ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE
ENGINEERING AND TECHNOLOGY

REDUCTION OF DENTAL ANXIETY AND STRESS IN CHILDREN USING A SOCIAL ROBOTIC COMPANION

M.Sc. THESIS

Mine YASEMİN

Department of Computer Engineering

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SOSYAL BİR ROBOT ARKADAŞ YARDIMIYLA ÇOCUKLARDA DENTAL KAYGI VE STRESİN AZALTILMASI

YÜKSEK LİSANS TEZİ

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Mine YASEMİN, a M.Sc. student of ITU Graduate School of Science Engineering and Technology 504131562 successfully defended the thesis entitled “REDUCTION OF DENTAL ANXIETY AND STRESS IN CHILDREN USING A SOCIAL ROBOTIC COMPANION”, which he/she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my family,

FOREWORD

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June 2016 Mine YASEMİN
(Computer Engineer)

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ABBREVIATIONS

CSE : Contents Script Editor
DOF : Degree of Freedom
FBRS : Frankl's Behaviour Rating Scale
FIS : Facial Image Scale
RAPIx : Robot Application Program Interface eXtended
RCP : Robot Contents Player
ROCOS : Robot Contents Organizing Software
RSC : Robot Script
SAC : Service Authoring Component
VoIP : Voice Over Internet Protocol
WoZ : Wizard of Oz
XML : Extensible Markup Language

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REDUCTION OF DENTAL ANXIETY AND STRESS IN CHILDREN USING A SOCIAL ROBOTIC COMPANION

SUMMARY

Young children have different ways of thinking from adults and less experience of the world. From their perspective, what seems ordinary to an adult can be very frightening to a child, for example, going to the dentist is a fear that many children share due to the pain and discomfort during the visit.

Dental anxiety is prevalent among children, especially in anticipation of treatment and cause problems during their dental procedure. So this causes a decrease in the success of dental treatment and risk of complications such as sedation and general anesthesia, and requires high cost and so much time. Dentists perform a variety of behavior guidance approaches in most situations depending on the child's developmental level and reaction to treatment. If the basic behavior management techniques such as tell-show-do, positive motivation, distraction are not effective, approaches like sedation and general anesthesia, which come at high costs and risk of complications, are applied.

Instead of the pediatric dentists communicating with each patient by asking standard questions before treatment, the usage of computer technologies (animation or robot), will take over these repetitive tasks. As a result, the dentist's chair time and energy loss is minimized and it is targeted to develop positive behavior and increase treatment success. The aim of this study is to provide an entertaining, and relaxing environment to the children patients with the help of robots in order to develop positive behaviors in children resulting to an increase in the success of dental treatment and to the circumvention of the high cost and risk of complications like sedation and general anesthesia.

There are only a few studies reporting the usage of robots to help in reducing the fear and anxiety during vaccination in children, but there is no any study about robots and their usage in reduction of dental anxiety and pain in dentistry in the literature. Therefore, our work is the first study in our country and in the world, which investigates the effect of child-robot interaction in reducing pain and stress during dental treatment.

To setup a more comprehensive and robust system that can make a child busy during medical procedures, we proposed a novel technique based on the use of a humanoid robot companion to improve the child's experience in the clinical environment by minimizing pain and anxiety during a dental procedure. Therefore, we aim to design and develop a long-term human-robot interaction with children. To ensure the robot appears to be performing flawlessly, we have used Wizard of Oz (WoZ) method, widely used in robot assisted studies to conduct our experiments. Our platform enables Wizard of Oz experiments to substitute the missing parts of the robot, for example, natural language interface in Turkish. All sessions were videotaped with cameras fixed at two different locations.

All of the children have been treated at a clinic in the Department of Pediatric Dentistry, in Istanbul University. These participants were randomly assigned to two groups, a standard control group which is subjected to the dentist's own skills alone and a robot group whose treatment is conducted with a dentist and assistance of the robot. All children are exposed to the same dental treatment in the same clinic environment. Treatment of first group is performed in the routine clinical procedure. In the second group, or robot group, the robot chats with the child, instructs the child before and during the treatment, distracts and encourages her/him, and plays animations favoured by the children. In this context, the robot appears acting naturally even in the lack of autonomy.

A set of questionnaires measuring levels of pain and anxiety are applied in both pre and post session to each participant and their parents in order to measure the effects of robot assistance and basic intervention methods. Children's anxiety level was recorded before, during and after treatment in terms of physiological pulse rate (bpm) by using a finger type pulse measuring device (Pulse Oximeter).

Based on the experimental results, a robot can socially and emotionally aid child patients in dental procedure to cope with stress and dental anxiety better than other conventional intervention methods. We present some very early quantitative observations of treatments conducted by dentist alone and with assistance of a robot. We will continue participant recruitment and present much quantitative measures relating to patient anxiety and pain. Our next plan is to explore the effects of another robot Nao to see whether there will be any differences.

SOSYAL BİR ROBOT ARKADAŞ YARDIMIYLA ÇOCUKLARDA DENTAL KAYGI VE STRESİN AZALTILMASI

ÖZET

Diş hekimliğinde hastalarda diş tedavileri ile ilişkili anksiyete durumuyla sıklıkla karşılaşılmakta, bu durum özellikle çocukları etkileyerek diş tedavilerinde problem yaratmaktadır. Her hekim ağız/diş bölgesinde tedavi gereksinimi bulunan ancak tedaviye uyum göstermeyen çocuk hasta ile karşılaşmaktadır. Çocuk hastaların tedavisi sırasında birçok durumda çocuğun gelişim derecesine ve tedaviye yanıtına göre diş hekimleri çeşitli davranış yönetimi yaklaşımlarını uygulamaktadırlar. Anlat-göster-yap, pozitif motivasyon, dikkat dağıtma gibi temel davranış yönetim tekniklerinin başarılı olamadığı çocuklarda sedasyon ve genel anestezi gibi maliyetli ve komplikasyon riski yüksek girişimlere başvurulmaktadır.

Sağlık çalışanları çocukları cesaretlendirmek, kaygıya odaklanmış zihinlerini başka bir yöne çekmek ve uygulanacak tıbbi prosedürü eğlenceli bir hale getirmek için renkli ve desenli giysiler giyerek, palyaço doktorlar kullanarak bazı yaklaşımlarda bulunmaktadırlar. Müzik dinletilmesi ya da çizgi film seyredilmesi ile de çocuklardaki ağrı ve endişenin azaldığına dair çalışma sonuçları bulunmaktadır. Bu durumda hoş olmayan algıların azaltılarak, negatif davranışların veya tedaviden kaçma davranışının önlenmesine çalışılmaktadır. Bu şekilde sedasyon, genel anestezi gibi ileri davranış tekniklerine gerek kalmadan tedavilerin tamamlanması hedeflenmektedir. Bu dikkat dağıtıcı sistemlerin işe yaradığı bilinmesine rağmen, ne kadar etkin oldukları ile ilgili kapsamlı bir çalışma bulunmamaktadır. Bu sistemler, her zaman çocuğun dikkatini ağrıdan uzaklaştırmada yeterince etkin olmayabilmektedir. Bu bilgiler ışığında, çocuğu tıbbi işlem sırasında meşgul edebilecek daha güçlü ve daha kapsamlı bir sisteme ihtiyaç duyulduğu görülmüştür. Günümüzde çoklu algı (multisensory) stratejilerinin görsel, işitsel, ve dokunsal uyaranların kombine edilmesi ile ağrı üzerinde tek bir uyaran (single-sensory) ile olduğundan daha büyük bir etki sağlayacağı düşünülmüştür. Bu çalışmadaki amacımız çoklu algı stratejilerini uygulayabilecek insansı robotlarla diş tedavileri sırasında çocuğun dikkatini ağrılı uyarandan eğlenceli bir başka yöne doğru çevirmek ve tedaviyi kabul etmesini sağlamak, bu şekilde tedavi seansının daha sorunsuz ve rahat sürmesini sağlayarak hekime konforlu bir tedavi ortamı sağlamaktır.

