically diverting the child's attention from a stimulus that is viewed as a threat (dental treatment). Visual or auditory stimulation can be used to modify behaviors in children with low and moderate dental anxiety [13]. In the pediatric departments of hospitals and clinics specialized for children, the attention of the child was usually diverted from painful treatments via auditory stimulation (MP3 players connected to headphones) during interventions such as intravenous needle insertion or stitching [14].

There are no studies on the effectiveness of different distraction techniques. In some studies in the field of medicine, there are data indicating that listening to music and watching cartoons reduces the pain and anxiety for children. However, as the systems do not require active participation, they cannot be used effectively to distract the child. Viewing videos on television screens in dental clinics is basically a distraction method, but the use of audiovisual glasses in dental treatments provides more interactivity, especially in children [14].

In studies conducted in the field of medicine, it has been reported that the sensation of pain can be reduced with virtual reality in interventions such as chemotherapy, physical therapy, burn wound care and surgery [15]. In dentistry, it has been reported that patients treated under virtual reality to remove dental plaque at gingival level in adults experience less pain compared to patients who watch movies or do not use any distraction method [16].

Auditory and visual passive distraction methods have been extensively studied in dentistry ([17], [18], [19], [20], [21]). These methods are frequently used by dentists and pediatric dentists today [22]. Recently, VR Headsets have begun to be studied on pediatric patients as one of the technological distraction methods [23]. In virtual reality studies a virtual world is simulated, allowing people to isolate themselves from the real world. Virtual reality systems are divided into two main categories as immersive and non-immersive. The level of immersion in virtual reality can be enhanced through different parameters, depending on the interaction of the person with the content of the system, the complexity of the images, and their stereoscopic nature. For this, there are caps, glasses and headphones that completely block the visual and auditory perception of the real environment [24].

In a recent study [25] the goal was similar to this thesis but the objective of this research was to create a robotic technology. Within the scope of the study, a social robotic system was designed to reduce the anxiety and pain levels of children in a dental clinic. The robot was able to talk, display meaningful facial expressions and body movements suitable for interacting with children. According to the evaluations of the experiments conducted by the dentists, using robots in dental treatments provides a decrese in the pain and anxiety levels of children. As the pediatric dental patients interacted with the robot that introduced and explained the treatment procedures and communicated with them, it has been reported that treatment success rates have increased [25].

However, the most important disadvantage of this system is the high cost of using robotic technology during dental treatments. In case robots are damaged on a hardware or software basis, they must be examined and rep aired by a competent specialist in terms of their hardware and software. Maintenance of comprehensive robotic systems requires high budgets. In addition, robots require a large volume of free space in clinics, due to their physical and operational field. In this thesis, it is planned to transfer the gains of using technological interaction to a mobile application that runs on extremely low-cost VR headsets and can be easily downloaded. The aim is obtaining prevalence so that technological distraction methods can be applied in all clinics by making technology cheaper.

The thesis is divided into 5 chapters, beginning with an introduction (Chapter 1) and literature review (Chapter 2). The literature review is made of a series of case studies in the field of medical treatment methods using VR, followed up by the positioning of the thesis subchapter explaining the technical differences of this thesis compared to previous studies. Afterwards, Chapter 3 entitled “Design and Implementation” is a detailed explanation of the development and implementation process of the VR application. Throughout this chapter, all of the used hardware and software units are presented and the implementation of the VR application is explained thoroughly. The main steps of the development process are: creating rigged characters and animations, designing virtual environments, using a game engine to attach the animations to the characters and create an application suitable for VR format. Chapter 4 displays the results of the experiment, explaining the criteria applied for the selection of the participants and the used evaluation metrics. Lastly, Chapter 5 summarizes the outcomes of the study and contemplates possible future work.

2. LITERATURE REVIEW

The term "virtual reality" (VR) was first used by Jaron Lanier in the early 1980s. In the following period, under the name of advanced human-computer interface, realistic environment simulations and the interactions were provided in VR. Virtual reality systems consist of: VR software, a computer, a video and audio vision system, advanced computer graphics, a tracking device that tracks the user's head movement and transmits information to the computer (in which direction the device is looking) and an interaction device such as a controller. The most popular VR display screens are head mounted displays with a video screen embedded in a device almost like a diving mask. Most VR headsets are designed for sitting or standing users, but they can be adjusted and used in medical procedures that require the patient to lie down, such as dentistry. Additionally, tactile feedback devices such as joysticks, vibrating pads, vibrating chairs and vests have been developed [26].

Another classification of VR headset can be done related to the degrees of freedom (DoF) the device provides to the user. DoF refers to how an object can move in 3D space. 3-DoF headsets and input devices track only head rotation, which can happen around *x*, *y* and *z* axes, also reffered as pitch, yaw, roll. 6-DoF devices include three more transitional movement along the axes, known as elevate, straff, and surge (Figure 2.1). Although experiences with three degrees of freedom are more limiting, this kind of headsets are more accessible, as they are more affordable. The VR application was developed for 3-DoF headsets as rotational movement provides enough flexibility for the scope of the study. Additionally, affordability is important to enable the widespread use of the application.

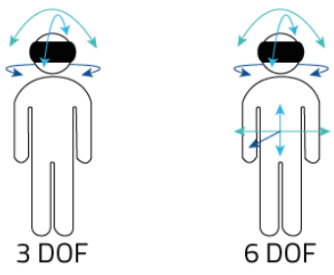

Figure 2.1: Degrees of freedom in VR headsets.

2.1. Medical Treatment Methods using VR

Recently, using VR as a distraction method in the medical practice environment has emerged as a promising technique for the adaptation of the child to the treatment and improvement of the relationship between the child and the physician. Virtual reality technology cuts contact with the physical world by replacing it with a virtual environment and using audiovisual feedback mechanisms. With a screen that can be worn like glasses, the virtual environment gives a sense of reality. The person perceives his/her environment in three dimensions and enters the environment created in the media. Virtual reality differs from other computer technologies such as audio-visual technologies with the strong effect and interactivity it creates on the individual, especially in a synthetic environment [27].

In a study conducted on children with severe autism the participants were devided into testing groups such that one group received normal dental treatment, the second group had dental treatment by watching a DVD video, the third group had dental treatment by watching their favorite movie in video glasses. As a result of the study, a decrease in the dental anxiety level of children was observed in the groups in which video glasses were used [28]. As a result of a study comparing the effects of audio-visual glasses and sedative agents on dental anxiety in children, it was found that audio-visual video glasses were more favorably received by parents, physicians and children [29]. In another study, the effect of pain felt during dental treatment was examined and it was shown that the use of video glasses was preferred by patients, although there was no significant change in the perception of pain [30]. A similar study was conducted on children to determine the beneficial effects of audiovisual distraction with video glasses on dental anxiety. The authors found out that primary tooth extraction treatments with video glasses did not make a significant contribution and did not show any prominent positive effect among the evaluated parameters [31].

It is known in the literature that virtual reality experiments have strong effects on the ideas and behavior of adults, but there are few data that have been applied on children. Virtual reality has been used in different clinical and medical studies for distraction in painful practices in children [32], spectrum disorder with autism [33], and for educational purposes in children with hearing disabilities [34], reducing physical and emotional pain in cancer treatment [35], wound care [17, 36], and reducing pain in

dental treatment [37]. However, there is limited research on the subject of using virtual reality to reduce pain by distracting children. It is reported that children focus less on their bodies and possibly feel less pain because they cannot see their bodies in the virtual environment. In virtual reality, children's attention is diverted from the physical world and drawn to the virtual world itself. It has been reported that children pain sensation decreases within the world of virtual reality [38].

In a study comparing music listening and movie watching through three-dimensional video glasses to reduce anxiety caused by local anesthesia in pediatric patients, it was shown that both methods were mostly advantageous and three-dimensional video glasses were superior to listening to music alone. Patient satisfaction level was found to be quite high in children in the group in which three-dimensional video glasses were used. As a result of this study, which was conducted as a randomized controlled experiment, the authors suggested that in the future, there is a need for studies involving children with a level 1 negative behavior according to the Frankl scale. Additionally, the authors have predicted that the use of three-dimensional video glasses in addition to the tell-show-and-play technique would be successful in children in this group [23].

2.2 Positioning of this Thesis

According to the studies and works conducted in the literature, it seems that a more comprehensive system is needed that can keep the child occupied during the medical procedure. The goal in this study is to inform the children who apply to a dentist for the first time by making the necessary explanations regarding the treatment in a fun way and turning their attention from the painful stimulus into a captivating and fun virtual environment. This goal also provides a comfortable treatment environment for the physician and the patient by ensuring that the treatment session continues more smoothly and comfortably.

There is a strong relationship between the child's dental anxiety level and the success of the dental treatment session. Measurement of vital signs, blood pressure, heart rate and oxygen saturation with different instruments such as pulse meter gives important information about anxiety level [39]. Dental anxiety physiological parameters (pulse rate, basal skin response), psychological/psychometric parameters (Venham's picture

test, Swedish version of the dental subscale of the children's fear survey schedule, dental anxiety scale), reflective parameters (dental fear picture test) can be evaluated and measured by different methods such as behavioral parameters (Frankl's Behavior Rating Scale, FBRS) [40].

In this study, a unique innovative objective measurement system is implemented to measure the cooperation level of the child. This measurement mechanism records 3-axis position and 3-axis orientation changes using the inertial measurement unit included in the VR, and returns a compliance score by calculating the correlation of movement information without the need for subjective evaluation of the doctor. It is thought that this objective measurement system creates a physician-independent compliance comparison and benchmark opportunity, which does not exist in the literature. Moreover, the effects of VR on children's anxiety levels during dental treatment is examined together with physiological, psychological and behavioral parameters. Today, it is known that low-cost VR headsets (such as 10 TL) are available in the market to encourage interest in VR applications, and it is possible for the software to enter every dental clinic. Additional outputs of the thesis are the ability of children to select interactive content with only head movements without moving their body or hands, and to establish an objective treatment cooperation criterion by measuring head movements.

3. DESIGN AND IMPLEMENTATION OF THE VR SYSTEM

Some key anxiety reduction strategies have emerged after a solid literature research phase on the relationship between anxiety and dental procedures. The main goal was the incorporation of these methods in the best possible way during the development phase of this application.

3.1 Analysis and Modeling

The design process has been motivated by the following key questions and their corresponding answers:

- Which VR headset model should be targeted?

The most available and affordable type of VR systems are mobile headsets, which combine a smartphone with a mount, allowing the standalone phone to also act as a headset. The application was therefore implemented on an Android device so that it could meet as many users as possible. Little investment is required; any smart phone running on Android operating system (at least Android 5.0) and a compatible mount display would be enough to use this technology.

- What kind of an ambience should be shown in the application?

The first approach is to clarify the procedures to be performed as the child is in a dental setting. The child should be able to select a movie and watch it after the educational introduction segment. The aplication opens another scene where the films are projected in a movie theater setting to make the user feel in a dreamlike environment. The films shown on the application were suggested by dentists from the Department of Pediatric Dentistry of Istanbul University.

- How can user engagement be achieved in restricted situations?

This thesis aims to achieve virtual reality technology with mobile headsets. There is no computer for the controller in this situation. In addition, because of the dental

patient's stance limitations, only slight movements can be performed. The interactivity has been defined by these two constraints. Gaze selection is an input tool that utilizes the direction of the user's gaze. The application was designed so that when the user was expected to make a selection, he/she used his head orientation to look at the option he wanted to choose and keep the camera positioned at that point to verify the selection.

3.2 Hardware & Software Requirements

3.2.1 Game engine

Unity is a game engine used mostly for the development of 3D games. Because of its cross-platform development capabilities, it is widely used by game developers. Unity can be used to build PC games, game consoles, web browsers, handheld devices, and VR applications.

Unity is an ideal option in the case of this application, as the built-in features allow the Android application to incorporate virtual reality without any other external coding. By modifying the built environment and player configurations, any application which is created in Unity can be transformed into a virtual reality application.

Unity also offers necessary tools for working with animations. It can be used to import and fit animation files from other sources into the character models already within Unity. Unity immediately allocates the animation to the model if both the character model and the animation file are for humanoid models.

3.2.2 Motion capture software

For capturing the initial animations, the Perception Neuron motion capture system was used. This system collects the user's gestures and transforms them into rigged humanoid animations, as the name implies. In the film and gaming industry, this technology is popular and is the best way to produce digital characters from live actors. There are two kinds of instruments for motion capture: optical and non-optical.

Although optical motion capture technology is more professional and is providing smoother performance, they need a setting and extra equipment for optical monitoring (cameras, special clothing). Non-optical motion capture was used for this thesis. This

technology is more affordable and requires no extra appliances. The downside is that it is more likely to capture erroneous movement that require other software applications to be corrected.

3.2.3 Animation creation software

Autodesk Maya is a software for 3D design which offers tools for various tasks such as animation, modeling, simulation and rendering. Among those functions, since it was originally designed for animation, Maya is mainly used for animation purposes. The animation software, primarily its graph editor, was mainly utilized in this thesis to correct the errors resulting from Vision Neuron.

The graph editor, is a method for animation manipulation. There are keys along its horizontal axis, reflecting different animation frames. In the animation model, the vertical axis represents the *x*, *y* and *z* coordinates of a selected point. This way, each frame can be selected individually for the duration of the animation and manipulated accordingly.

3.2.4 Three dimentional modeling software

Autodesk 3ds Max, formerly known as 3D Studio Max, is a software application for creating 3D animations, models, games and photographs in 3D computer graphics. It is used by game developers, commercial TV studios, and architectural visualization studios. It is also used for film effects and pre-visualization of movies.

This software was used to model the virtual environments inside the application. In addition, it has been used for character rigging as well. Afterwards, all 3D models are exported and imported into Unity in fbx format.

3.2.5 Head tracking sensor

The accelerometer is an acceleration measurement sensor consisting of a small mass that has pressure sensors around it. The mass shifts toward a pressure sensor when the sensor is accelerated, so that the direction and magnitude of acceleration can be measured. Accelerometers are one of the many sensors used on smart phones. For any smart phone, its key usage is to decide the phone's orientation, whether it is in portrait or landscape mode. There are some other examples of accelerometer use, one of which

is virtual reality. In VR, the direction of the user's head should lead to a scene being presented to the user. Essentially, it allows the VR headset to distinguish between up and down. With the accelerometer, it is possible to measure this orientation and show the correct images to the user. In addition, the accelerometer can be used to monitor user head movements, as was the case for this thesis.

3.2.6 VR headset

A VR headset is a head-mounted device which provides the wearer virtual reality content. Virtual reality headsets are commonly used for video games, but they are still used in other fields, including simulators and trainers. They have a stereoscopic head-mounted monitor, stereo sound, and head motion tracking sensors (providing separate pictures for each eye). Mobile headsets, which combine a smartphone with a mount, allow the standalone phone to also act as a headset, are the most accessible and affordable kind of VR systems. Therefore, the program was launched on an Android smartphone so that it could reach as many users as possible. Any mobile phone running on an Android operating system and a compatible headsets is sufficient.

Mobile headsets offer 3-DoF. While experiences with three degrees of freedom are more limited, since they are more affordable, this form of headset is more available. The VR application was built for 3-DoF headsets, as rotational movement provides enough flexibility for the study scope. Additionally, affordability is essential to allow the widespread use of the application. Today, in order to promote interest in VR applications, low-cost VR headsets (such as 10 TL) are available on the market, making it is possible for the software to reach any dental clinic.

3.3 Design of the Application

3.3.1 Application flow

In Figure 3.1 the flow diagram of the VR application is presented. Each step is colored according to the agent executing the described procedure. Blue boxes represent the inputs given by the dentist, at the beginning of the application. Green boxes illustrate the user inputs, which are the selections of the pediatric dental patients via gaze selection. The rest of the states are orange, representing the flow of the application.

These steps constitute our algorithm for the VR application assisting the dental procedure.

The VR application for soothing child dental patients is structured in such a way that it provides interactivity while ensuring that the child is staying stable during the treatment due to security requirements of a dental procedure. The application running on a mobile device (i.e., phone) begins as a mobile application where the dentist enters the patient information regarding ID, gender, age and treatment type to be executed. Afterwards, the UI leads to the launch screen where the doctor is supposed to insert the mobile device inside the headset and the virtual reality format is enabled. After launching the VR application, the starting coordinates of the patient are recorded. This is an important step for the application content to be displayed in the field of view of the patient, who must stay sitting during the dental procedure. The application begins inside the virtual dentist clinic scene. Gaze selection is explained to the user interactively, as the animation characters ask the child which avatar to select. Afterwards, the user is allowed to choose whoever he/she wants and the application continues with the selected avatar from that moment on.

The educational animations take place, incuding the general explanation of the treatment and the dental tools are presented playfully (e.g., the suction tube is compared to an elephant trunk). After the educational animations are over, the user is allowed to choose between two different virtual worlds that were designed for children. It is expected that the girls would choose the girl avatar and pink castle world while the boys would choose the boy avatar and the blue sci-fi world. Lastly, the user is teleported to the selected scene, where he/she has the movie tiles at disposal. From this point of the application, the child is free to choose the desired movie. The movie screen locks with the user viewport, ensuring the ability to watch the movies even if the dentist may ask the child to change head position or rotation. The application contains one last feature: blurriness effect is enabled if the patient is unstill and non-cooperative, as sudden movements are dangerous and undesired by the dentist during the treatment. The user must stay still for the blurriness to go away and the video to become clear again. Head movements are measured with the help of the accelerometer inside the mobile phone, and when the movements exeed the specified limit blurriness effect is enabled. The avatar character appears in front of the locked in movie screen and warns the user.

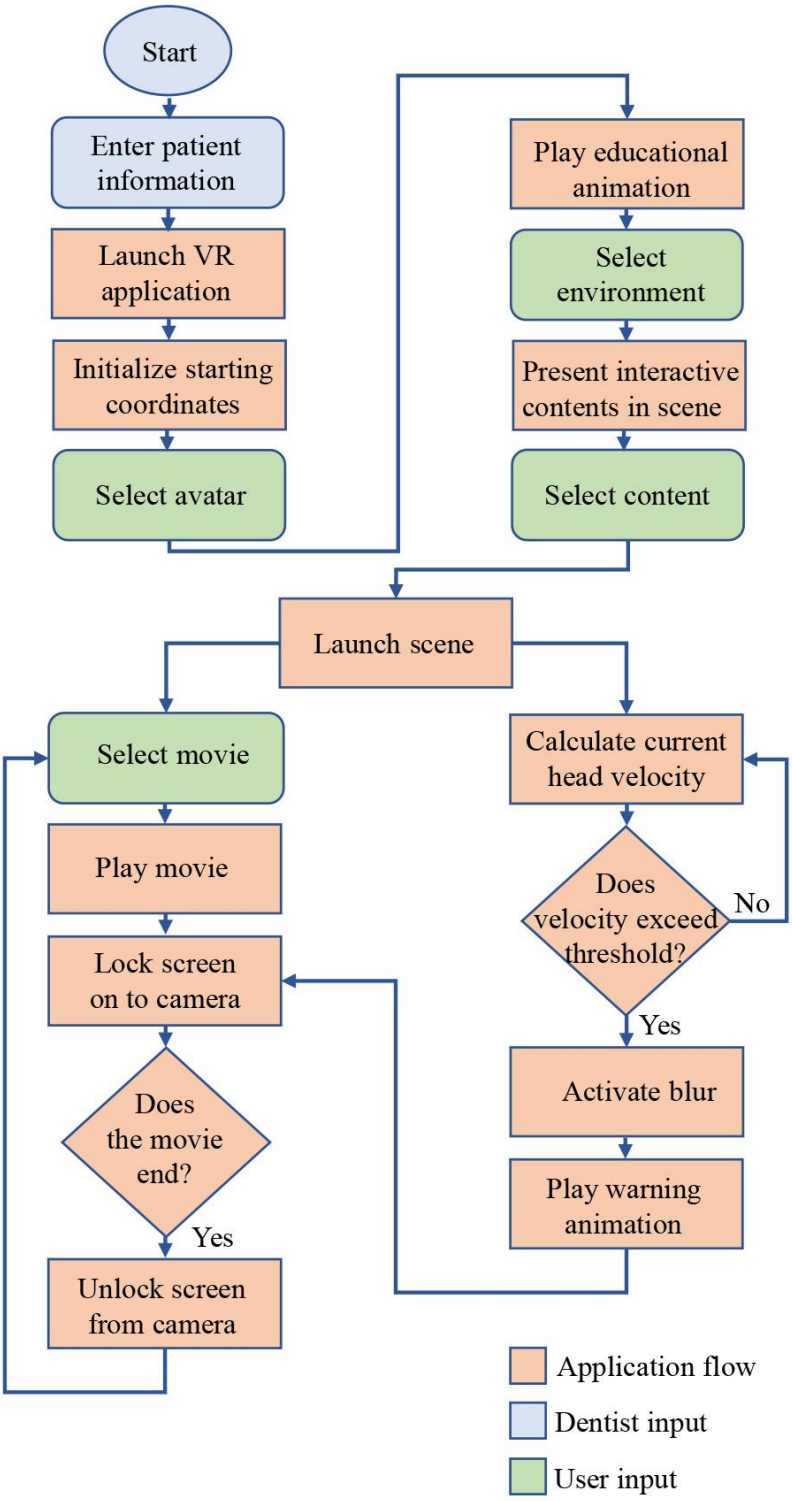

Figure 3.1: Flow diagram of the VR application.

3.3.2 User interface design

The application begins as a 2D mobile application and then transforms into a virtual reality environment. This transposition occurs when the user presses the launch button. As displayed in Figure 3.2, there are three mobile screens that were designed for a vertical use layout. First of the images is for entering user information, second displays the “Launch” button and third is displaying a countdown. This time period gives the dentist enough time to insert the mobile phone inside the VR Headset and putting it on to the patient. The VR related process of the application has no UI, but the user interaction utilizes the gaze selection (Section 3.3.5) instead of touch interface

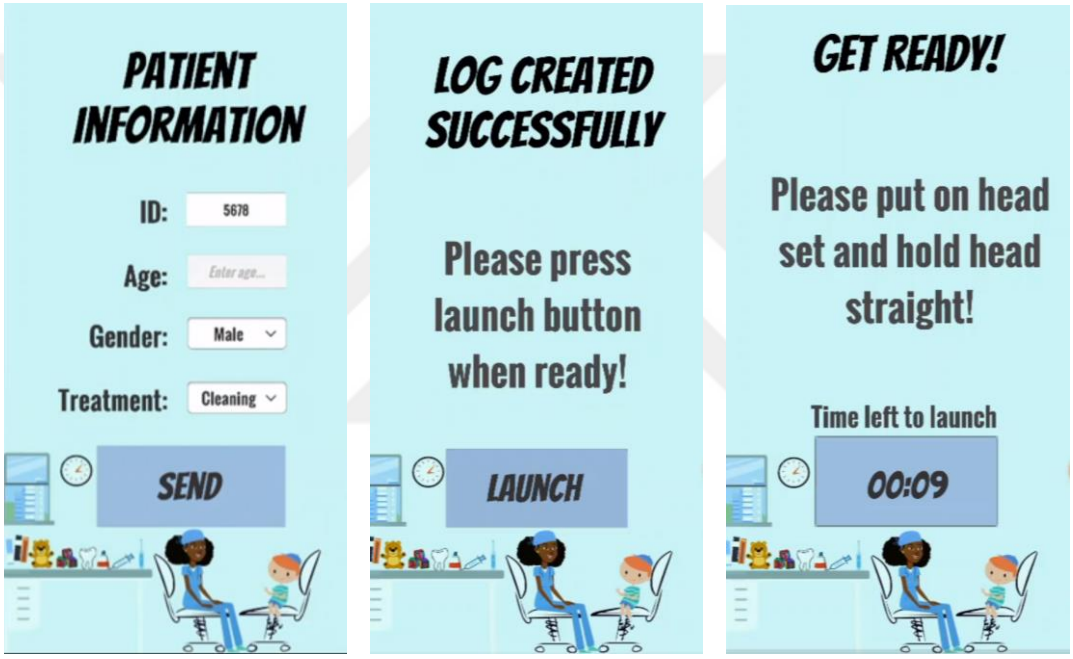

Figure 3.2: UI design layout.

After launching the VR application, the patient’s starting coordinates are recorded. This is essential for the content of the application to be reflected in the patient's field of view, who must remain seated throughout the dental procedure. Positional tracking senses the exact location of the head-mounted display and game objects inside euclidean space in virtual reality. Since the aim of VR is to mimic perceptions of reality, it is important for positional tracking to be both precise and accurate so as not to disrupt the three-dimensional space illusion. To accomplish this, many methods have been developed to monitor the position and orientation (pitch, yaw and roll) of the VR headset and any related game objects. All of these methods use sensors that

record transmitter signals and then send that information to the computer to maintain an estimate of their physical positions. In general, one or more of the three coordinate systems are used to describe and define these physical locations: the cartesian rectilinear system, the spherical polar system, and the cylindrical system. To provide a smooth user experience, such interfaces must work closely with positional tracking systems. Mobile headsets use inertial tracking.

Inertial tracking uses data from accelerometers and gyroscopes. In 3 DoF VR headsets, gyroscopes are used to determine angular velocity and rotational tracking while accelerometers are used to measure linear acceleration. Since the position derivative with respect to time is velocity and the velocity derivative is acceleration, it is possible to integrate the accelerometer output to find the velocity and then integrate it again to find the position relative to some initial point. It is also possible to integrate the angular velocity to calculate the angular location relative to the initial stage.

3.3.3 Scene design

In order for the software to keep the patient mentally away from the treatment process and anxiety, the VR application must offer an immersive and effective environment. The main elements of such an environment are the characters and the virtual world where these characters are positioned. These 3D scenes are places where the patient should feel comfortable. In this respect, an appropriate virtual clinical scene and two fantasy lands (targeting boy and girl patients) are created considering the age range of the test group.

The design process of the virtual dental clinic scene started with an architectural research on the production of child-oriented clinical interior design. A mood board is an arrangement of images, a type of visual presentation or collage consisting of photographs, text, and object samples in a composition. The mood board (Figure 3.3) was created after reviewing real world case studies of the pediatric medical clinics. This was realised in Adobe Photoshop, which is a program used globally for photography editing, visualisation and more.

Figure 3.3: Mood board for concept design of the scene.

The 3D modeling process started after the idea was determined. The interior architecture of the dentist was modelled from scratch, with the dentist chair being the only imported type from Sketch-up 3D Warehouse. 3ds Max serves, among other applications, not only for modeling, but also for rendering. The rendered image displayed at Figure 3.4 was made by using the V-ray plugin for 3ds Max, assigning fabrics, lighting and camera. The rendered file is edited in Photoshop.

Figure 3.4: Dental clinic scene.

The other two scenes displayed at Figure 3.5 and Figure 3.6 were created for offering the user two different versions of virtual enviroments to be teleported. The user has

the freedom choose whichever he/she may prefer. The expectation is for the girs to choose the fairy world and boys the futuristic world.

Figure 3.5: Fairy world scene.

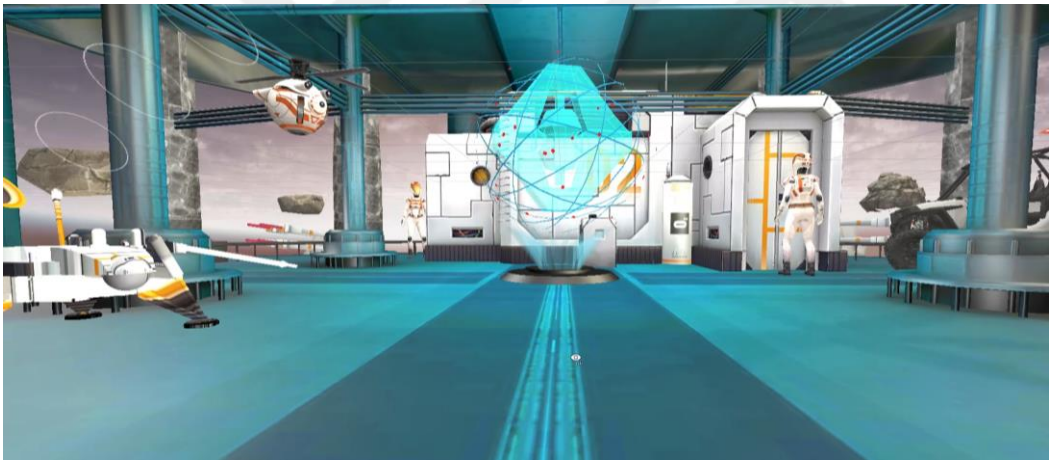

Figure 3.6: Futuristic world scene.

3.3.4 Character design

The character creation and rigging process in 3ds Max was required before importing all created models into Unity. In computer animation, skeletal animation or rigging is a technique where a character (or a humanoid creature) is divided in two parts: a representation of the surface used to display the character (called the mesh or skin) and a hierarchical series of interconnected pieces (called bones or the skeleton) which is a synthetic armature used to animate the mesh. It is possible to break the process into three steps: constructing the skeleton, skinning the character and building controls for

animation. Animation controllers are helpful external geometries that alter the character's pose, when shifted or rotated. While the boy model inside the application was rigged in the described manner (Figure 3.7), the girl character was imported from Mixamo.com in rigged form.

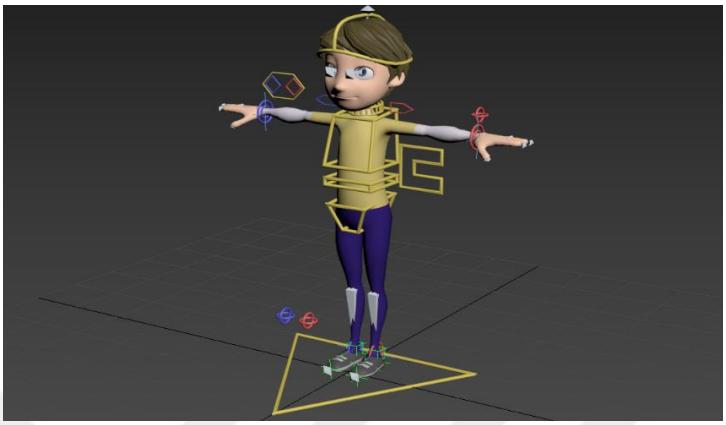

Figure 3.7: Character creation and rigging.

The building phase of the Unity game scene started after importing the created 3d models as fbx files into Unity. Initially, the application had only one character and the dental chair was placed in the middle of the virtual clinic (Figure 3.8). The final version displayed in Figure 3.9 has two characters of which the user is free to select the desired one. Another difference is the fact that in the final version the user is viewing the game scene while sitting in the virtual dental chair, being able to see the virtual representation of his/her body.

Figure 3.8: Initial game scene.

Figure 3.9: Dental clinic scene with selectable boy and girl avatars.

3.3.5 Gaze selection

The interactivity of the developed software occurs when the patient makes choices. In order to provide the selection and interaction features, the gaze selection technique is used. This technique was introduced for this program for picking an avatar, environment and film of the users choosing. There are three reasons why using a controller is not feasible for the purpose of this thesis:

- As the target group includes children, the interaction should be as transparent and intuitive as possible.
- The patient should not struggle to operate a controller during a dental operation.
- An extra controller adds additional hardware costs to the system.

Therefore, we decided to use gaze selection as an interaction tool, which is the only way to gain interactivity without an additional device. The user view is described in Unity as a camera from which the user sees the virtual world. This point can be used as an input by finding the precise location in which the user's vision is oriented. Through Unity's raycasting and collider schemes, raycasting can be accomplished. Raycasting can be envisioned as shooting an invisible ray from a point with a specific

direction. Any object in the path of that beam collides with the ray, if the object has a collider body attached inside the game engine.

The origin of the ray is the camera's position, and the path of the ray is the angle of the camera, which is bound to the user's head orientation. The necessary choices are shown as 3D models in the virtual world when the user is asked to make a decision, to make them available for gaze selection interaction. The inclusion of rigidbody and collider components to the selectable objects enables the method of gaze selection. Unity calculates the path of the ray in each frame and in case of collision, the corresponding event is triggered. Colliding this ray a certain amount of time with an entity decides the feedback of the user and the object becomes red if the collision with the target object lasts for a certain amount of time as seen in Figure 3.10. In the left panel, the pointer is standing in the middle without colliding with any of the boxes. It has the shape of a dot meaning that the raycasting system doesn't collide with any object. In the middle panel it can be observed that the pointer has transformed into a white circle and while the user continues to target the same game object the circle is being filled in with blue. The right panel shows a fulfilled selection, as the pointer circle became fully blue, which triggered the event of the box turning into red

Figure 3.10: Gaze selection.

In order to keep track of the position of the gaze the VR technology includes head monitoring. The vision of the consumer must be adjusted in tune with the head rotation; calculation of head orientation is therefore needed. This is achieved by an internal sensor in virtual reality headsets. By using an accelerometer, a chip made up of axis-based motion sensing, smartphones and other mobile technologies measure their orientation. It is the accelerometer that permits the monitoring of the head.

3.3.6 Head motion mitigation

The patient is expected to keep the head movements to a minimum during the treatment. For this purpose, head movement measurements can be used. With these measurements, an increase in the patient's head movements can be detected instantly. In cases where these increases exceed the desired levels, the patient can be warned and automatically asked to keep his/her head still.

Considering the patient age range, an additional incentive to reduce head movements may be required. For this purpose, the content seen by the patient in the virtual reality environment can be artificially blurred in case of unwanted increase in head movements. Then, the patient is warned by the animation character that this blurring is caused by head movements and can be eliminated by staying still. If the child is cooperative and the head movements are reduced to the desired levels, the blurriness fades and the VR content becomes clear again. This can be observed in Figure 3.11.