Güncel literatür incelendiğinde aşı sırasında çocuklarda oluşan korku ve anksiyetenin azaltılması ve davranışların yönlendirilmesi amacı ile robotların kullanılmış olduğu bazı çalışmalar bildirilmiş olsa da dünyada diş hekimliğinde dental anksiyete ve ağrının azaltılması konulu robot kullanımı konusunda henüz herhangi bir çalışma yapılmamıştır. Bu sebeple bu çalışma dünyada ve ülkemizde diş hekimliği tedavisinde çocuklarda ağrı ve stresin azaltılması amacı ile çocuk-robot etkileşiminin kullanılacağı ilk çalışma olma özelliğini taşımaktadır.

Bu çalışmada diş tedavileri sırasında tekno-psikolojik dikkat dağıtma tekniği kullanarak 4-10 yaş arası çocuklarda anksiyete, stres ve strese bağlı ağrının azaltılması

için insansı robotlar kullanılmıştır. Bu robotlar için ses-bazlı diyaloglar, görüntü-bazlı videolar ve yüz, baş, kol ve vücut hareketlerine dayanan jest ve mimikler ile bu etkileşimi çoklu kipli bir şekilde destekleyecek sistemler geliştirilmiştir. Bu sistemlerin etkinliği, birinde diş hekiminin tedaviyi tek başına yürüttüğü ve diğerinde robotun diş hekimine yardımcı olduğu iki farklı grup çocuk üzerinde test edilerek gösterilmiştir. Bu deneyler sırasında, robotların farklı kaygı ve korkulara etkilerini ölçebilmek adına hem (iğne kullanımını gerektiren) anestezili işlemler, hem de anestezisiz işlemler üzerindeki etkileri incelenmiştir. Sistemin başarısı, hastalara uygulanacak anketlerle öznel bir şekilde, kamera görüntü analizleri ve tedavi süreleri ölçümleri ile de nesnel bir şekilde değerlendirilmiştir.

Çocuk diş hekiminin tedavi öncesinde her hasta ile belirlenen sabit sorular ile iletişim kurması yerine bu görevi tekrarlanabilir işlerin bir zorluk ve masraf yaratmadığı bilgisayar teknolojilerinin (animasyon veya robot) devralması sonucu hekimin zaman ve enerji kaybının minimize edilerek olumlu davranışların geliştirilmesi ve tedavinin başarısının artırılması hedeflenmiştir. Araştırmanın sonucunda robotların yardımı ile çocuklara eğlenceli ve rahat bir ortam sağlanarak çocuklarda olumlu davranışların geliştirilmesi, diş tedavilerinin başarısının artırılması ve sedasyon ve genel anestezi gibi maliyetli ve komplikasyon riski yüksek girişimlere olan ihtiyacı azaltmak nihai hedeftir. Bu çalışma dünyada ve ülkemizde diş hekimliği tedavisinde çocuklarda ağrı ve stresin azaltılması amacı ile çocuk-robot etkileşiminin kullanılacağı ilk çalışma olma özelliğini taşımaktadır.

Devam etmekte olan bu projenin temel ilgi odağı, insansı robotların, dental kaygıları olan çocukların diş tedavisi sırasındaki kaygılarının azaltılmasındaki etkisini araştırmak ve test etmektir. Sistemi ilk olarak yetişkinlerle yapılan pilot testlerle, daha sonra çocuk hastalarla klinik ortamında test ettik. Yapılan bu ön deneylerdeki amacımız çocuklarla test etmeden önce deney kurulumunu iyileştirmek ve robot ile çocuklar arasındaki etkileşimi en uygun hale getirmektir.

Projenin gerçeklenmesi bir insan operatör aracılığıyla insansı bir robotun çocuk ile sohbet ederek dikkat çekici mimikler ve vücut hareketleri sergilenmesi ile sağlanmıştır. Bu amaçla insan operator tarafından kullanılacak bir bilgisayar ve gerekli çıktıların elde edilmesini ile sağlayacak kameralara ihtiyaç duyulmaktadır. Robotun fiziksel olarak taşınmasının kolaylığı sayesinde de sistem, internet, bilgisayar ve kameralar bulunan her ortama aktarılabilmiştir.

Çalışmada robot ile tedavi grubunda Güney Kore'de Yujin Robot firması tarafından geliştirilmiş olan iRobiQ adlı robot ile çalışılmıştır. Proje kapsamında ilk olarak robot içeriklerinin hazırlanması ve bu içeriklerin operatör tarafından yönetilmesini sağlayacak işlemler gerçekleştirilmiştir. Başlangıçta kafa ve el sallama gibi temel vücut hareketleri ve mutlu, üzgün, şaşkın vb. yüz mimiklerinin tanımlanmasına karar verilmiştir. Bu çalışmada robot sabit bir konumda duracağı için robotun tekerlekleri ile sağlanabilecek konum değiştirme hareketleri programlanmamıştır. Gerçek testlere geçmeden önce yapılan ön testlerde çocuğun dikkatini çekecek robot figürleri ve eğlenceli videolar belirlenmiş ve robota yüklenmiştir.

Çalışmaya katılacak tüm çocuklar Türkçe konuşabildiği için ve robotun Türkçe metin-konuşma(text-to-speech) modülü olmadığı için, sistemin gerçeklenmesinde insan-robot etkileşimi alanında popüler yöntemlerden biri olan Oz Büyücüsü (Wizard of Oz) yöntemi tercih edilmiş ve bu yöntemle robotun çocuklar ile sözlü etkileşimi sağlanmıştır.

Robot grubu ile yapılacak deneyler öncesinde proje ekibi için sistemin kurulması, donanım ve yazılımların çalıştırılması konusunda gerekli eğitimler verilmiş ve ayrıca yazılı olarak tüm bu bilgilerin maddeler halinde belirtildiği Deney Kılavuzu hazırlanmıştır. Oturumlar sırasında aynı anda 2 farklı noktadan sabit kameralarla çekim yapılarak tüm tedaviler kayıt edilmiştir.

Diş tedavileri her iki grupta da aynı prosedürde gerçekleştirilmiştir. Çocuklara ve ebeveylerine araştırma protokolünün ayrıntılı açıklanmasını ve gönüllü onam formlarının doldurulmasını takiben tedavi işleminden önce çocuğun anksiyete derecesini ölçmek üzere anket formlarının doldurulması istenmiştir. Çocukların kaygı seviyelerini kontrol etmek amacıyla parmak tipi nabız ölçer (Pulse Oximeter) ile nabız hızı (bpm) ölçümü yapılmış ve her hastanın tedavi öncesi, sırası ve sonrasındaki nabız değerleri kaydedilmiştir. Temel müdahale yöntemleri ve robot asistanlığının etkisini ölçmek için her hastaya ve ebeveynlerine tedavi öncesi ve sonrasında ağrı ve kaygı seviyeleri ölçen anketler uygulanmıştır.