To decrease the necessary head movement, the movie tiles showing the posters of the available films are positioned next to each other, in the user's center of view. The video is chosen with gaze selection until the child patient looks steadily at one of the film tiles. The application opens a white screen that is clipped to the viewport , and the chosen video is played on this screen. The created virtual environments in which the movie watching takes place were designed with the aim of distracting the child patient with the supernatural virtual world to forget the actual location and the treatment taking place.

Figure 3.11: Blurring Effect (left panel: before blurring, right panel: after blurring).

The results of the text file which is generated from the head tracker script were visualised in Figure 3.12. In the text file, data is stored as comma separated values, which were visualized as line charts. While recording the results, the test subject moved his head in still, moderate and high levels of rotational speed. After inspecting the charts, the value of 0.25 was chosen as the threshold of stillness. It can be seen that in the worst case head movement data exeed 0.5, reaching 2.0 at most. Intense head movements show up around after the threshold of 0.5 therefore a higher rate of blurriness should be applied if this value is exeeded.

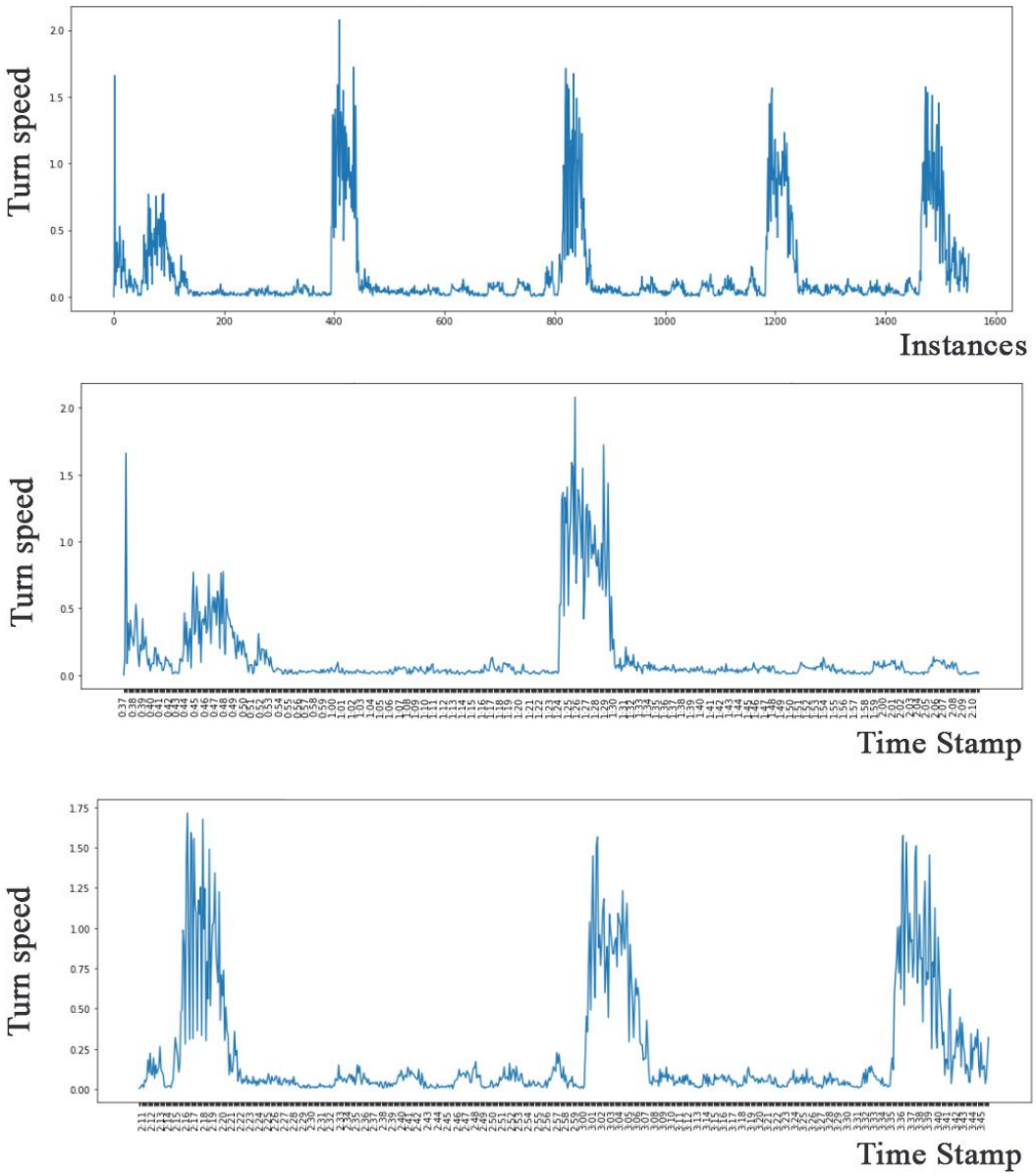

Figure 3.12: Head movement data distributed over time.

The first chart shows all of the data recorded per the experiment with respect to the number of samples obtained. The second and the third charts show the same data divided into two figures with respect to the time stamp in the real world. The high peaks in the figures represent quick movements. By looking at the x-axis of the figure one can tell how many seconds fast shaking was performed. In all of the five peaks the head was shaken horizontally (left and right). The faster the movement, the higher the velocity value recorded by the accelerometer is. For the dentist project, such high values are undesired because it means that the patient is thrashing around or moving too fast for the dentist to perform their work safely.

The small peaks represent a combination of slow movement and stopping. The first low peak interval has slow horizontal movement (left → stop → right → stop) repeated several times. The second interval has several slow vertical movements (up → stop → down → stop). The third interval has several slow diagonal movements (upper right corner → stop → lower left corner → stop). The fourth interval has several slow reverse diagonal movements (upper left corner → stop → lower right corner → stop).

The difference between a stop and slow movement can be seen as they have a slight magnitude (height) difference. The movement has a slightly higher magnitude compared to the stopping. In the case of diagonal movements, this is even more obvious since it is slightly more difficult to control the diagonal movement smoothness of the neck. In the case of vertical and horizontal movement, it is not so obvious. The stop interval also has some speed magnitude values since one cannot perfectly still his/her head. And since the accelerometer is very sensitive it will capture that slight movement as well.

For the dentist project, such movements are acceptable since they do not interfere with the dentist's job. We allow such movement below the threshold of blurring because if we set the threshold any lower than these values then the screen will be always blurred. However, faster movement may be dangerous so we set a threshold for best performance.

3.3.7 Animations

Animations are one of the essential aspects of this thesis, as the whole child- dentist communication is replaced with the characters inside VR environment. Therefore, the

characters need to act naturally and portray adequate behaviour. During the creation process of the animations, some gestures like standing idle, clapping etc. could be found on on open-source asset stores. However, some special movements of dentists (such as showing dental tools etc.) are not available as ready-made animations.

Therefore, the special animations were created to reflect the movements of dentists exactly, thanks to a motion capture system. These animations were captured using motion capture, as the default animations available on external sources did not cover the thesis scope entirely. With the motion capture system, new animations have been made. This system is made of a wearable suit device and has the ability to transmit the movements to the computer environment. After the captured animation is transferred to the computer environment, the created animation is attached on the previously rigged characters. In this way, animations in which the characters move in the most natural way are obtained and realistic virtual reality environments are created for the patients.

The humanoid model is used for animation after the character formation and rigging process is over. Two steps are primarily important for this process. First step is designing humanoid animations that are to be placed on rigged characters and the second is assigning the animation to the desired character by using Unity's in-built Animator.

For attaching the animation on the character, the animation file and the targeted character must be of the same animation type (meaning humanoid animation and rigging) to make the assigning process possible. The created animations are not for a single character, but for all human-like rigged characters. The character model has a humanoid rig specific bone structure (Figure 3.13). When imported into Unity, both the animations and the characters must be picked as humanoid from their property screen. This makes it possible for Unity to attach the animations to the corresponding body parts of the character. Thus, the animations and the model can work together.

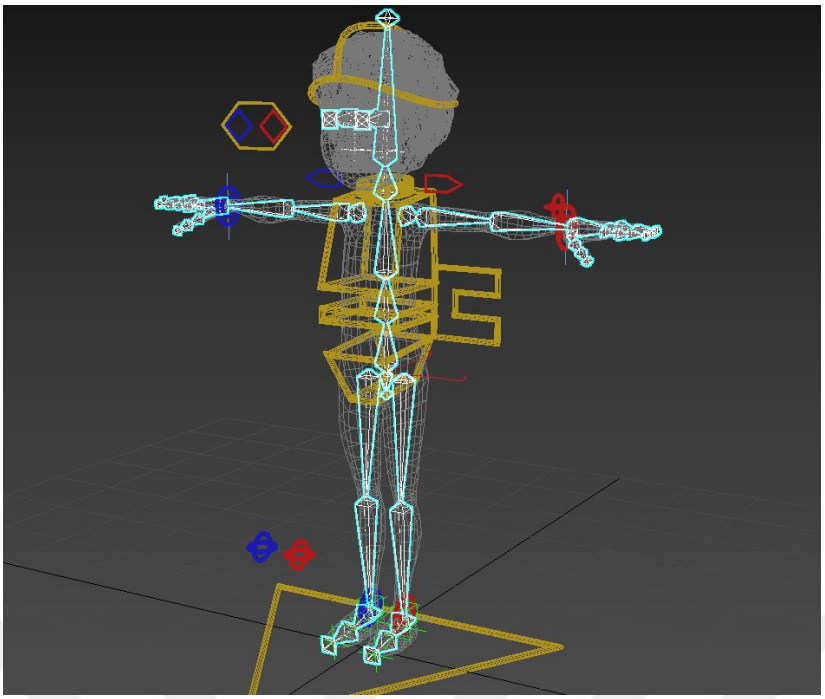

Figure 3.13: Rigging in 3ds Max.

Finally, Unity uses a state machine for the playing of the animations. This instrument allows the flow between various animations, called states, to be organized and arranged. The Animation State Machine offers an overview of all animation clips connected to a single character. Various movements can be activated with the help of a trigger and smooth transitions between different animations can be achieved. The Animation State Machine seen in Figure 3.14 displays the linearly emerging animations that were created for the tell-show-do part of this thesis. The tell-show-do technic is a basic behavior orientation technique used in dentistry where the dental tools are shown and explained before being used. The corresponding animations were created with a motion tracking system while the dentist was executing the required motions for: welcoming the patient, realizing a short self-presentation, telling the purpose of the treatment to be executed, showing the dental mirror tool, showing the dental aspirator, presenting the dental brush, realizing a countdown for anesthesia and finally presenting the movie tiles of which the child patient is allowed to select and watch the desired movie. The mentioned animations are located in the Animation State Machine with a corresponding title and linear execution. Only the first tile has a trigger and afterwards the white arrows allow the animation to flow automatically from one state to the next when the animation is finished executing.

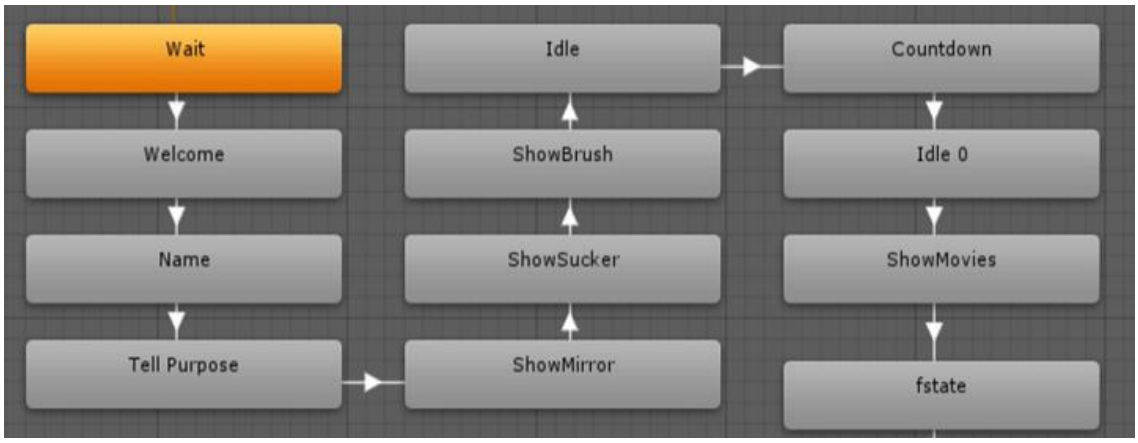

Figure 3.14: Animation State Machine in Unity.

Another type of animation within the application are the animated game objects placed in the virtual environments. In order to create interesting, dynamic and engaging spaces such elements have been added to all of the three scenes. For instance, such animated game objects are: the cloud-shaped ceiling lamps in the dental clinic scene, the hologram, flying drone and meteorites in the futuristic world scene and the clouds placed in the fairy world scene. These animations were recorded inside Unity game engine. This is done by opening the animation window within Unity. After clicking record button, all of the displacement, rotation and scaling modifications applied to the game object are recorded to the desired keyframe. Additionally, some other characters were added whose animator loops in a steady animation (for instance the astronaut character in the futuristic world scene and the dragon in the fairy world scene).

3.3.8 Gamification elements

By definition, gamification refers to using game-specific elements in non-game contexts and activities in order to increase users's involvement. Gamification leverages the inherent impulses of people for competitiveness and accomplishment. Tools used in game design, such as rewarding users for success, leveling-up, and winning badges, are taken into other context to help inspire people to reach their objectives or improve efficiency.

In order to keep the child engaged and pay attention to the instructions given by the avatar character some gamification elements and game objects (Figure 3.15) have been added. While the dental procedure is explained by the avatar, the user gains additional stars. At harder stages celebration confetti appear. The confetti effect was created via

particle effect tool within Unity. The aim is to keep the child focused, engaged and rewarded.

Figure 3.15: Gamification elements: trophy, certificate, star and confetti effect.

At the end of the procedure the dentist asks the child to gaze at the trophy. Selecting the trophy game object via gaze selection triggers the final animation. This animation rewards the user with the last star, meaning that the child has completed all previous steps successfully. Therefore, the child wins a “brave child certificate”, meaning that the procedure is over and he/she is sent off by the avatar.

4. EXPERIMENTS

During the design of the experimentation process of the study, the primary aim was to ensure that the treatments are performed in a comfortable environment both for dentists and patients. While developing the experimental framework, following considerations are made:

• Making use of cartoons suitable for VR for children and dental treatments;

• Creating original VR content for the first time in dentistry and being an exemplary study in our country and in the world with this aspect;

• Investigating the effects of VR use on children's behavior in dental treatments;

• Determining whether VR has superiority over traditional distraction technique.

4.1 Overview of the Experimental Design

The VR application begins in a virtual dental clinic where the avatar character explains the treatments to be executed. At this point, the character also presents and briefly explains the dental instruments to be used during dental treatment. Meanwhile the dentist carry out the following tasks:

(1) The child sits passively in the dental chair.

(2) A visual examination of the oral cavity is made by placing the oral mirror in the child's mouth, while the dental mirror tool is explained to the patient in the VR application.

(3) Air/ water spray, aerator etc. tools are introduced virtually while the dentists place the tools one by one in the mouth, and the explanatory animations are played.

(4) During the local anesthesia injection, a counter that allows the child to wait without moving is activated virtually inside the application.

(5) When the physician starts the treatment, the child is allowed to watch the cartoon he wants.

(6) At the end of the treatment, the child is congratulated and sent off.

Thus, it is aimed to complete the treatment more comfortably without interruption by mentally shifting the children from the real environment to the virtual one through VR technology. With the successful treatment of children and the development of positive behaviors, it is also aimed to reduce the need for high-cost techniques with complication risks such as sedation and general anesthesia applied in children with lack of cooperation. In addition to these, it is expected that it is possible for dentists to work more comfortably during the treatment of pediatric patients, and to reduce the stress that the physician experiences while persuading the child.

In the fifth step of the scenario, instead of the participant taking part in the environment passively, such as watching cartoons or listening to music during the treatment, the child is given the opportunity to start a cartoon, by controlling the child's choice with gaze selection in the virtual environment, and the interaction causes less painful stimuli, as the attention is distracted.

4.2 Selection of Participants

The participants of the study are chosen according to the following criteria:

- Children who are applying for their first examination ever, at Istanbul University Faculty of Dentistry Department of Pedodontics

- Healthy children between the ages 6-10 are chosen randomly

There are two test groups:

• Group I. Standard treatment;

• Group II. The active distraction group is treated while wearing the VR headset and interacting with the designed application.

Dental treatment procedures for which the indications are set by the specialist pediatric dentist of the patients are performed in accordance with routine treatment protocols.