Değerlendirme kriterlerinden elde edilen sonuçlara göre, robotlar sosyal ve duygusal açıdan çocuk hastalara stres ve kaygı ile başa çıkabilmeleri konusunda diğer geleneksel müdahale yöntemlerinden daha çok yardımcı olabilmektedir. Bu tezde verilen sonuçlar başlangıç niteliğinde olmasına rağmen anksiyete değerlendirmesi açısından önemli bir eğilimi vurgulamaktadır. Gelecekte katılımcı alımına devam edilmesi ve hastaların ağrı ve kaygı durumları ile ilgili daha çok hasta üzerinde ölçümler yapılması planlanmaktadır. Daha sonraki çalışma ise tedavinin akışında veya çocuklarla etkileşimde herhangi bir fark olup olmayacağını görmek amacıyla başka bir insansı robot olan Nao'nun etkilerini araştırmak olacaktır.

1. INTRODUCTION

In this chapter, the motivation, the purpose of work done in this thesis, and the research questions of the thesis are introduced, respectively.

1.1 Motivation

Dental anxiety is prevalent among children, especially in anticipation of treatment and cause problems during their dental procedure. Some children having oral/dental pathology do not comply to have a treatment. Dentists perform a variety of behavior guidance approaches in most situations depending on the child's developmental level and reaction to treatment. If the basic behavior management techniques such as tell-show-do, positive motivation, distraction are not effective, approaches like sedation and general anesthesia, which come at high costs and risk of complications, are applied.

Some methods preferred by healthcare workers are wearing colored and patterned clothes, and using clown doctors to encourage children to distract their mind and to make medical procedures more fun [1]. There are some studies showing that listening to music or watching cartoons reduced pain and anxiety in children [2]. The goal of this approach is to reduce unpleasant perceptions, to avoid negative behaviors and escaping from the treatment. In this way, completion of treatment without the need of such advanced medical techniques like sedation and general anesthesia is targeted. These systems may not always be affective enough to distract child's attention away from pain.

Recently, many studies have been conducted using robots as a platform to apply behavior approaches for reducing anxiety and stress. The first study using robots in distraction during vaccination [3] demonstrated that a humanoid robot successfully decreased the level of stress of a child during flu vaccination procedure.

According to the analyses noted above, there is obviously a need of a more comprehensive system to enable a child to engage more deeply during medical procedures. Nowadays, combining visual, auditory and tactile stimuli by making use of multi-sensory strategies is believed to provide a greater impact on pain than using a single stimulus. In this study, we aim to direct child's attention from a painful stimulus to a more entertaining and amusing direction during their dental treatment using a humanoid robot and by making the therapy session less problematic and more comfortable in order to provide much cozier treatment environment to the dentist.

1.2 Purpose of Thesis

In this study, it is aimed to use humanoid robots to implement a techno-psychological distraction technique for children during their dental treatment in order to reduce their anxiety and stress-related pain. We aim to design and develop a long-term human-robot interaction with children in the 4-to-10 year old age range. To ensure the robot appears to be performing flawlessly, we present an experimental platform that will enable Wizard of Oz experiments to substitute the missing parts of the robot by a human operator. This thesis also includes a critique of our system based on observations of how a robot can relieve the pain and anxiety in children during their dental treatment. In order to evaluate the robot's effect on the anxiety and fear of children during these experiments, procedures with no anesthesia (not requiring the use of needles) have been carried out. The system has been evaluated subjectively by applying a variety of questionnaires to patients, and dentists as well as objectively by measuring patient's heart rates.

1.3 Research Question

This thesis attempts to answer this research question; "Can a robot socially and emotionally help children to cope with stress and anxiety during their dental treatment better than other conventional intervention methods?". The thesis aims to design a social robotic setup that is able to engage pediatric patients between 4-10 years of age with emotional expressivity, to create a teleoperation interface for dentists to control the robot smoothly, to find appropriate behaviors and nature for the teleoperated robot to improve the overall experience in a clinical environment during the procedure and to design an experiment setup that will prove the superiority of a social robot in comparison to other conventional interventions.

1.4 Thesis Overview

Chapter 2 illustrates prior works on social and non-social robots used in healthcare field, and conventional methods used to minimize pain and anxiety in children. Also, examples of robots used in hospitals and roles of medical staff who work with patients and their family are represented. Difficulties caused by running an user study in individual patient unit are explained to give better insights on what it is like to deploy robots in the wild. Chapter 3 provides an overview of the hardware and software system of the IRobi robot. Also, the teleoperation interface is extensively explained. In Chapter 4, the experiment procedures designed in collaboration with Department of Computer Engineering in Istanbul Technical University and Department of Pediatric Dentistry in Istanbul University are described. Chapter 5 claims the hypotheses for the proposed experiment and explores the insights gained from several pilot runs at the clinic site. Chapter 6 summarizes the contributions of the thesis and works to be done in the future.

2. LITERATURE REVIEW

This chapter includes literature review for similar studies and also for the methodology used, and reports the latest progress in the healthcare field of social robotics. Main healthcare applications of social robots include eldercare, autism, and rehabilitation therapy so far. For the past several years, robotics has been applied in the field of healthcare in various ways. Social and medical robots in this domain aim to motivate and encourage humans to keep up with the medical routine and to provide psychological therapies [4].

2.1 Management of Dental Anxiety and Fear in Children

Dental fear is an emotional reaction against the frightening stimulus during dental treatment. *Dental anxiety* is defined as unease about the fearful events that occur during dental treatment and as a feeling of loss of control accordingly. Negative expectations due to earlier experiences, negative behavior within the family, a feeling of anxiety about the pain, failed and painful experiences that occurred in earlier treatments were reported as the most important factors in feeling fear [5]. Factors associated with dental fear could be considered as age, the attitude of parents towards dental treatment, the bad experiences transmitted by those close to the child, concern about sensation of pain and past experiences of the child [5] [6] [7]. In various research carried out on the human test subjects, the incidence of dental fear, anxiety and behavior management problems in children have been reported to range between 20-74% in several countries (74% in Brazil [8], 30.6% in Singapore [9], 27.02% in Croatia [10], 25.6% in Turkey [11], 23.1% in Sweden [12], 22.2% in Finland [13], 20.6% in Taiwan [14]).

Management of pain during dental procedures is crucial to the success of treatment. Prevention of pain is made possible by a healthy relationship between dentist and patient, establishing trust, elimination of fear and anxiety, and the creation of a positive attitude for future visits. However, the subjective nature of pain perception may alter the patients' response to treatment and prevent the correct diagnosis and treatment approaches of physicians by affecting the accurate assessment scale against painful stimuli [15].

A variety of approaches have been proposed to prevent or completely eliminate children's dental fear. The purpose of directing behaviors of the child during treatment is escaping from unpleasant and failed experiences and to ensure that child accepts the treatment more easily. The physician treating the child should be knowledgeable about the various behavior management techniques and be able to predict the child's response to treatment by properly evaluating the data regarding child's developmental level, temperament and attitude during the operation. In this sense, the behavior of dentists and accompanying dental staff plays an active role in determining children's attitudes to the treatment [16].