In selecting the age group, attention has been paid to ensure that the children can evaluate the questionnaires to be applied and their responses to VR before / during the treatment are appropriate for the mental and physical development of the child. Children who meet these criteria are evaluated by the same dentist during the first examination with FBRS according to their behavioral attitudes and is listed by numbering according to the order of application. Patients who do not come to the treatment appointment are recruited again. The inclusion criteria of the volunteers in the study were selected as follows:

• Physically and mentally healthy,

• Between the ages of 6-10,

• Children who need pulp treatment for the lower jaw first milk molar or second milk molar (inferior alveolar block)

Figure 4.1 displays the age range and gender distribution of participants in the study. While the VR group is formed of 14 participants, the Control group is formed of 6 participants. According to the collected data in the experimentation phase, age groups and gender distributions have not made a visible difference in the outcomes. Therefore, the evaluation graphs of the study have been realized according to the average values of the total paticipants in both study groups.

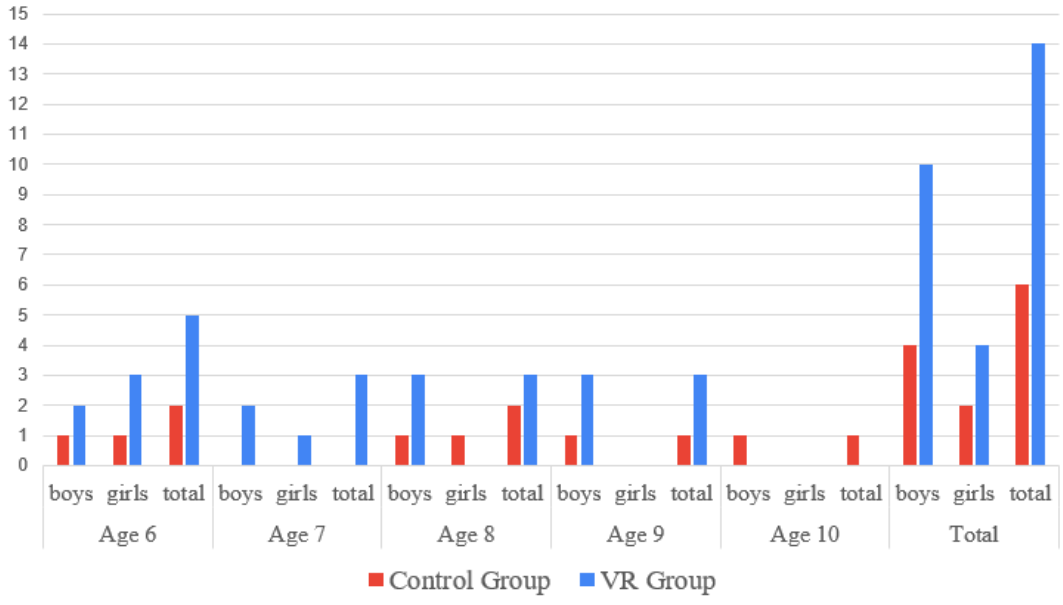

Figure 4.1: Age range and gender distribution of participants.

4.3 Evaluation metrics

The success of the proposed approach is analyzed through the statements of the child, by the researcher observing the treatment session and the child's psychological and physiological data. The following scales are used for this:

1) Facial Image Scale: With this scale, it is aimed to measure the pain perception of the child during dental treatment. Subjective responses from children before and after dental treatment is evaluated with five different facial expressions seen in Figure 4.2 ranging from "very happy" (1) to "very unhappy" (5). Answer number 1 shows the most positive effect (no pain) and answer number 5 shows the most negative effect (severe pain) [41]. The visuals numbered 1 and 2 in the scale to be used express a positive attitude, in other words, there is no pain. Each child is asked to choose the face shape that best reflects their feelings before and after treatment. With this questionnaire, which is applied to children before and after treatment, it is planned to measure the pain perception of the children and make a comparison between the groups.

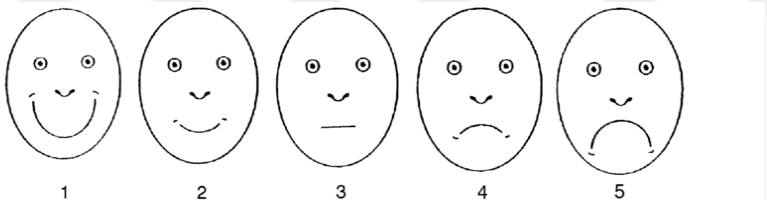

Figure 4.2: Facial Image Scale.

2) Children's Fear Survey Schedule-Dental Subscale: This scale is one of the most common scales used in evaluating the dental anxiety level in children [42]. It consists of 15 questions covering different aspects of dental treatment. It was done by asking children to score from 1 (not at all) to 5 (extremely scared) for each question (1 = Not scared at all, 2 = Slightly scared, 3 = A little scared, 4 = Very scared, 5 = Extremely scared). All scores are added together and the total score is obtained between 15 and 75. 15-31 points indicate low level, 32-38 points to moderate, and 39 and above to indicate high level of anxiety. At the end of this scale, in order to evaluate whether the children in the group are willing to use VR again in their next appointment, a question like "Would you like to use VR at your next dental treatment appointment?" is asked.

The answers given to this question are evaluated in 5 stages between "I would never want to" and "I would like it very much".

3) Pulse: Finger-type pulse oximeter (Pulse Oximeter, Tekinmedikal) is used to control the anxiety levels of all treated children (experimental and control groups) at certain critical moments of the treatment being: 1) 5 minutes before, 2) right before, 3) during, 4) after and 5) 5 minutes after the treatment of local anesthesia. The values are recorded by measuring the pulse rate 4 times. Whether there is a significant increase or decrease in heart rate is evaluated and a comparison is made between groups.

4) Frankl's Behavior Rating Scale: The Frankl Behavior Rating Scale (Figure 4.3) is applied before and after the treatment [43]. According to the scale, the child's attitude towards treatment is divided into 4 groups and scored between 1-4 meaning: 1 point absolutely negative (child refuses treatment, strong fear and crying), 2 points negative (reluctant to accept treatment), 3 points positive (child accepts treatment, but is cowardly and timid) 4 points absolutely positive (compatible with pediatric dentist). This scale is used to measure the behavioral responses of the child. Experiments are and interpreted with FBRS by the researchers.

Figure 4.3: Frankl's Behavior Rating Scale.

5) Duration of treatment: After the questionnaires are filled, the time from the child sitting on the seat to leaving the chair at the end of the procedure is recorded in the experimental and control groups. Total treatment time is compared between groups.

6) Questionnaire applied to VR Group: The children included in the experimental group are asked 15 questions (Appendix A) related to their experience with VR and the developed application. With these questions, it is aimed to learn the tendencies of children towards VR technology and understand the aspects they liked and disliked.

7) System usability scale: The system usability scale (Appendix B) is a simple, ten-item scale giving a global view of subjective assessments of usability. It is filled by professionals, in this study the dentists. The aim is to measure the effectiveness and efficiency of the application and the satisfaction of the dentists. The participant's scores for each question are converted from the original sum of scores of 0-40 to 0-100.

4.4 Treatment Details

Dental treatments are performed in the same procedure in both groups. The anticipated mean treatment time was determined as 30 minutes. The treatments are planned to be completed in a single session under local anesthesia. Parents are not be kept with their children during the treatment according to the routine clinical procedure. A fixed camera is used to record the sessions. The camera is placed in front of the child, recording the child's facial and body expressions and behavior, then interpreted with FBRS.

Basic behavior orientation techniques (tell-show-do, positive encouragement) is applied by the dentist during the treatment of the first group. According to a study conducted in Turkey and published in 2019, the most preferred movies were "Super Wings" for boys and "Frozen" for girls, which are among the most watched animations by Turkish children [44]. Therefore, these movies were added to the VR application. VR headset are used during the treatment of the second group. Oral communication of the dentist with the child is kept minimal. A similar "tell-show-do" technique used in group I is simulated on VR. The instruments to be used by the dentist during the procedure are introduced on VR, and then the procedure starts. In this group, the dentist is passive.

The treatment to be applied is described in detail as follows:

• The dentist lets the child sit on the dental seat and leaning back, hands together on the lap.

• The dentist sits on the dentist's seat,

• The dentist turns on the reflector light,

• The dentist places the mirror in the child patient’s mouth,

• The dentist places the saliva sucker in the child patient’s mouth,

• The dentist applies topical anesthesia,

• The dentist lets the child watch animations for 60-90 seconds,

• The dentist performs mandibular block anesthesia,

• The dentist lets the child watch animations for 5 minutes,

• The dentist places the aerator in the mouth,

• The dentist removes the tooth decay,

• The dentist places a base,

• The dentist waits with the countdown animation for 10 seconds, wases the acid off,

• The dentist dries the cavity and applying bonding, holding an air spray,

• The dentist does the placement and lighting of the filling,

• The dentist asks the child to bite the articulation paper,

• The dentist finishes polishing operations,

• The dentist celebrates the child for being courageous.

4.5 Pilot Studies and Observations

Pilot studies were conducted on two child patients (Figure 4.4, Figure 4.5) within the Faculty of Dentistry of Istanbul University in Mediko complex. The testing was done with an Android mobile device with Bluetooth 5.0 which allowed connecting two

Bluetooth devices simultaneously. While the child patient was wearing the Bluetooth headset in order to clearly hear the sounds and not get interrupted by the noise of the dental tools, the dentist team has been listening to the same sounds via a Bluetooth speaker. That way sound mirroring was achieved and the dentists knew at what stage of the application the child was. The treatment was executed in real-time with the explanatory animations. While the first test subject (Figure 4.4) was uncooperative and the VR Headset had to be removed during the procedure, the second test subject (Figure 4.5) was highly cooperative and the VR application showed success.

Figure 4.4: Uncooperative test subject.

Figure 4.5: Cooperative test subject.

It has been observed that even though the first test subject was considered positive according to Frankl's Behavior Rating Scale before the procedure, her anxiety levels have increased after sitting in the dental unit and she started crying. However, after putting on the VR Headset she calmed down, as she was distracted by the content of

the application. The positive state continued until the application of local anesthesia. While the avatar character was explaining this procedure, the local anesthetic was injected. At this stage it is thought that the patient has correlated the pain of the anesthesia with the VR application and started to feel intimidated by the headset, and wanted it removed.

The second test subject was highly cooperative according to the collected data and observations of the testing team. Scales named "Facial Image Scale (FIS)", "Children's Fear Survey Schedule-Dental Subscale" and "Frankl's Behavior Rating Scale" were applied and the results were recorded. Before the dental treatment, he has identified himself as positive according to Frankl's Behavior Rating Scale. Additionally, his heart rates were normal at all stages of recording data with the pulse oximeter.

While analyzing the patient's Children's Fear Survey Schedule-Dental Subscale recorded before and after the treatment, it has been observed that he has mostly replied as not being afraid of most of the elements questioned in the scale with a few exceptions. Before the treatment he identified as being very afraid of injection. After the treatment he identified as being a little bit scared of injection and the noise of the dental tools, showing improvement before and after the treatment accompanied by VR.

According to the survey form (Appendix A), the child patient gave mainly positive responses and claimed that his visit to the dentist was very comfortable. He mentioned having difficulties breathing due to the dental procedure, not the VR headset. He claimed that it was easy to give gaze selection inputs. While affirming the eagerness to use VR in his next appointment, he mentioned that his favorite feature within the application were the movies. As the treatment lasted for 20 minutes, he was able to watch two movies within this period. He declared to like only one of the movies. This was due to the fact that the first movie was selected voluntarily by choosing the desired movie (Ice Age), but the second selection was done accidentally (Barbie), while the dentist assured his head is not moving and the gaze selection went on. The assumption of girl users choosing the girl avatar and fairy world scene and the boy test subjects choosing the boy avatar and futuristic world scene has proved itself to be valid in the case of the pilot studies. Therefore, to avoid this kind of problems (choosing undesired movies) a simple solution could be placing cartoons that have a girl dominated target

audience in fairy world scene and cartoons that have a boy dominated target audience in the futuristic world scene.

Other than the test subjects, the dentist team has also tested the VR application and gave feedback. They have stated that children tend to forget keeping their mouth open during the dental procedure, therefore the avatar character could be making reminders like “Open your mouth wider” or “Keep your mouth open”. Another valuable feedback was related to the motion blur feature. It was suggested to decrese the bluring threshold as the images were distorting even at acceptable head shake levels. Finally, it was observed that the VR content is visible only by sitting in an upright position and it was suggested that it should be relocated such that it can be clearly visible from a leaned back position.

Other observations were made related to the hardware devices. It has been observed that the VR headset can be large and encumbering for some smaller children, and a lightweight headset would work better. Similarly, it has been concluded that headphones would be more suitable than earphones, as these have fallen down a few times during the dental treatment. Lastly, higher quality speakers that can diffuse higher volume would be more suitable for the purpose of the study, as the dental tools might be noisy.

5. RESULTS

5.1 Results on Facial Image Scale

The participants were asked to identify themselves with one of the figures in the facial image scale ranging from "very happy" (1) to "very unhappy" (5) before and after the treatment. Figure 5.1 displays the mood change of the participants. While interpreting this bar chart one must realize that the closer the values to the baseline, the happier the participants. Therefore, shorter bar graphs indicate better results. Comparing the data before and after the treatment it can be seen that the results were higher for all participants. While the average FIS records of the VR group have increased significantly, there was only a slight increase in the records of the control group, almost remaining constant. Therefore, VR group obtained higher results in generating a high mood after the treatment. Another observation that can be drawn is that the records before the treatment are higher for the VR group. This may be caused by the fact that the VR group participants are informed before the treatment that they will be watching cartoons during the treatment experiencing a new technology, which might cause excitement.

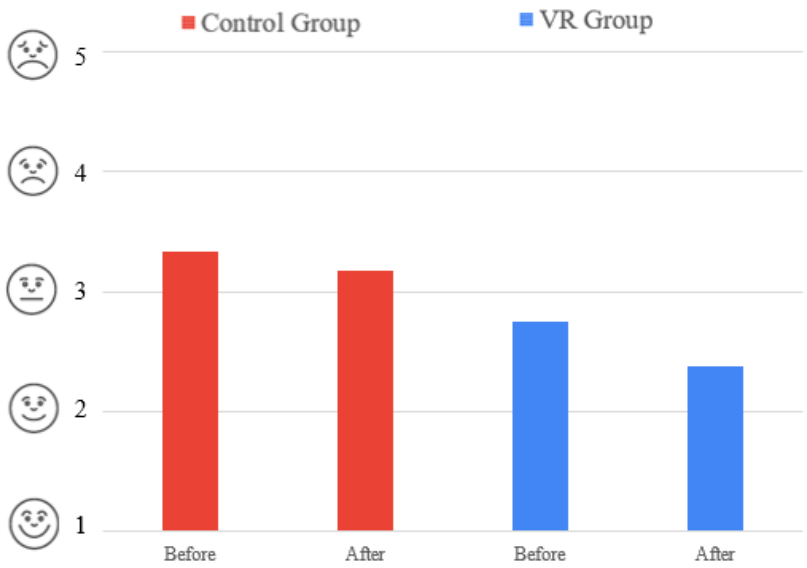

Figure 5.1: Average FIS records of the Control and VR Groups before and after treatment.

5.2 Results on Children's Fear Survey Schedule-Dental Subscale

The participants have answered 15 questions related to fear levels concerning different aspects of dental treatment by choosing a score ranging from 1= Not scared at all to 5= Extremely scared. Figure 5.2 shows that the overall results for both groups were indicating low level of anxiety meaning that the total score is in the range of 15-31. When comparing the data gathered before and after the procedure, it is seen that both groups have experienced a relief after the procedure displaying a decrease in the level of anxiety. However, the decrease is more significant in the case of the VR group.

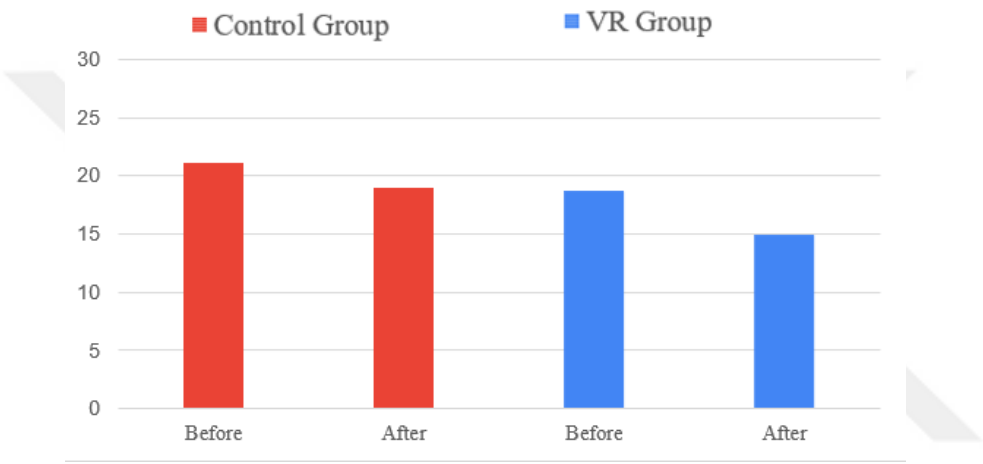

Figure 5.2: Average total scores Using Children's Fear Survey Schedule-Dental Subscale.