Several techniques have been developed to perform dental care in children with success by applying basic behavioral methods including tell-show-apply technique, self control, positive orientation and diverting attention [17]. Especially recently, unusual stimuli and technological equipments started to be utilized in the process of attracting attention to another point. In this case, the attempt is to prevent negative behavior or escaping from treatment by reducing the unpleasant perception. In this way, it is planned to complete the treatment without the need for advanced behavioral techniques such as sedation, general anesthesia.

Although there are studies indicating that listening to music and watching cartoons reduce pain and anxiety in children exposed to medical treatment [1] [2] [18] [19], such systems are non-interactive. Stimulating the child as just listener/viewer is not always sufficient to be effective to divert the child's attention away from the pain.

Today, it is believed that combining multisensorial strategies with visual, auditory, and tactile stimuli (e.g. using robots) provide a greater impact on pain than the effect of a single stimulus. Beran et al. have first used robots in distraction during vaccination for a study performed on 57 children between 4-9 years of age [3]. While nurses were vaccinating, it was planned that the robot interacted with the child. Compared with control group, it has been shown that children with the robots are next to them during vaccination smiled more. After this experience, parents have noticed that their children remembered the robot more than the needle and they wanted robot to be in next vaccinations. Robots have been found quite fun, and helpful for diversion of a child's attention and also useful for enabling children to feel less pain and anxiety during painful medical procedures [20].

In another study, in the bilateral meetings held on 21 children between 7-9 years of age, the mechanisms of communication with humans and robots were compared [21]. Talking with children has been performed by an adult in the first group and by a robot in the other group. As a result of analysis of child behavior during the bilateral talks, it has been observed that children in robot group have made eye contact more and talked for longer. Researchers have reported that robot technology can be utilized in the field of social services and healthcare applications, where robots are superior to people in contact with children.

There is also a study aimed at increasing children's health information using robots, in which children with Type-I diabetes between 8-12 years of age have been subjected to quizzes via robots [22]. The study has shown that children have been motivated, had fun while answering questions and their level of knowledge about diabetes was increased in this way.

2.2 Healthcare Robotics

Medical robots are transforming the face of healthcare, ranging from microbots that scrape plaque from arteries to personal assistant robots that help care for patients [23]. Since the da Vinci Surgical System, the surgical assistant the FDA (The U.S. Food and Drug Administration) approved back in 2000, the system has conducted more than 20,000 surgeries and has paved the way for robotic advancements in healthcare. Later on, a number of new robots have been introduced to better provide care to remote patients and help with various physical therapies. For example, Magnetic Microbots are a group of tiny robots used in various operations, such as removing plaque from a patient's arteries or helping with ocular conditions and disease screenings. They can travel through a human's or an animal's blood vessels. They are tasked with delivering medicine to any designated area of the body. They mimic humans by giving medicine to someone.

The Aethon TUG is an automated system that performs the delivery and transportation tasks to free clinical and service staff to focus on patient care [24]. The TUG autonomous mobile robot is able to serve a wide variety of departments such as pharmacy, nursing, food and environment services and laboratory, etc. The robot acts as a distribution system to move through hospital corridors, elevators and departments to make either scheduled or on-demand deliveries.

The InTouch Vita is the first remote presence solution for patient care that combines the telemedicine technology from InTouch Health with autonomous navigation and mobility from iRobot [25]. It offers doctors the ability to take command of any clinical, patient or care team management process remotely. The robot connects physicians with their patients, no matter where they are. The Vasteras Giraff, a similar telemedicine system, enables the elderly to communicate with the outside world [26]. It is remote controlled, and it has wheels, a camera and a monitor. In fact, it provides two-way video calling similar to Skype. Caregivers use such robots to enhance telemedicine and care for those restricted to their homes. They can control the robot using a typical PC.

Surgical robots and service robots are currently used in hospital settings and have become a part of medical procedures [4]. These robots generally help staffs and patients by performing simple or complicated physical tasks. On the other hand, social robots on healthcare aims to motivate and encourage people to keep up with the medical routine, to provide psychological therapies, and to help staying healthy.

2.3 Social Robots in Healthcare Field

From telemedicine to bioelectronics, the health ecosystem is evolving quickly. Researchers have been developing robotic platforms and designing interactions for social robots to use with children for clinical therapy and interventions in the hospital setting [4].

PARO is an advanced interactive robot developed by AIST and it is designed specifically to be used in robotic therapy. The robot responds to patting and can express different moods. It has been designed to actively seek out eye contact, respond to touch, hug people, remember faces, and learn actions that generate a favorable reaction.

PARO was found to have the effect of reducing the stress, which was shown through the physiologic test [27] [28].

Pearl is developed by Carnegie Mellon University, aimed most heavily on functional assistance [29]. It is a mobile robot that can help elderly people navigate their environments. The activities requiring navigation are ranging from regular daily events, doctor appointments or physiotherapy, social events, to simply walking exercising. It has a user-friendly interface with a face, and can also provide cognitive support such as reminding people about routine activities such as eating, drinking, taking medicine, and using the bathroom.

People have been introducing technology to cope with aging and increasing healthcare costs for decades. However, these technologies are not engaging and fail to keep us coming back and using them and unfortunately most of them have fallen short. With the aim of improving patients' health and extending the capabilities and efficiency of healthcare companies, Catalia Health designed the Mabu personal healthcare companion, an intelligent and socially interactive robot whose conversations are tailored to each patient that evolve over time [30]. Mabu is designed to be friendly and approachable and is fairly straightforward in terms of the robotics. She is not mobile, but can make eye contact while carrying on a conversation with someone and is capable of simple gestures with her head and eyes. She holds a tablet-like screen in front of her that she uses during conversations to convey additional information.

2.4 Wizard of Oz Experiments in Human Robot Interaction

The development of autonomous robots often takes significant time. Although autonomy is often an ultimate aim for robots, focusing only on autonomy may prevent exploration of the interaction design space. In Human Robot Interaction (HRI) field, many researchers use Wizard of Oz (WoZ) as an experimental technique to conduct their robot interaction studies [31] [32] [33].

Wizard of Oz is an approach whereby a human operator, unknown to the participants, operates a robot. This method, used for full teleoperation or for partial control, enables simulating and modeling the interaction and allows the collection of data and experimenting without relying on specific system components. In child-robot interaction studies which use this method, the wizard speaks with the children through the robot [34].

The Huggable is a robotic companion being developed at the MIT (Massachusetts Institute of Technology) Media Lab [35]. It is being used for healthcare, education, and social communication applications. The Huggable robot helps mitigating stress, anxiety and pain. It is capable of expressing verbal and non-verbal behaviors through Wizard of Oz teleoperation from a remote laptop device.

A child-sized humanoid robot, KASPAR has been designed for use as a social mediator, encouraging and helping children with autism to interact and communicate with adults and other children [36]. It has movable arms, head and eyes, which can be controlled by the teacher or parent but also can respond to the touch of a child. KASPAR has the ability to engage in a range of interactive play scenarios, such as turn-taking or shared-gaze activities.

2.5 Positioning of This Thesis Towards Existing Work

Although considerable work using robots on healthcare has hitherto been done, there is no study about robots and their usage in dentistry in the literature. Therefore, our work is the first study in the world, which investigates the effect of child-robot interaction in reducing pain and stress during dental treatment.

3. PROPOSED APPROACH

The focus of interest of this study is to test and investigate the effects of humanoid robots in reducing anxiety of children with dental anxiety during dental treatment. In this chapter, we propose a clinical setup to minimize children's dental fear.

As subjects of the project are children, the proposed solution, first of all, must be designed so that it attracts the attention of children. For this purpose, the solution is to design the treatment process as a fun job using animations or cartoons favored by children. Including pre-treatment, during treatment and post-treatment, the designed system should be entertaining, relaxing and also educational. In the light of this aim, children should think that dental treatment is a fun experience instead of being scared or running away from the treatment. Moreover, this experience should positively affect the attitude of the children in future treatment sessions.

The implementation of the project should be provided that a humanoid robot chats with the child by a human operator and performs remarkable facial expressions and body movements. With this aim, a computer that will be used by the human operator and cameras that provide to obtain the required output are needed. Also thanks to the ease of physically moving the robot, the system can comfortably be transferred to any environment having internet, computers and cameras.

3.1 Design of the Robotic System

The project objective is to equip a robot with perception and understanding capabilities of natural language so that it can bring some comfort to sick children. However, a too complex system has to be avoided for continuity of interaction. Human acceptance of a companion robot is a very important issue for long-term interaction, the robot must be able to communicate with people in a natural and human-like way, and be excellent in its tasks. To realize natural communication for a robot, traditional human communication has to be used that it can be provided by gestures, speaking, writing, touch, etc. To improve the expression ability of the robot, we associated body gestures to facial expressions.

Within the project, firstly, the preparation of robot contents and the taransactions that allow the operator to manage these contents needs to be carried out. Initially, we have decided to implement the robot to perform simple body movements such as nodding and waving and facial expressions (happy, disappointed, normal, surprised, shy). Because the robot will be placed in a fixed position, changing the position of the robot were not programmed though it can be achieved by the robot's wheels. Before proceeding to real tests, the robot figures that attract the attention of the child and entertaining videos were determined and then installed on the robot in the preliminary tests.

As all participants in the study can speak Turkish and the robot does not have Turkish text-to-speech module, the Wizard of Oz method, which is a popular approach in the field of human-robot interaction, was preferred to implement the system. This method provides a verbal interaction between the children and the robot and flexibility to make the children involved in the interaction.

3.1.1 Wizard of Oz method

The Wizard of Oz experiment is a research experiment, in which subjects interact with a computer system that subjects believe to be autonomous, but which is actually being operated by an unseen human being [37]. This approach is particularly useful in exploring user interfaces for pervasive, ubiquitous, or mixed-reality systems that combine complex sensing and intelligent control logic [38]. Furthermore, it allows people to explore and evaluate designs before investing the considerable development time which is required to build a complete prototype. Thus, designers avoid getting locked into a particular design or working under an incorrect set of assumptions about user preferences. The missing system functionality that the wizard provides may be implemented in later versions of the system. It may even be speculative capabilities that current-day systems do not have. So, its precise details are generally considered irrelevant to the study. Rather than to measure the quality of an entire system, the goal of such experiments are to observe the use and effectiveness of a proposed user interface by the test participants.

Through Wizard of Oz control of our iRobiQ robot, we were able to observe an ideal and optimal interaction between the robot and the patient. Thus, the robot appeared acting naturally.

3.1.2 Clinical setup

Prior to the start of the experiments to be performed with the robot group, all the project employees were trained to set up the whole robotic system and run the software and hardware components in order to perform a fluent interaction with suitable robot behaviors on time. An employee, not a member of the project, pretended to be a child patient in the dental unit and acted out possible response to the robot. After the practice session, we discussed the missing elements in the system or new ideas for behavior patterns, teleoperation interface, questionnaires, etc. to improve the interaction. Furthermore, a user guide that contains all the required information was prepared and the instructions were itemized as well. This document includes guidelines that must be followed carefully before, during and after the experiments.

The WoZ setup of the system is shown in the Figure 3.1. All sessions are videotaped with cameras fixed at two different locations. First camera, placed in front of the child, records his/her face and body expressions and behaviors. Second camera is placed in a spot with a view of the dentist, robot and child interaction. The voice of the operator is received by a microphone from wizard room and sent to the clinics room through the speakers of the robot. And the webcam gives a direct visual feedback to the operator. These auditory and visual data are transmitted over a local network.

3.1.3 iRobiQ

The robot selected for this study, iRobiQ, which is depicted in Figure 3.2, has been developed by Yujin Robot company. It is both an educational and service robot, containing many features. It can teach English and tell the children nursery rhymes, entertain the family by singing and dancing, and provide home security.

There are many studies that iRobiQ helps children accelerate their learning language and speaking education [39] [40]. Han et al. [41] in their study, specifically designed and investigated IROBI (previous version of iRobiQ) for tutoring and educational services. They compared the effects of non-computer based media (using a book

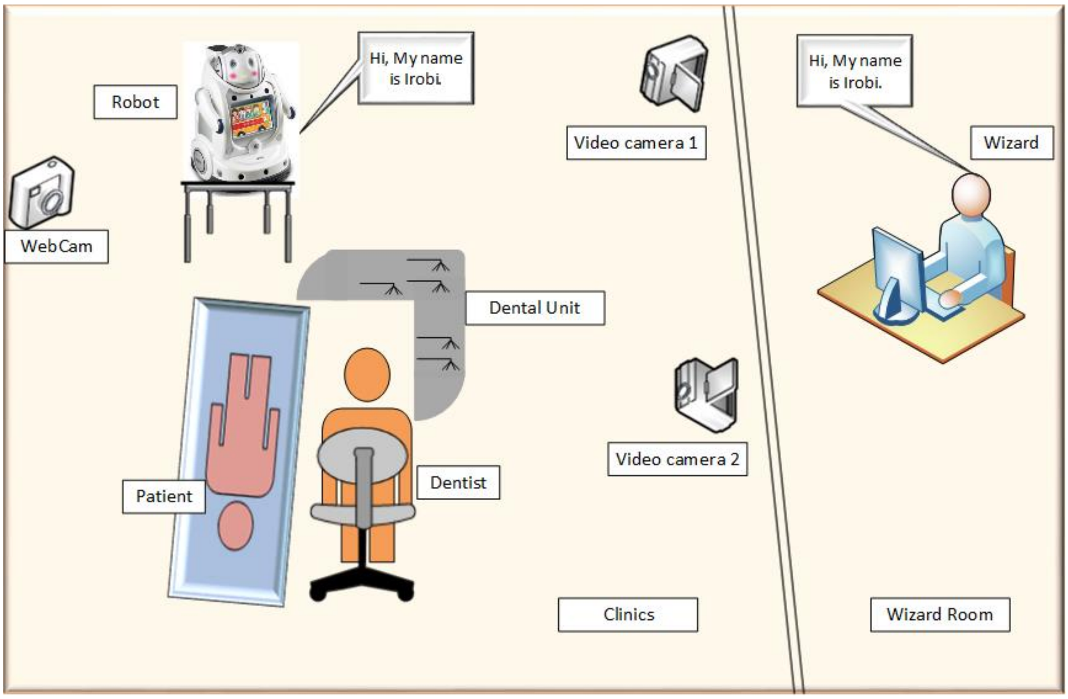


Figure 3.1 : The proposed Wizard of Oz setup of the system.

with audiotape) and web-based instruction with the effects of robot-assisted learning for children. The robot gestured and spoke in English, and children could touch its monitor if it did not recognize their voice command. The hands-on interaction associated with IROBI is thought to improve children's concentration, interest, and academic achievement. It is also thought to be more user-friendly than other types of instructional media.