Figure 5.3 displays that the children have shown low levels of anxiety for all categories. Among all categories, fear of injection has peaked for both the control and VR groups, but has decreased more significantly in the case of the VR group. Another observation that can be made is related to the fear of dentistry tools. While this value has remained the same for the control group, VR group has shown a significant decrease. This data might indicate that the non-pharmacological techniques such as tell-show of the dentistry tools inside the VR application have shown success in reducing the anxiety levels of the child patients.

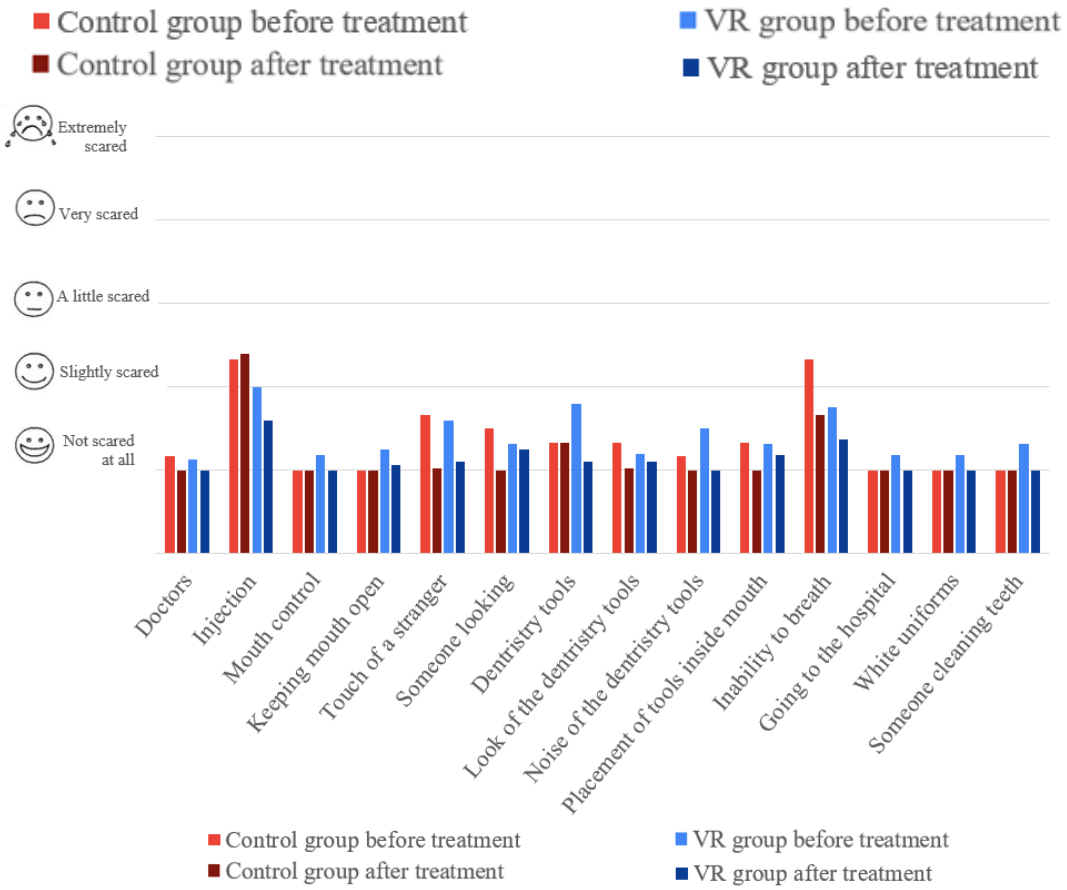

Figure 5.3: Average fear according to categories.

5.3 Results on Pulse Rates

Figure 5.4 shows the average heart rates of both the control and VR groups at different stages of the procedure being: 1) 5 minutes before, 2) right before, 3) during, 4) after and 5) 5 minutes after the treatment of local anesthesia. One might observe that the general trend is the same for both groups- an increase of average heart rates until the injection followed by a decrease. The difference is mostly visible in the data collected 5 minutes after the procedure, where the decrease is more significant in the VR group. This result may indicate that the VR application has successfully soothed the child patients during the dental procedure.

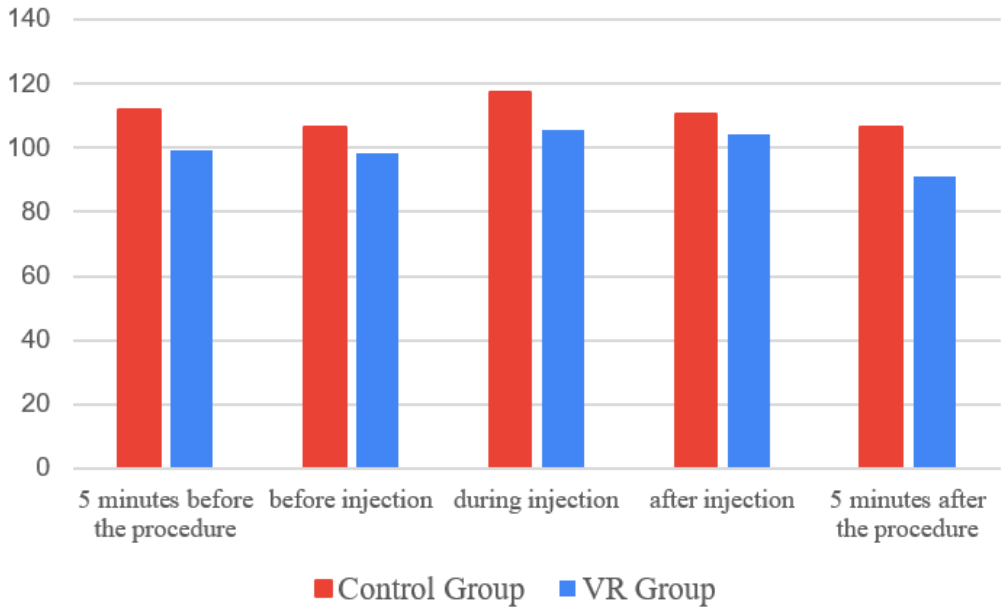

Figure 5.4: Average heart rates of the control and VR groups.

5.4 Results on Frankl's Behavior Rating Scale

As the research is targeting only “positive” and “definitely positive” test subjects rated in terms of the Frankl’s Behavior Rating Scale only, the volunteers having lower values in the scale were not accepted to the treatments (Figure 5.5). However, the participants could become reluctant to accept treatment during the procedures. Such cases were scored as negative in the values recorded after the treatment (Figure 5.6).

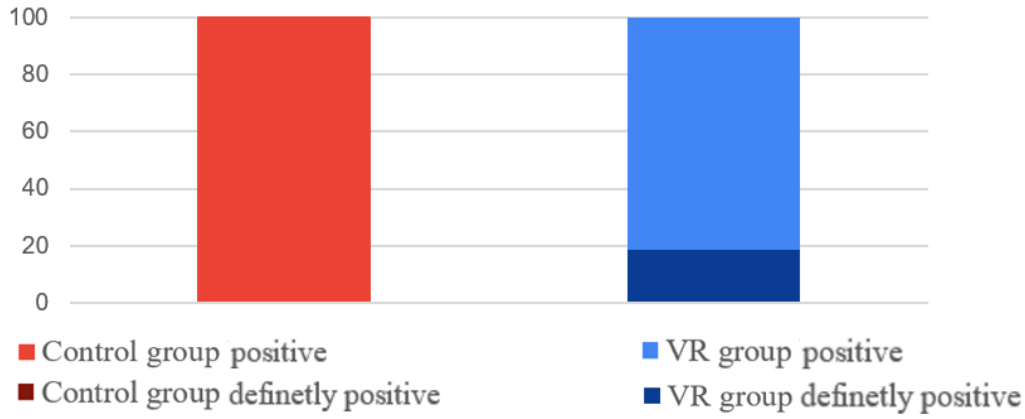

Figure 5.5: Percentage distribution of Frankl's Behavior Rating Scale before treatment.

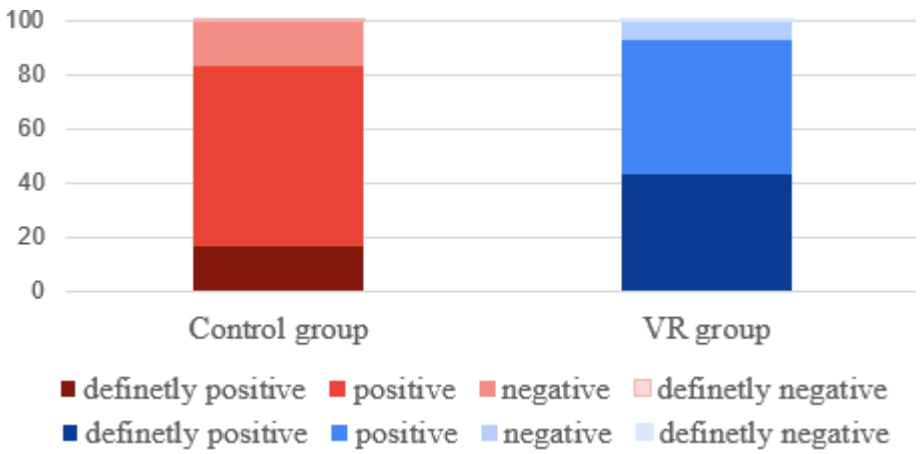

Figure 5.6: Percentage distribution of Frankl's Behavior Rating Scale after treatment.

Comparing Figure 5.5 and 5.6 one might observe that more patients in the control group have become reluctant to accept treatment during the procedure than in the VR group. Additionally more patients in the VR group have turned into “definetly positive” both results indicating the success of the VR application according to Frankl's Behavior Rating Scale.

5.5 Results on the duration of treatment

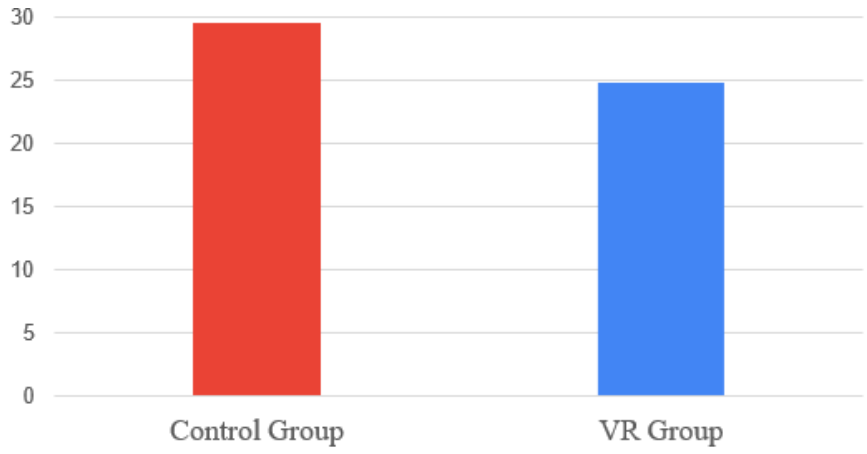

Figure 5.7: Duation of treatment.

The results represented in Figure 5.7 display that use of VR has shortened the duration of treatment by 5 minutes. It has been observed that the difference time interval is caused by the introductory phase of the treatment. In the VR group, it is the VR application (not the dentist) that realizes the explanation of the treatment to be done.

Although the difference is a short time interval, this automated system is also beneficial for the dentists, as with the VR application they do not have to repeat the same explanations at each treatment.

5.6 Results on the questionnaire applied to VR Group

Figures 5.7-5.22 show the results of 16 patients of the VR group, who have answered the questionnaiere prepared for the developed VR application (Appendix A) made of 15 questions. For questions 1-13 (Figures 5.7-5.22) the participants have been given 5 different options ranging from definetly positive responses to absolutely negative responses. For instance, the possible answers for the first question (Figure 5.8) are: very nice, nice, neither nice nor unpleasant, unpleasant, very unpleasant.

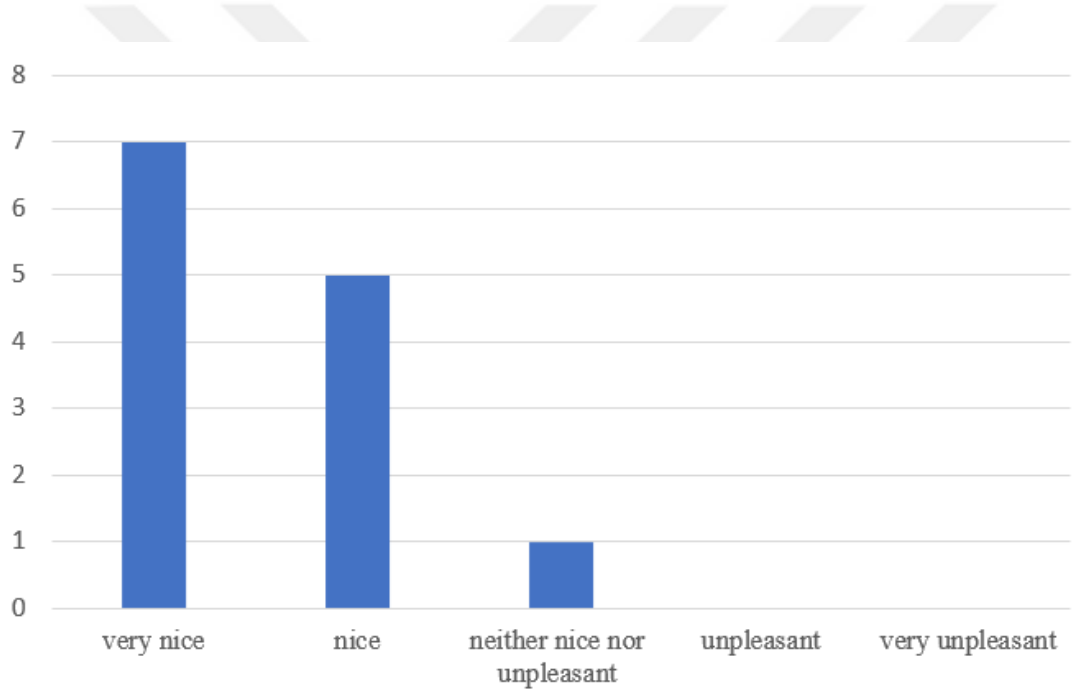

Figure 5.8: Answers for question 1: “How was your visit to the dentist today?”.

The answers of the 16 participants have been all presented as a bar charts. The last two questions (question 14 and 15) of the questionnaire are open ended questions related to the most liked and disliked aspects of the treatment. Participants have claimed to mostly like watching cartoons and disliked the application of the anesthesia.

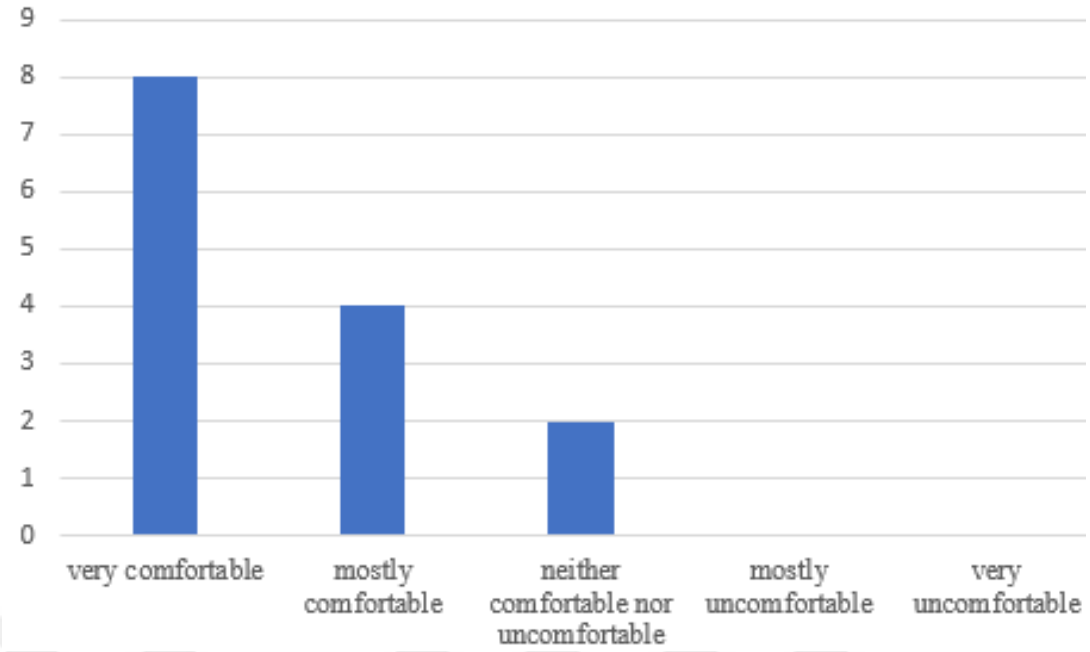

Figure 5.9: Answers for question 2: "How comfortable were you during the procedure?".

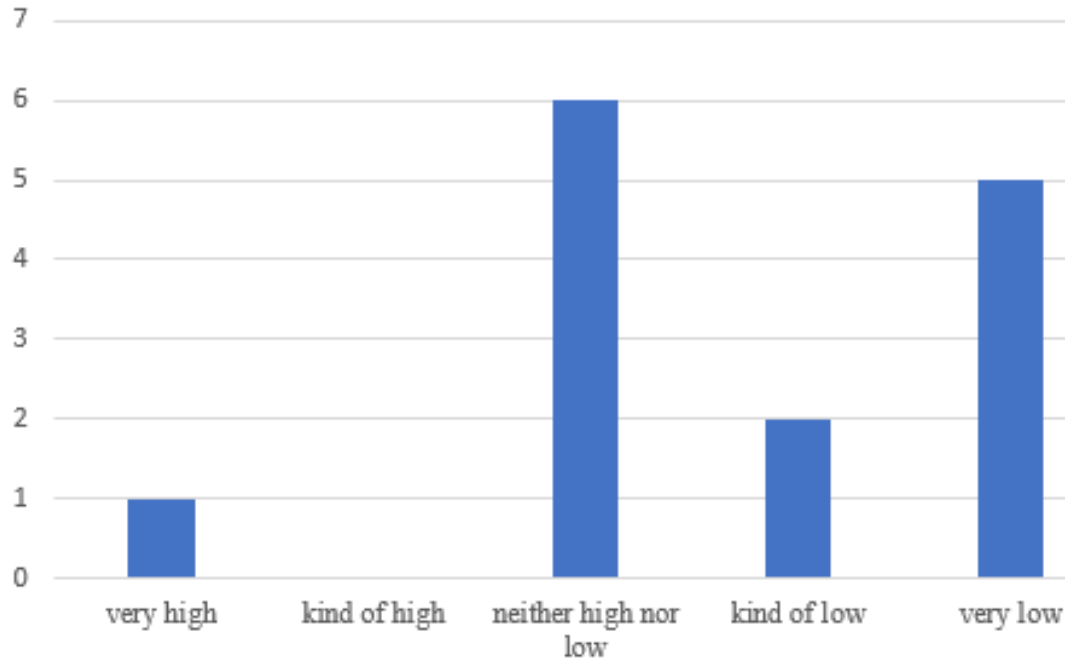

Figure 5.10: Answers for question 3: "How loud were the sounds and noises of the procedure?".

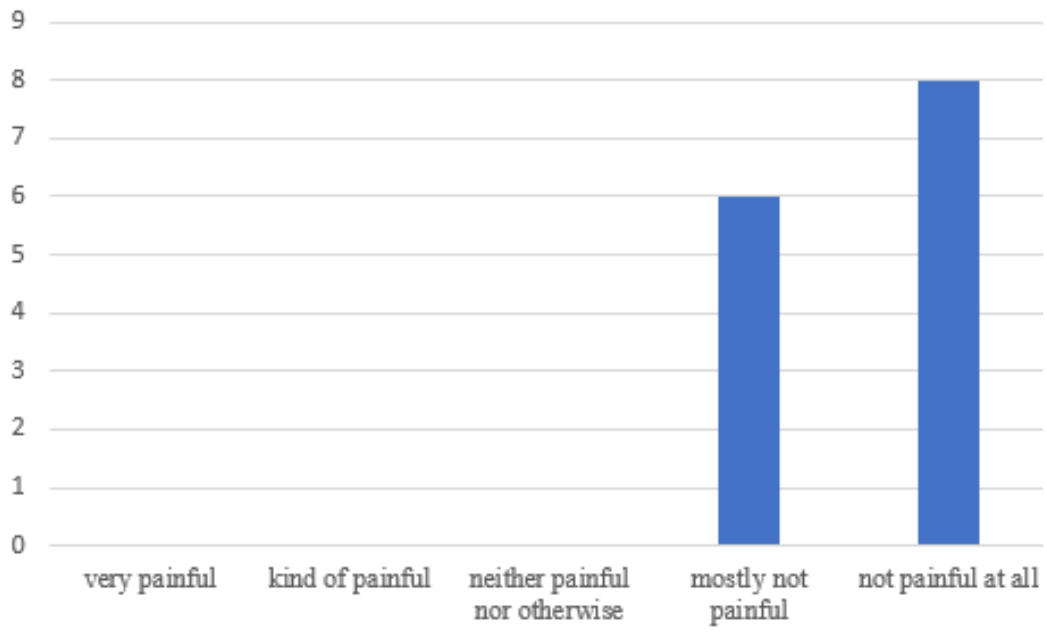

Figure 5.11: Answers for question 4: “How painful was the procedure?”.

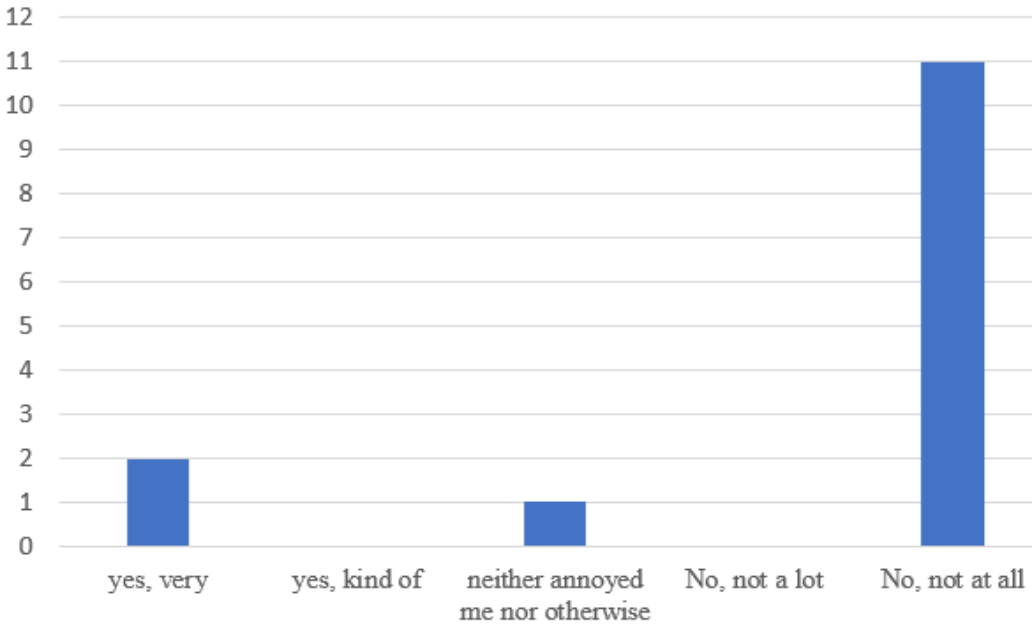

Figure 5.12: Answers for question 5: “Did keeping your mouth open annoyed you?”.

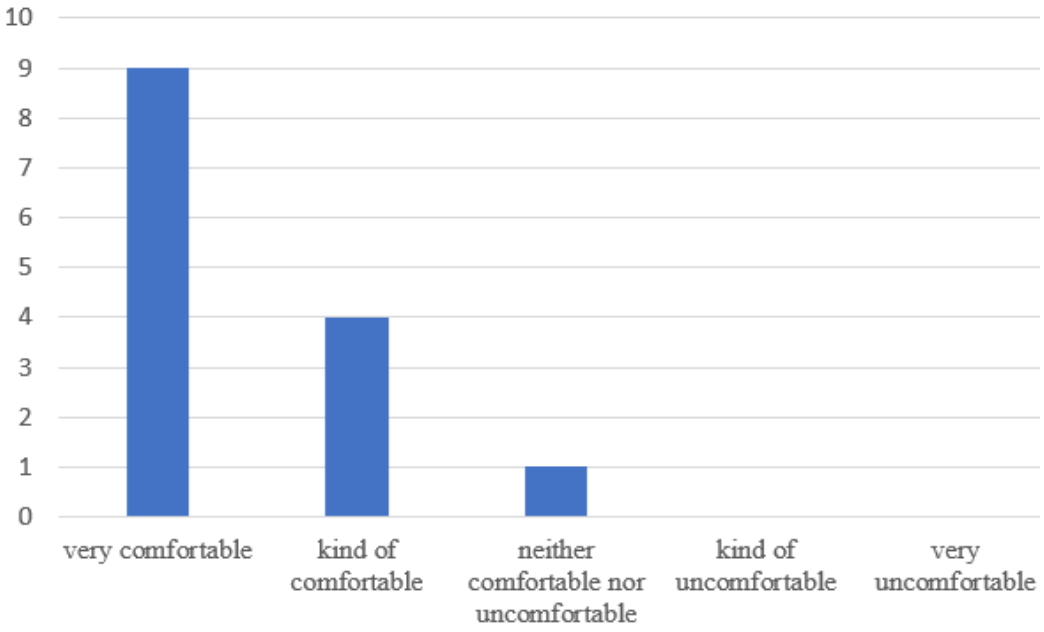

Figure 5.13: Answers for question 6: "How comfortable was your breathing during the procedure?".

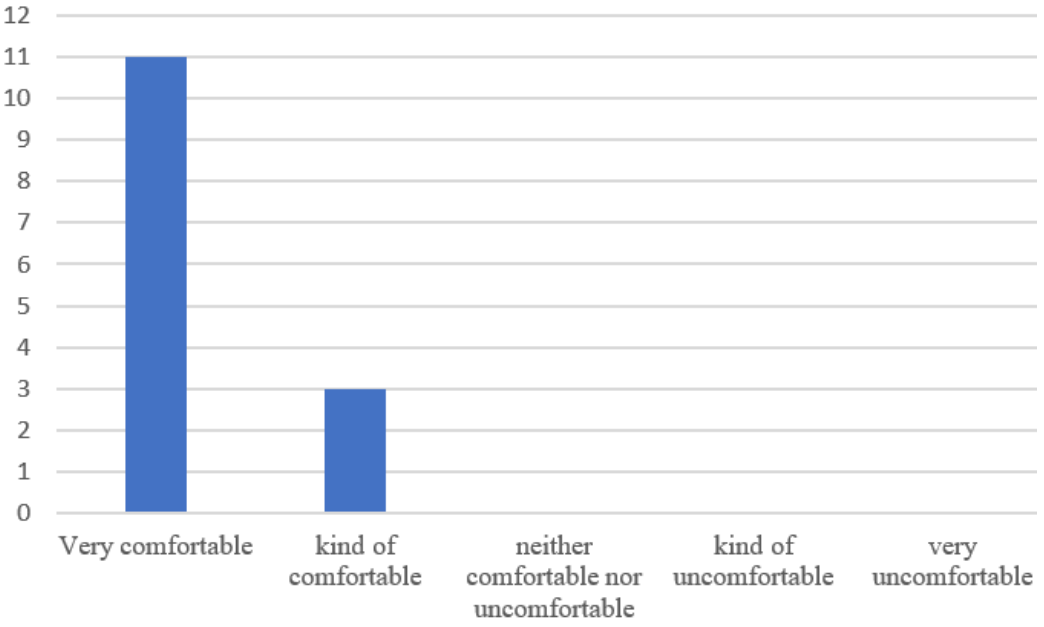

Figure 5.14: Answers for question 7: "How comfortable was the headset you wore during the procedure?".

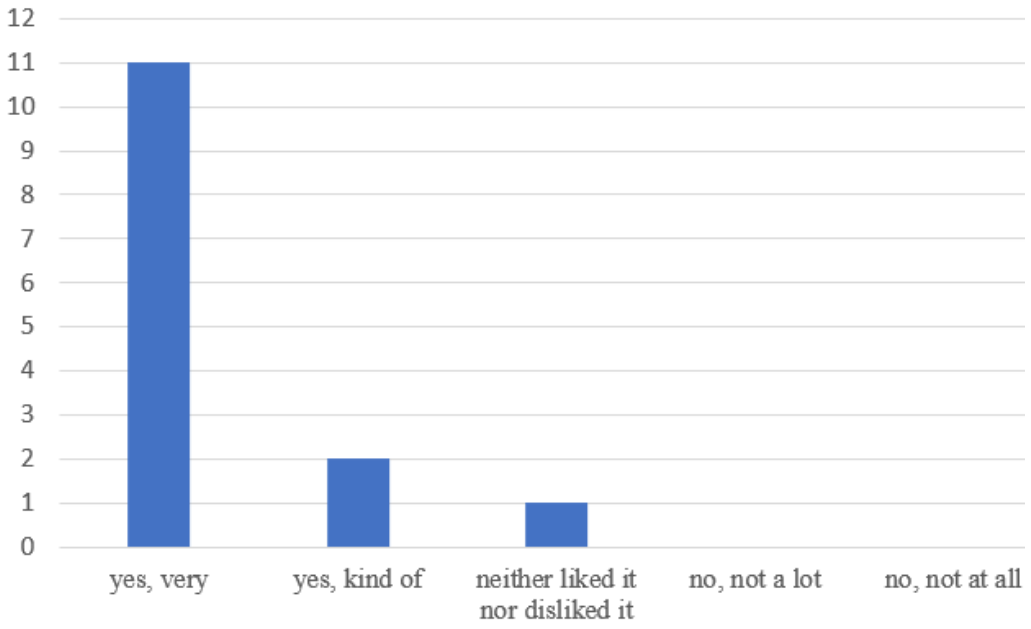

Figure 5.15: Answers for question 8: “Did you like your Avatar friend?”.

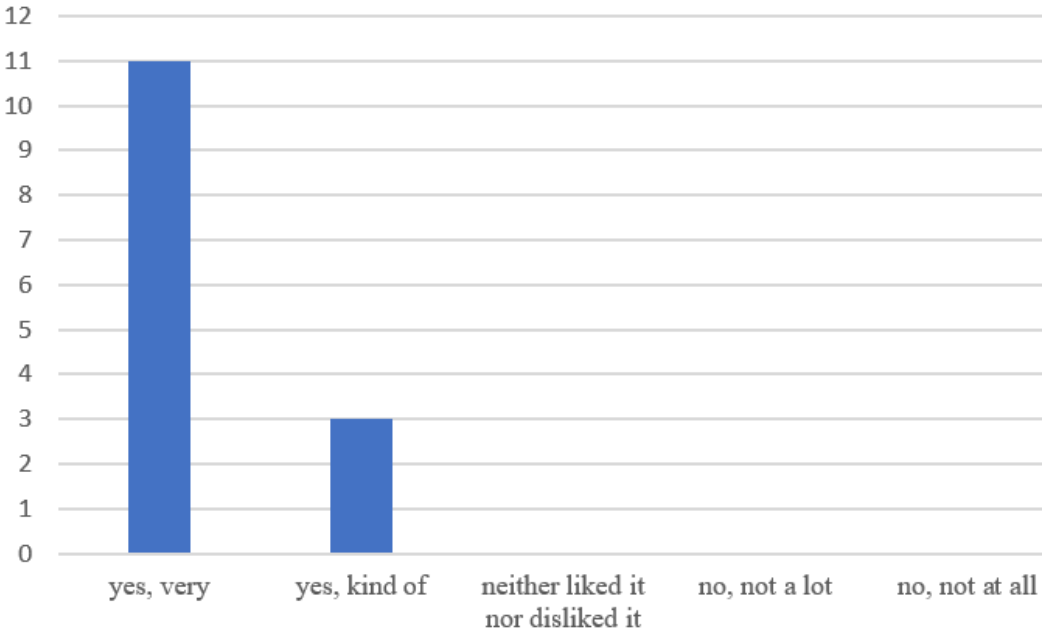

Figure 5.16: Answers for question 9: “Was your avatar friend helpful in explaining everything you need?”.

As observed in the bar charts displayed in Figures 5.7-5.16 the participants have agreed on experinecing a nice and comfortable visit with moderate levels of sounds and noises of the dental tools. They have claimed that the procedure was not painful and they could comfortably breathe during the treatment. Participants have also expressed that the headset was comfortable (Figure 5.14).

These results indicate that the VR headset has not caused a discomfort to the patients and did not interfere with the requirements of the treatment. Moreover in Figures 5.15-5.16, the collected data suggests that the participants have enjoyed the VR application, as they liked the avatar character very much and it was very helpful in explaining the dental procedures.