IRobiQ can generate behaviors such as singing, talking and dancing (left and right turning, forward and backward moving) required for communication with children. The operating system of the robot is Windows XP. IRobiQ has the following specification as shown in Table 3.1.

It is designed with an Liquid Crystal Display (LCD) panel on its chest to support easy communication with children. It can move its head, arms, and wheels, but does not change its position despite of having this ability thanks to its wheels. It has a 2 megapixel camera and sound devices such as a speaker and a microphone, and various sensors, such as vision on its head, sense of touch on its LCD chest panel and audio sensors on its ears. It has 3 Degree of Freedom (DOFs) on its head and 1 DOF on each arm. The robot has facial Light Emitting Diodes (LEDs) as a part of its own

Figure 3.2 : iRobiQ.

Table 3.1 : Specification of IRobiQ.

ITEM	CONTENTS
Main Board	NP951-B16C(3.5"SBC)
CPU	Intel Atom N270 1.6GHz
RAM	1GB DDR2 RAM
Storage	SSD 16GB
USB	USB 2.0
Serial	RS232
I/O	LVDS, TV-out, etc.
Camera	2 Megapixel camera
Sensors	Touch Sensor, Ultrasonic, Bumper, Floor Detection
Speed	Maximum 50 cm/sec

hardware system and can display five types of facial expressions: shy, disappointed, neutral, happy, and surprised as seen in Figure 3.3.

3.1.4 Programming environment and software tools

In this study, iRobiQ is programmed to motivate the patient during the treatment and support the interaction with the child by performing short-time movements such as face, head and arm gestures or using audio and videos. The robot expresses emotion through the sight and sound effects of the LEDs on its mouth, eyes, and face and through the movement of hands so as to capture the children's attention and arouse their interest. IRobiQ asks children questions, gets responses and allows them to make choices on LCD screen.

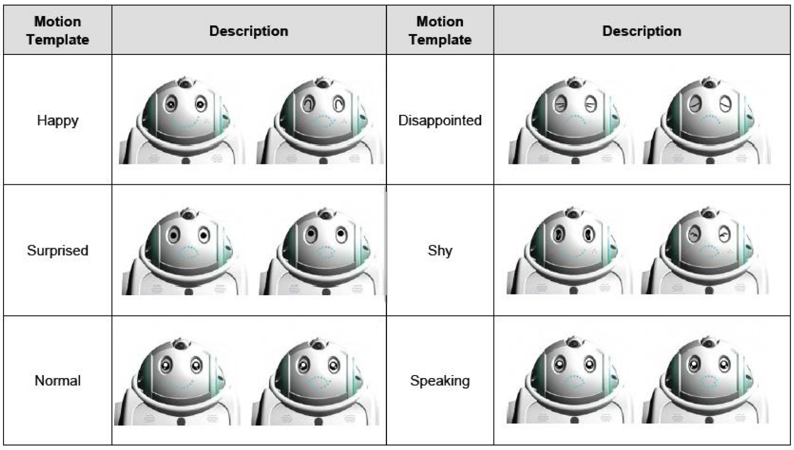


Figure 3.3 : Facial expressions of iRobiQ.

The robot behaviors as well as dentistry animations and songs have been integrated to the robot by using ROCOS (Robot Contents Organizing Software), an integrated robot content platform [42]. Basic robot behaviors are programmed using ROCOS Studio. And user defined behaviors are implemented in C++ using Microsoft Visual Studio. We have also prepared multimedia content in Adobe Flash to strengthen the interaction between the children and the robot.

The manufacturer of iRobi robots, Yujin Robotics, offers several software tools to use with the iRobiQ robot.

3.1.4.1 ROCOS platform

ROCOS is a service-based robot platform, stands for **RO**bot **C**ontents **O**rganizing **S**oftware, and refers to the software to develop the content for robots. It also can be applied and used in many types of robot.

ROCOS provides an integrated development environment to easily develop the robot content. It enables the user and developer to add applied modules to fit multimedia based content, scenario based content and requirements of the user to enhance the utilization of robot content. Based on this, the robot content can be applied to wide range of fields including education, home monitoring, guide and health case etc.

ROCOS platform consists of modules, in other words components that cooperates with each other and communication of these components is provided with an XML-based framework. Special components such as RCP, RSE, COMOS, etc. and the configuration of ROCOS platform with RAPIx is shown in Figure 3.4.

RCP is specialized for displaying multimedia based contents. RSE is also an XML-driven component, but specialized in parsing and executing scenario-based contents by RSML. Furthermore, COMOS is another special component for common functions in ROCOS [42].

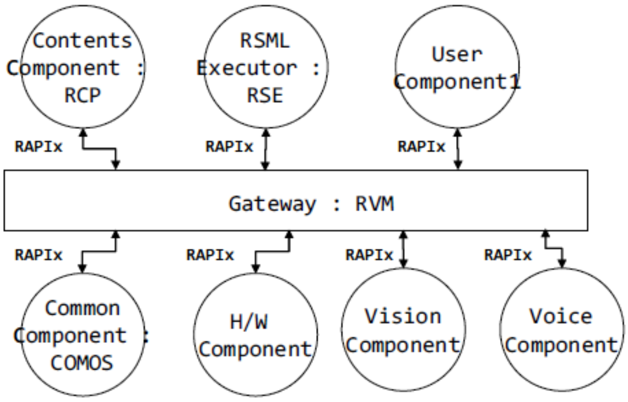


Figure 3.4 : The configuration of ROCOS platform [42].

3.1.4.2 Authoring robot contents

ROCOS Studio is a platform used to author robot contents. ROCOS Studio is also composed of IDE (Integrated Development Environment), Simbugger, and Contents Browser. Integrated development environment within ROCOS Studio includes CSE (Contents Script Editor) which has the function of authoring the scripts to be used in the multimedia based robot content and SAC (Service Authorizing Component) to develop scenario based robot content. Scenario based content refers to the scenario format configured with operational control of the robot and generally refers to the interaction with the user or free activity pattern of the robot. For example, the content can be developed to respond to the touch or voice recognition etc. Also the other multimedia based robot content refers to the content including the operational control command of the robot in multimedia content such as video, flash etc [43]. Figure 3.5 shows the main screen of the ROCOS development environment program. In this study, we prepared multimedia contents in Adobe Flash to display on LCD screen of the robot.