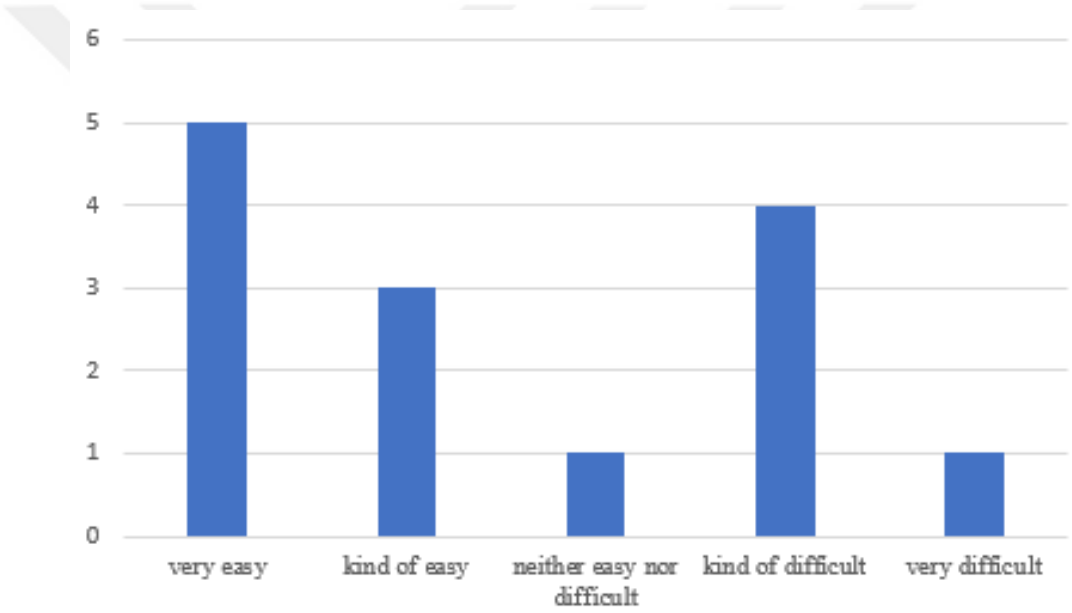

Figure 5.17: Answers for question 10: “Was selecting your avatar friend and movies easy?”.

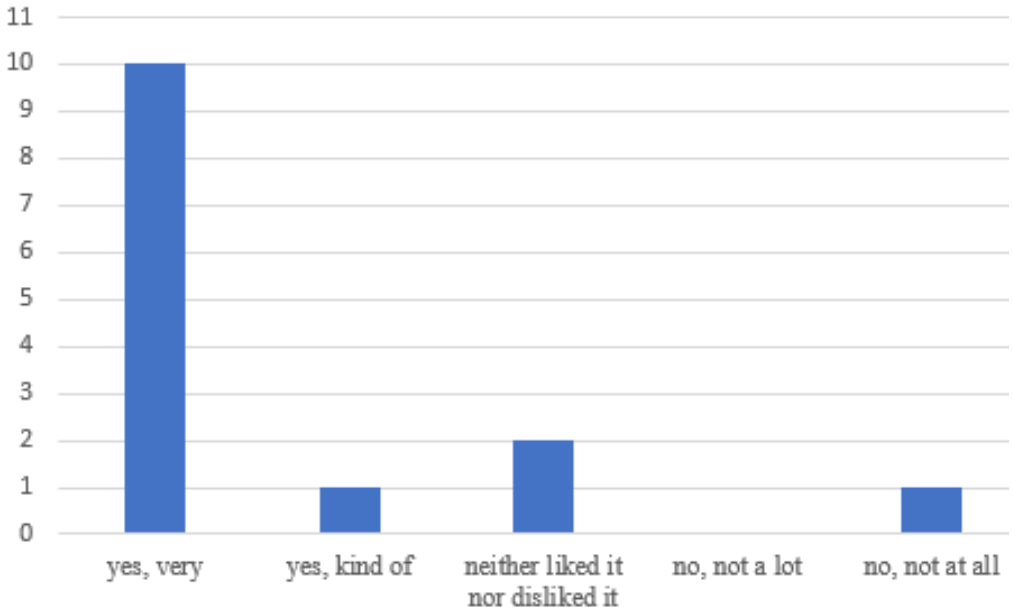

Figure 5.18: Answers for question 11: “Did you enjoy the movie you watched with your avatar friend today?”.

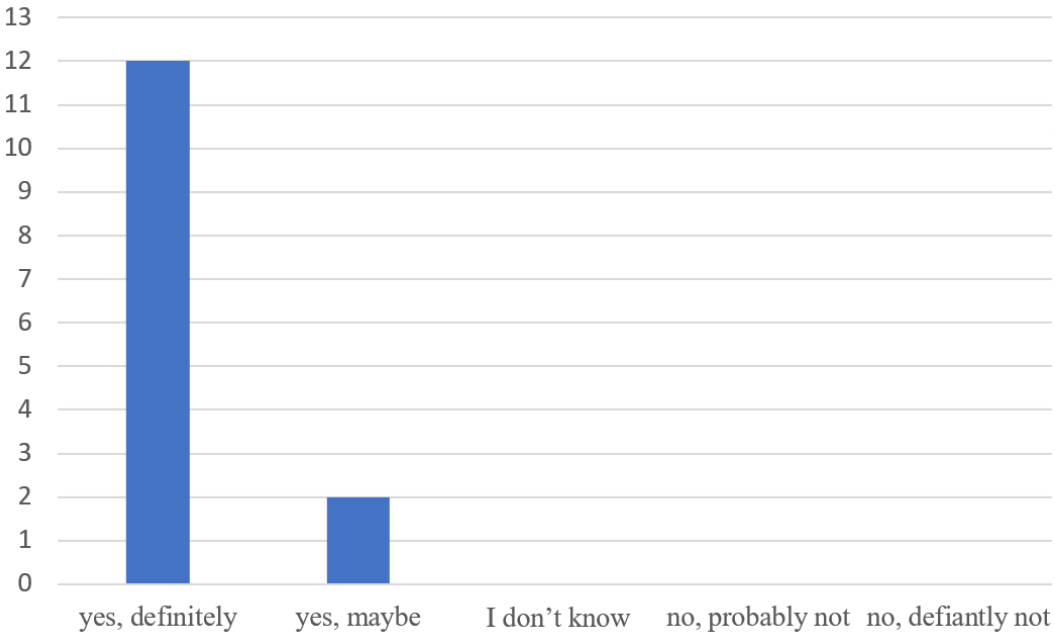

Figure 5.19: Answers for question 12: “Next time you have a tooth pain, would you like to come here again?”.

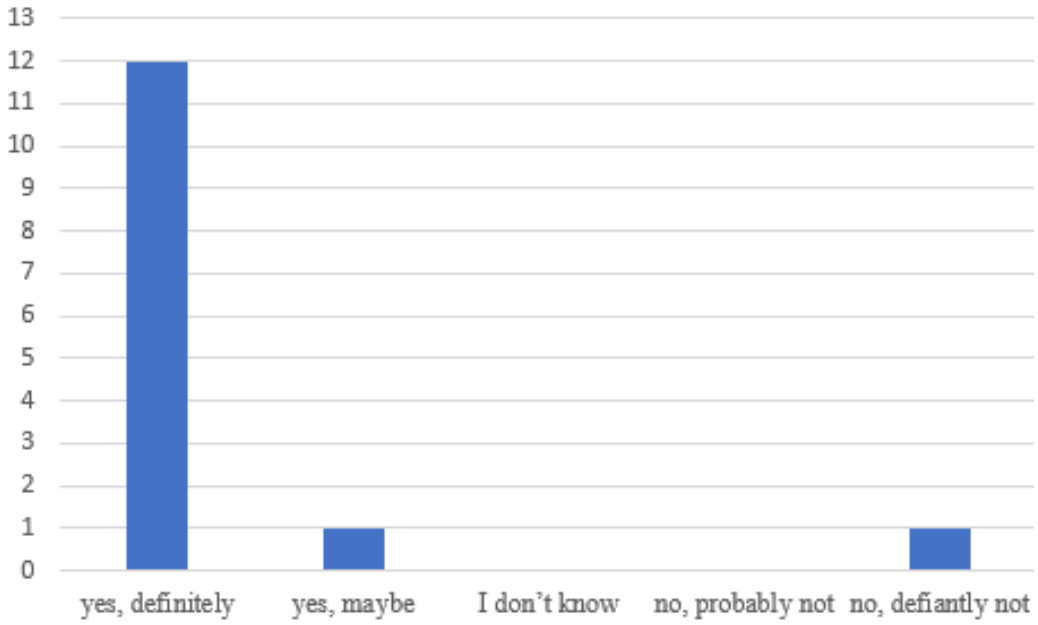

Figure 5.20: Answers for question 13: "If you had to come next time would you want the company of your avatar friend again?".

The only outstriking results have been recorded related to the difficulty of using gaze selection (Figure 5.17). Some participants had difficult time understanding how this feature is enabled. This fact has been observed during the early experiments, and the VR application was updated such that the gaze selection could become easier (Movie tiles and avatar colliders have been scaled up in size). Therefore the experiments after the update were more successful.

Figure 5.18-5.20 show that nearly all participants have enjoyed watching cartoons and they would like to use the VR headset once again at their next appointment. This data validates the positive tendencies of children towards VR technology.

5.7 Results on System Usability Scale

The system usability scale with the questions given in Appendix B was filled in by five professionals, in order to measure the effectiveness and efficiency of the application and the satisfaction of the dentists (Figure 5.21). Participants were asked to score ten items with one of five responses that range from "Strongly Agree"=5 to "Strongly disagree"=0.

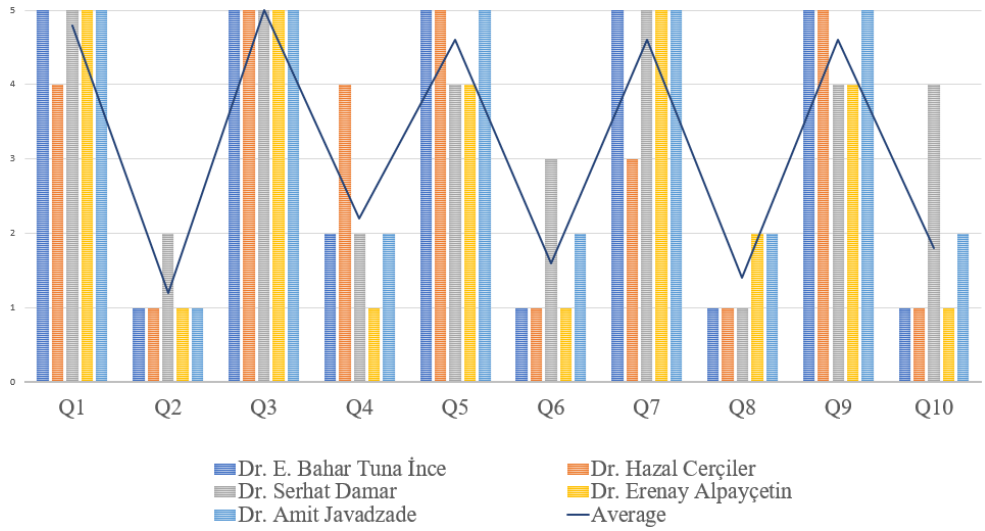

Figure 5.21: System Usability Scale responses.

In Figure 5.22 average scores by categories can be seen, where the possible maximum score is 4 and minimum is 0. To calculate the SUS score, all scores are added and multiplied by 2.5. In this study, the average SUS score has been determined as 76. When System Usability Scale Score Evaluation metric in Figure 5.23 is considered, this value demonstrates that the application is highly desirable by the professionals. The value of 76 is placed at high acceptability category and C Grade Scale. The adjective rating is placed between “good” and “excellent”. Dentists tend to consider the system to be user friendly and easy to use. It is strongly agreed that the functions in the system are well integrated. The results demonstrate that the professionals are slightly concerned that the system might need the support of a technical person or that they might need to learn a lot of things to get going with the system.

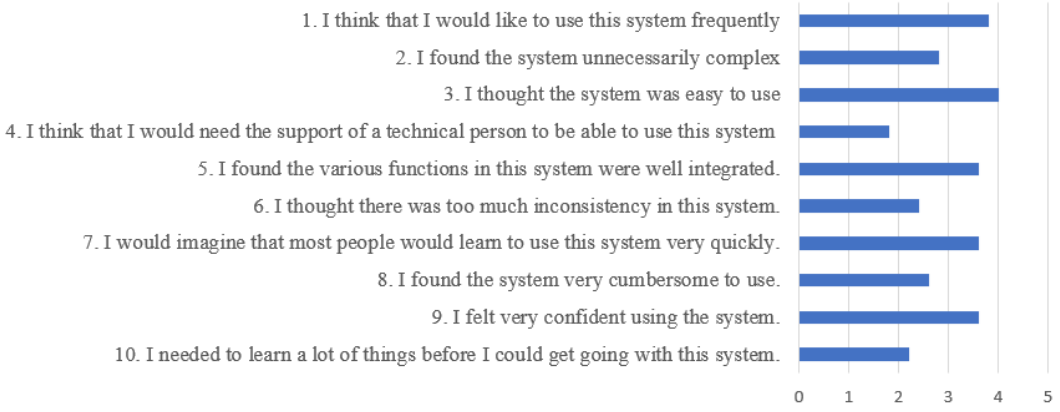

Figure 5.22: System Usability Scale average scores by categories.

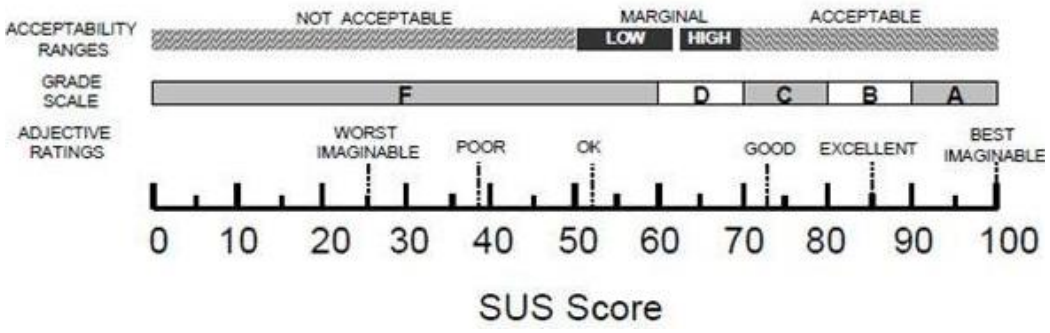

Figure 5.23: System Usability Scale score evaluation.

5.8 Discussion

Within the scope of this thesis, dental treatments are carried out with a VR headset to be attached to the child. Patients in the 0-15 age group frequently apply at the Istanbul University Faculty of Dentistry Department of Pedodontics. Their dental treatment expenses are covered by the Social Security Institution (SGK). Therefore, the testing clinic of this thesis is one of Turkey's busiest dental clinics. Using the system developed in this study, it is predicted that the time and energy loss of the dentist is minimized with the assistance of computer technologies, where repeatable tasks do not cause difficulties and costs, instead of communicating with the long list of patients by providing the same standard explanations repeatedly. As an outcome of the thesis, it is aimed to reduce the need for advanced methods such as sedation, deep sedation and general anesthesia applied in children whose dental anxiety and fear cannot be relieved, requiring equipment and a medical team (anesthesia technician, nurse) accompanied by a fully equipped operating room. Because of the difficulties mentioned above for these procedures, a very limited number of patients can be served at the end of long appointment and waiting periods.

Originally the testing process was planned to be conducted on 90 healthy children (45 girls, 45 boys) devided into three test groups: Group I. Standard treatment on 30 children; Group II. Treatment accompanied with a cartoon playing on a remote screen on 30 children forming the passive distraction group; Group III. The active distraction

group of 30 children wearing the VR headset and interacting with the designed application.

Unfortunately, a series of non-desirable circumstances have occurred. The Istanbul University Faculty of Dentistry, which has been specified as the institution where the testing is carried out, was examined after the earthquake in 2019. It was determined that there were significant structural damages caused by physical conditions and the evacuation of the building was decided on October 1, 2019. Due to the mentioned problem the Pedodontics Department Clinics has been moved to Istanbul University Medico Social Center Building since 21 October 2019.

Following the evacuation decision, the COVID-19 pandemic broke out and the Coronavirus restrictions were applied. Since clinical practice is mandatory for graduation in dentistry, it has been decided to open clinics with limited capacity only within the scope of practical application training of students in their undergraduate education, so it has not been possible to start with the patient groups within the scope of the study. The fact that the current clinical use is mandatory for the dentistry students, has led to the dean's office prioritizing the clinical practice training of undergraduate students and not approving the experiments within the scope of the thesis. Therefore, the testing phase could not be conducted as it was originally planned and was only restricted with the VR group formed of 14 participants and the control group formed of 6 participants.

However, considering the collected data, we believe that this thesis is expected to be successful in using VR computer technologies, which is applied to reduce anxiety and fear in children before and during dental treatment for the first time in the world and in our country. In addition, this technology and method could be announced and applied in other pediatric dentistry clinics all around the globe.

So far, to our knowledge, virtual reality applications in the field of dentistry could not go beyond watching videos and listening to music. However, in this thesis, it is aimed to present dental treatment as an enjoyable activity to children thanks to the virtual characters and other contents on the virtual reality application, thus reducing the anxiety and fear of the child patient. Apart from the characters, which are animated suitably, 3D scenes that appeal to a child's imagination are designed and modelled.