To author multimedia robot content, a project is first created in ROCOS Studio. When the project is created, the RSC (Robot Script) file, which is the script file unit, must be created. Authoring can be done easily by drag & drop robot action units on CSE

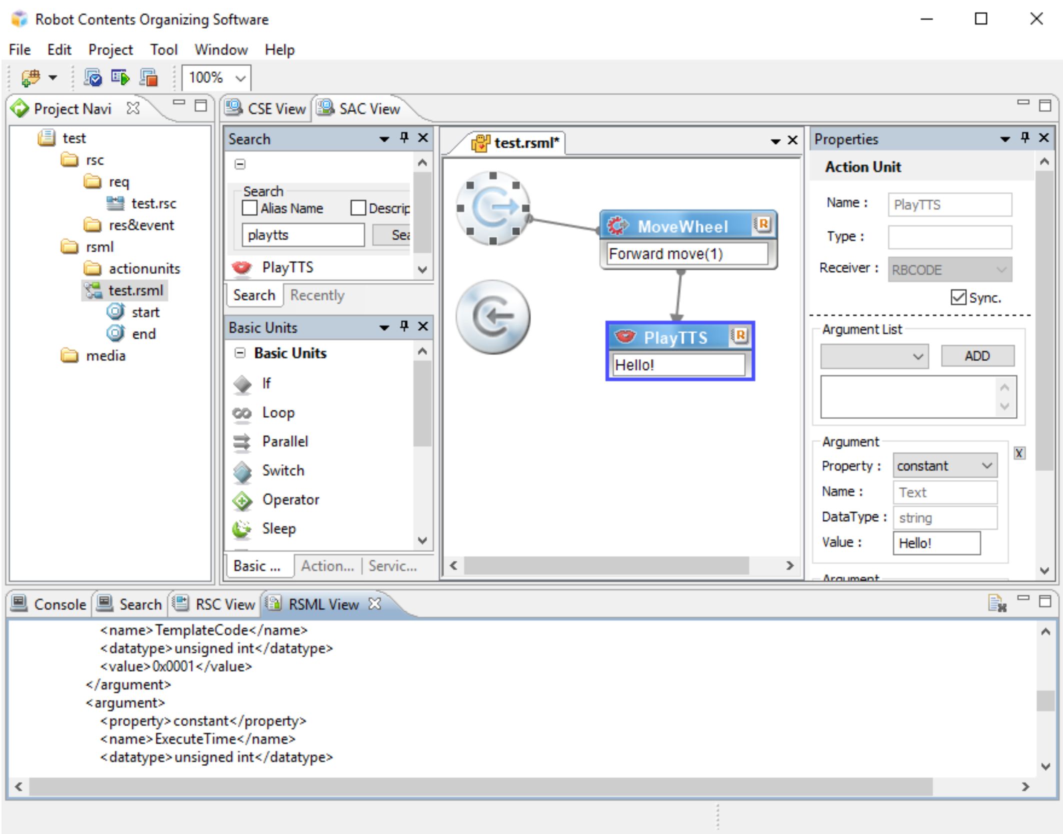


Figure 3.5 : Main screen of ROCOS Studio.

screen. After entering the required arguments for each unit, the script content file is build. The script codes generated by build process are displayed on RSC View window and can be copied in order to use in a software which enables to prepare flash (.swf) files.

Flash files can be considered as animations with rich visual content to be executed on the robot's screen. It is important to create flash content in order to increase the user interaction with the robot. The contents and interfaces to be displayed on the screen of the robot are created in ActionScript 2 using Adobe Flash CS5. The script codes copied from ROCOS Studio as mentioned above are pasted inside of the frames and/or function bodies. To initiate or react to actions on the robot's screen, we have used the keyboard to interact with Flash movies. In this way, some robot behaviors are assigned to key event functions. Using keyboard commands requires listening to keyboard events. We need to use the addEventListener() method to register with a KeyboardEvent. Unlike other objects in AS2, the keyboard is not necessary attached to any specific object and the Keyboard Event is usually registered with the stage. In

Figure 3.6, the stage object registers for a keyboard event to be triggered whenever a keyboard key is pressed down.

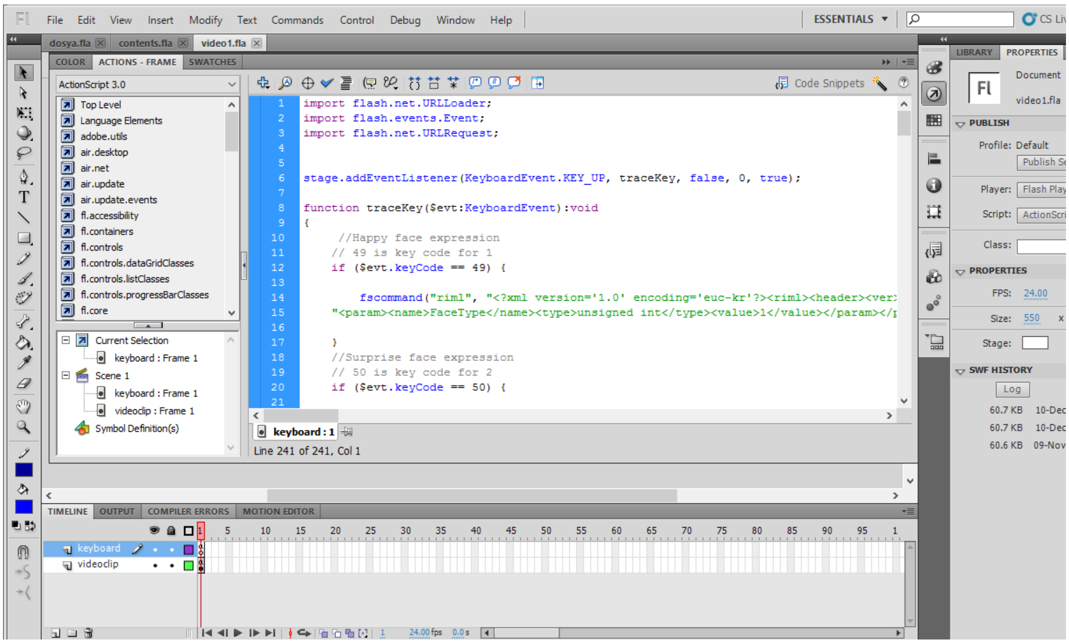


Figure 3.6 : Preparing flash movies with Adobe Flash.

Finally, after swf files generated by compiling the script codes are uploaded to the corresponding sections in the robot's drive. An example flash movie is shown that an animation is displayed on the screen of the robot in Figure 3.7.

Figure 3.7 : An animation played on the robot's screen.

3.1.4.3 Simulation interface

Simbugger, a tool that ROCOS provides, enables 3D simulation and debugging so that the developer can debug the content without the actual robot. It is used to test the contents that we prepared for the user experiments. A screenshot from the main screen of Simbugger is shown in Figure 3.8. The user can check the virtual movement of the robot from the simulation screen.