Within the scope of the thesis it is possible to increase the oral health care of the child dental patients due to the decrease of using advanced pharmacological methods in pediatric dentistry and to decrease the cost of health expenses. It is also expected that the VR application, which is developed with this thesis, may turn into a potential product to contribute to our economy in the field of oral and dental health throughout the world and opening it to use in national and international dentistry clinics. The development of an application that is easily downloaded from the mobile application store (Google Play and App Store) to run on the affordable virtual reality glasses is an important step in its widespread usage and its dissemination.

6. CONCLUSION

The main purpose of this thesis is to develop a virtual reality application that, by providing a virtual world, can soothe the discomfort endured by child patients during dental procedures. So far, the realizations can be summed up as follows. The child's mood is improved by turning the ambiance into a place of happiness, carefully designed for this purpose. In a vivid dentist room, the explanatory introduction part takes place while the movies are watched in a fairy world or a futuristic world to separate the user from the actual location and context. Specially created animations have enhanced the virtual environment. The application was designed to function in such a way as not to require outside intervention. From start to finish, the application interacts with the user through gaze selection and head tracking mechanisms. The avatar characters provide information related to the dental treatment in a joyful manner. Gamification elements such as gaining stars and collecting rewards have been used to keep the patient engaged. Motion blur feature ensures the patient to keep head still as sudden movements are dangerous and undesired by the dentist during the treatment.

The most important finding of the thesis is that, the developed system has proved itself to be beneficial for both sides: the child patients and the dentists. The collected data demonstrates the soothing effect of the VR application on children, both physically (improvement in the measurement of vital signs- blood pressure) and psychologically (improvement of the applied psychological/psychometric scales). Additionally, the results on the questionnaire applied to VR Group demonstrates that nearly all children included in the experimental group are willing to use VR at their next dental appointments. This data validates the positive tendencies of children towards VR technology. Similarly, the beneficial aspects of the VR application for the dentists have been demonstrated in the shorter duration of treatment and high system usability scores. Finally, it is observed that this system is helpful to dentists because they do not have to repeat the same explanations at each procedure, instead this becomes an automated feature of the VR application.

For further development of the system, the gaze selection feature can be improved and a short tutorial might be added to the start of the application. Furthermore, instead of the gaze selection technology, the possibilities with eye-based selection can be investigated by the use of eye tracking VR headsets- which are unaffordable in the present but may become accessible in the near future. This way the child patient could realize even more interactable tasks, as he/she could give inputs while holding head still- as required during the dental treatment. The animations can be further polished for additional development. In addition, it is possible to enlarge the scope of the study in such a way that the use of this program will not be restricted to dentists. Starting with other medical areas, new areas of use can be explored. A child who is afraid of vaccines, for example, may use another extended version of the application to overcome fear and get vaccinated easily. After consultation with doctors from different medical fields, this form of use can be expanded. The use of virtual reality in fields such as dentistry is still experimental, but compelling advances can be seen in this field with the help of researchers, experts, scientists and industry leaders.

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APPENDICES

APPENDIX A.1: Questionnaire Applied to VR Group English

Child survey form

Name----------

Age----------

Treatment type ----------

Procedure duration ----------

1) **How was your visit to the dentist today?**
   ☐Very nice ☐ nice ☐neither nice nor unpleasant ☐unpleasant ☐ very unpleasant
2) **How comfortable were you during the procedure?**
   ☐Very comfortable ☐mostly comfortable ☐neither comfortable nor uncomfortable ☐mostly uncomfortable ☐ very uncomfortable
3) **How loud were the sounds and noises of the procedure?**
   ☐Very high ☐kind of high ☐neither high nor low ☐kind of low ☐ very low
4) **How painful was the procedure?**
   ☐Very painful ☐kind of painful ☐neither painful nor otherwise ☐mostly not painful ☐ not painful at all
5) **Did keeping your mouth open annoyed you?**
   ☐Yes, very ☐yes, kind of ☐neither annoyed me nor otherwise ☐No, not a lot ☐ No, not at all
6) **How comfortable was your breathing during the procedure?**
   ☐Very comfortable ☐kind of comfortable ☐neither comfortable nor uncomfortable ☐kind of uncomfortable ☐ very uncomfortable
7) **How comfortable was the headset you wore during the procedure?**
   ☐Very comfortable ☐kind of comfortable ☐neither comfortable nor uncomfortable ☐kind of uncomfortable ☐ very uncomfortable
8) **Did you like your Avatar friend?**
   ☐Yes, very ☐yes, kind of ☐neither liked it nor disliked it ☐No, not a lot ☐ No, not at all
9) **Was your avatar friend helpful in explaining everything you need?**
   ☐Yes, very ☐ yes, kind of ☐ neither liked it nor disliked it ☐ No, not a lot ☐ No, not at all
10) **Was selecting your avatar friend and movies easy?**
   ☐ very easy ☐ kind of easy ☐ neither easy nor difficult ☐ kind of difficult ☐ Very difficult

11) Did you enjoy the movie you watched with your avatar friend today?

☐Yes, very ☐yes, kind of ☐neither liked it nor disliked it ☐No, not a lot ☐ No, not at all

12) Next time you have a tooth pain, would you like to come here again?

☐Yes, defiantly ☐yes, maybe ☐I don't know ☐No, probably not ☐ No, defiantly not

13) If you had to come next time would you want the company of your avatar friend again?

☐Yes, defiantly ☐ yes, maybe ☐ I don't know ☐ No, probably not ☐ No, defiantly not

14) Write in the box below what was the thing you disliked most in your visit today?

15) Write in the box below what was the thing you liked most in your visit today?

APPENDIX A.2: Questionnaire Applied to VR Group Turkish

** Çocuk anket formu **

İsim----------

Yaş----------

İşlem ----------

Tedavi süresi ----------

1) Bugün dişçi ziyaretiniz nasıldı?

☐ Çok güzel ☐ güzel ☐ ne güzel ne de tatsız ☐ tatsız ☐ çok tatsız

2) İşlem sırasında ne kadar rahattın?

☐ Çok rahat ☐ çoğunlukla rahat ☐ ne rahat ne de rahatsız ☐ çoğunlukla rahatsız ☐ çok rahatsız

3) Prosedür ne kadar gürültülüydü?

☐ Çok yüksek ses ☐ oldukça yüksek ses ☐ ne yüksek ne de düşük ses ☐ oldukça düşük ses

☐ çok düşük ses

4) Ne kadar ağrılı bir işlem oldu?

☐ Çok ağrılı ☐ ağrılı ☐ ne ağrılı ne değil ☐ az ağrılı ☐ hiç ağrılı değil

5) Ağzınızı açık tutmak sizi rahatsız etti mi?

☐ Evet, çok ☐ evet,oldukça ☐ ne evet ne hayır ☐ Hayır, çok rahatsız olmadım ☐ hayır, hiç rahatsız olmadım.

6) İşlem sırasında nefes alışınız ne kadar rahattı?

☐ Çok rahat ☐ rahat ☐ ne rahat ne de rahatsız ☐ rahatsız ☐ çok rahatsız

7) İşlem sırasında taktığınız kulaklık ne kadar rahattı?

☐ Çok rahat ☐ rahat ☐ ne rahat ne de rahatsız ☐ rahatsız ☐ çok rahatsız

8) Animasyon karakteri arkadaşınız hoşunuza gitti mi?

☐ Evet, çok sevdim ☐ evet ☐ ne evet ne hayır ☐ hayır, çok sevmedim ☐ hayır, hiç sevmedim.

9) Animasyon karakteri arkadaşınız ihtiyacınız olan her şeyi açıklamada yardımcı oldu mu?

☐ Evet, çok açıklayıcıydı ☐ evet ☐ ne evet ne hayır ☐ hayır, çok açıklayıcı değildi ☐ hayır, hiç açıklayıcı değildi.

10) Animasyon karakteri arkadaşınızı ve filmleri seçmek kolay mıydı?

☐ Çok kolaydı ☐ kolaydı ☐ ne kolay ne de zordu ☐ zordu ☐ çok zordu

11) Bugün animasyon karakteri arkadaşınızla izlediğiniz filmi beğendiniz mi?

☐ Evet, çok beğendim ☐ evet ☐ ne evet ne hayır ☐ hayır, çok beğenmedim ☐ hayır, hiç beğenmedim.

12) Bir dahaki sefere diş ağrın olursa, buraya tekrar gelmek ister misin?

☐ Evet, kesinlikle ☐ evet, belki ☐ bilmiyorum ☐ muhtemelen hayır ☐ hayır, asla

13) Bir daha gelmek zorunda kalsan, işlem sırasında animasyon karakteri arkadaşının tekrar seninle olmasını ister miydin?

☐ Evet, kesinlikle ☐ evet, belki ☐ bilmiyorum ☐ muhtemelen hayır ☐ hayır, asla

14) Bugünkü tedavide en sevmediğiniz şeyin ne olduğunu aşağıdaki kutuya yazın.

15) Bugünkü tedavide en çok beğendiğiniz şeyi aşağıdaki kutuya yazın.

APPENDIX B: System Usability Scale

Please enter your participant number: _____

System Usability Scale (SUS)

This is a standard questionnaire that measures the overall usability of a system. Please select the answer that best expresses how you feel about each statement.

	Strongly Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Strongly Agree
1. I think I would like to use this tool frequently.	☐	☐	☐	☐	☐
2. I found the tool unnecessarily complex.	☐	☐	☐	☐	☐
3. I thought the tool was easy to use.	☐	☐	☐	☐	☐
4. I think that I would need the support of a technical person to be able to use this system.	☐	☐	☐	☐	☐
5. I found the various functions in this tool were well integrated.	☐	☐	☐	☐	☐
6. I thought there was too much inconsistency in this tool.	☐	☐	☐	☐	☐
7. I would imagine that most people would learn to use this tool very quickly.	☐	☐	☐	☐	☐
8. I found the tool very cumbersome to use.	☐	☐	☐	☐	☐
9. I felt very confident using the tool.	☐	☐	☐	☐	☐
10. I needed to learn a lot of things before I could get going with this tool.	☐	☐	☐	☐	☐

How likely are you to recommend this website to others? (please circle your answer)

Not at all likely 0 1 2 3 4 5 6 7 8 9 10 Extremely likely

APPENDIX C: Dialog of the Avatars in the VR Application

VR Grubu için Çocuk Hasta ve Karakter Diyalog Akışı

1_Merhaba ben Ceren ve bu da arkadaşım Can. Bugün sana diş tedavinde yardımcı olacağım. Seninle çizgi filmler seyredip çok eğleneceğiz., sen de yıldızları toplayacaksın, 10 yıldıza ulaştığında Cesur Çocuk Belgesi'ni kazanacaksın ve sonunda bembeyaz parlayan bir dişin olacak.

2_Merhaba arkadaşım ben Can, Ceren'in de dediği gibi bugün ikimizden biri sana yardımcı olacak. Haydi başlayalım!

3_Şimdi bana bakmanı istiyorum ve bana 3 saniye boyunca baktığın zaman yuvarlak gösterge ile beni seçeceksin. Kafanı bana doğru çevir.

4_Aferin beni seçmeyi başardın, şimdi aynı şekilde Can'ı seç

5_Tebrik ederim, beni de seçmeyi başardın. Artık yanında kimi istiyorsan onu seçebilirsin.

Can veya Ceren:

6_Yaşasın beni seçtin. Şimdi dişlerini kontrol edeceğiz bakalım ağzında mikrop var mıymış?

7_Ağız açacağı: Seninle bir yandan çizgi film seyrederken doktorun dişlerini temizleyecek. Çizgi film izlerken ağzının açık kalıp yorulmanı istemem. Şimdi ağzını kocaman aç ve şu gördüğün yeşil silgiyi ısır. Doktoruna izin ver, doğru şekilde yerleştirsin. Böylece artık ağzını açık tutmak zorunda kalmayacaksın. İşte bir yıldız kazandın bile. Çok kolay.

8_Tükrük emici: Bu hortumu görüyor musun? Bu hortum ile dişine dolgu yapılırken oluşan sular ve ağzındaki tükrük toplanacak. Tıpki bir fil hortumu gibi suları emecek.

9_Topikal anestezi: Dişlerinde gördüğüm siyah mikropları rahat temizletmen için önce onlara sihir yapıp uyutmamız gerek. Uyumazlarsa onları fırçalarken sana rahatsızlık verebilirler ve seni rahatsız etmelerine izin vermeyeceğim. Öncelikle alışman için oraya muz ve nane aromalı bir parfüm sıkıp biraz bekliyoruz (literatürde 90 sn). Parfüm sıkılan yeri biraz değişik hissedeceksin, bu normal. Diline bulaşan tatları hiç merak etme, Bay Fil gelip onları içecek ve en sonunda ağzında hiç nane tadı kalmayacak. Şimdi 2. yıldızını kazandın ve bekliyoruz. Mikropların uykusu gelmeye başladı bile.

10_Lokal anestezi: Parfümden sonra şimdi de mikropları uyutan sihirli suyu damlatacağız. Bu suyun tadı epey naneli, lütfen şaşırma. Nane tadını azaltmak için kıpırdamadan heykel gibi durmak ve burnumuzdan nefes alıp 10'a kadar saymak çok işe yarıyor. Haydi kıpırdamadan duralım ve yavaşça saymaya başlıyorum. Biraz dayan lütfen. 10-9-8-7-6-5-4-3-2-1… En zoru buydu, tüm mikropları uyuttuk, artık rahatız. Üstelik şimdi 2 yıldız birden kazandın! Haydi çizgi filmini seç, izlemeye başlayalım.

11_Dolguya başlama- Kavite açılması: Biz çizgi film izlerken doktorun dişlerini sulu fırça ile temizleyecek, Bay Fil de burda, çok susamış, suları ona verelim. Sonunda 5. yıldızını kazanacaksın (yaklaşık 2 dakika).

12_Dolgu konulması: Yaramaz mikroplar dişinde bir yuva açmışlar, orayı diş hamuru ile kapatmamız gerek, yemek yerken dişine kaçmasın diye. Bunun için dişinin yanına yastıklar yerleştiriyoruz. Doktorun dişine küçük küçük hamurlar yapıştıracak. Bitince 6. yıldızını kazanacaksın.

13_Dolgu konulması-Matriks aşaması: Diş hamuruna güzel bir şekil vermek için bir kalıp kullanacağız. Sana en güzel dişi yapacağız. Şimdi doktoruna izin ver, kalıbı sıkı bir şekilde aynı bir yüzüğü parmağa takar gibi yerleştirecek. Sonunda 1 yıldız daha kazanacaksın.

14_Restorasyon: Şimdi ışıklı bir diş yapıyoruz. Kalıba ışıklı hamurları koyarken kıpırdamadan beklemek dışında yapacağımız bir şey yok. 1 yıldız daha.

15_Matriks sökümü: Artık dişin bitti. Kalıbı çıkarıyoruz, rahatlayabilirsin.

16_Cila: Aslında dişin bitti ama üzerine biraz daha parlatalım, annen baban görünce şaşıracak. Biraz su ile fırçalayacağız. Sonunda 9. yıldızını alacaksın.

17_Oklüzyon kontrolü: Silgiyi de çıkarıyoruz. Şimdi dişini biraz boyayalım, renkli kağıdı ısır, dişlerini gıcırdat. Şimdi ağzını aç ve fazla hamurları temizleyelim, son yıldızı toplamamıza az kaldı. Bunu bir kere daha tekrar ediyoruz. Kağıdı ısır, dişlerini gıcırdat ve ağzını aç. Yıkıyoruz… Bu kadar… 10. yıldızını aldın. Artık cesur bir çocuk oldun. Doktorun şimdi sana sertifikanı verecek.

18_ Artık cesur bir çocuksun, bu yüzden buradan gidebiliriz. Arkamdaki kürelerden gitmek istediğin yeri seç

19_ Son olarak arkamdaki filmlerden istediğini seçebilirsin. İyi seyirler!

20_ Dikkat et. Eğer başını sallarsan ekran flulaşacak. Bu yüzden başını sabit tutman lazım

21_ Oh hayır, görüntü yok oluyor. Lütfen başını sabit tut!

CURRICULUM VITAE

Name Surname **:** Fatma Betül Güreş

EDUCATION

- **B.Sc.** **:** 2018, Bilkent University, Faculty of Art, Design and Architecture, Department of Architecture

PROFESSIONAL EXPERIENCE AND REWARDS:

- 2020 “Kod Ödülleri” Game Competition Finalist
- 2020 “Oyna Öğren” Game Competition Winner

PUBLICATIONS, PRESENTATIONS AND PATENTS ON THE THESIS:

- **B. Gures, G. Ince**: Virtual Reality Application for Relieving the Pain of Child Dental Patients, Proceedings of the PUDCAD Universal Design Education Practice Conference (PUDCAD 2020), to appear

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