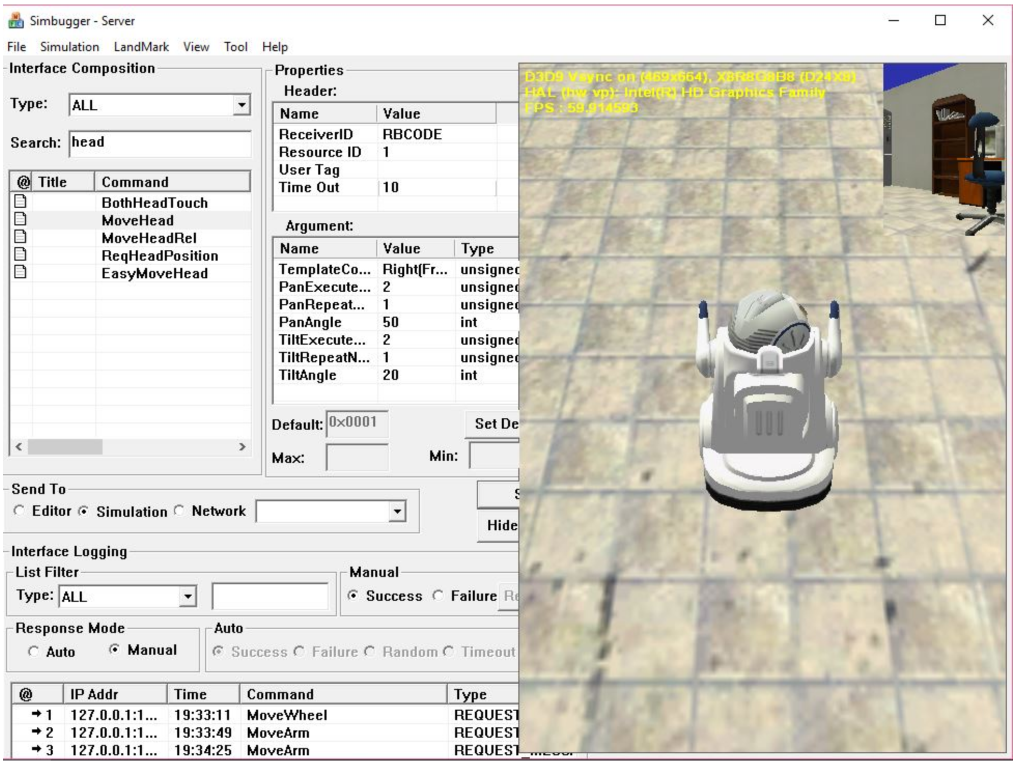


Figure 3.8 : Simbugger main screen.

3.1.5 Procedures for operating the robot

There is a need of a robot control interface for running Wizard of Oz style experiments. It should be easy enough to be used by the non-programmer collaborators of the study.

Our platform enables Wizard of Oz experiments to substitute the missing parts of the robot, for example, a natural language interface in Turkish. The wizard who is an experimenter of our team sees the children's reactions, and speaks with the children through the robot. She executes robot commands using a keyboard interface which acts as an intermediary between the robot and a wizard. Each predefined robot behavior is assigned to a specific key. Based on the child's behavior, the robot performs these body movements and facial expressions to distract his/her mind.

It is a fact that having a spoken dialog with children is an important aspect of a companion robot [44]. It attracts the children and can demonstrate an intelligent system. Because speech recognition is a major unresolved problem in robotics, robots still lack complex dialog capabilities. To develop such a dialog system is a challenging task in real world conditions. The children would be unsatisfied with an uncompleted system. Hence, the speech recognition system is replaced by a human operator using a Wizard of Oz method to create the impression for the child patients, that the robot is already able to talk to them in a natural way. In this way, high level parts of the dialog system can be evaluated, and other subsystems can be tested under real world conditions without annoying children too much. As the robot that we used in this study has limited verbal skills, we have decided to follow this approach rather than speech recognition system.

Transferring the images from the cameras as well as an audio stream to the operator, the robot seems to behave naturally. This way communication between the robot and the operator's laptop has been provided with VoIP (Voice Over Internet Protocol). VoIP is a technology that converts analog audio signals into digital signals and transmits these signals over the internet.

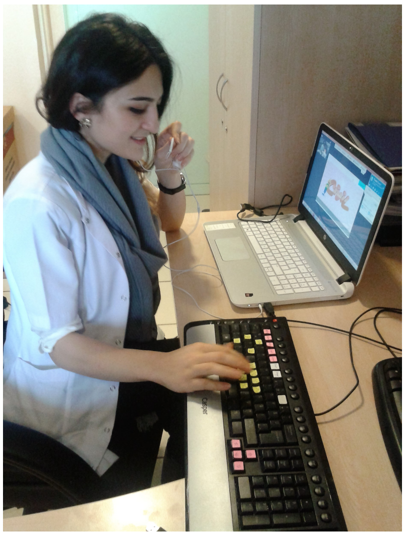


Figure 3.9 : The wizard or experimenter is operating the robot using a keyboard interface.

During the procedures, the robot performance to attract the attention of the child is also achieved by the human operator. IRobiQ is pre-programmed to perform some arm and body movements and facial expressions and to play visual contents. These tasks are required to be performed in real time. Therefore, each task is seperately defined and assigned to a keyboard event, and some combination of robot movements are provided with a single key press. The experimenter acting as operator is able to control the robot in real time using the keyboard shorcuts assigned to each task. With this interface, not only the operator's time to learn has been minimized, but also the work to control the robot has been simplified. As seen in the Figure 3.9, the operator in the wizard room acts the robot using the keyboard interface.

4. EXPERIMENTS

We have firstly tested the system with pilot tests with adults, then with child patients in a clinical setting. The aim of these preliminary experiments is to improve the experiment setting before testing it with children and to optimize the interaction between the robot and children. This chapter includes the inclusion criteria of the participants into the experiment, measures to evaluate the effects of robot assistance and basic conventional intervention methods and an example scenario of dental procedure.

4.1 Participants

33 children (21 boys, 12 girls) were recruited for this study, ranging in age from 4 to 10 years old. The tests were run at a clinic in the Department of Pediatric Dentistry, Faculty of Dentistry in Istanbul University. Figure 4.1 shows the clinical environment.

The inclusion criteria of the children into the experiment were the following:

- Applying to the clinic for the first time.
- Lacking of dental treatment experience before.
- Not having pyhsical or mental disabilities.
- Not having long term bleeding or pain in teeth.
- Being given restorative or endodontic treatment plan by a dentist.
- Being accompanied by at least one parent.
- Not having any genetic syndrome or a serious systemic disease.
- Agreeing to fill out the questionnaires (both by the children and parents).

Figure 4.1 : The clinical environment.

4.2 Measures

The study was approved by the institutional review board at the Istanbul University Medical School (2014/461). A set of questionnaires measuring levels of pain and anxiety are applied in both pre and post session to each participant and their parents in order to assess the effects of robot assistance and basic intervention methods. Some questionnaires were administered to explore the feelings of the child during the interactions, how they perceived the robot as well as their mood during the interaction [46].

Before the procedure, it is required to fill the questionnaire to measure the child's anxiety levels. Thus, an experimenter explains the research protocol in detail to the children and their parents admitted to clinics and ask them to complete the consent forms. The consent was filled by the children and their accompanying parent in the waiting room of the clinic. After the consent was granted, parents were asked to primarily answer demographic questions, then the questions related to their children's familiarity to robots and computer technologies.

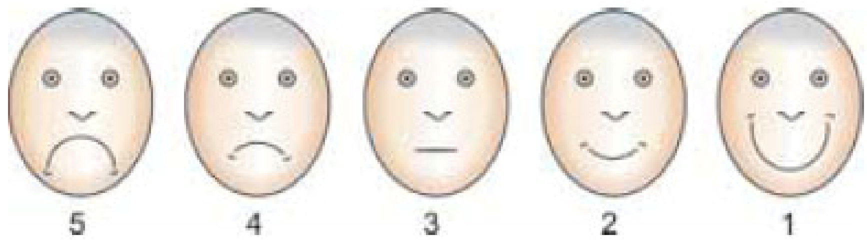


Figure 4.2 : Facial Image Scale (FIS) and the questionnaire used to assess dental fear and anxiety.

After the child entered the room, the Facial Image Scale (FIS) was administered [47]. The FIS is a measure to assess the state of children's dental anxiety and comprises a row of five faces ranging from very happy to very unhappy as given in Figure **??**. This scale is scored by giving a value of 1 to the most positive affect and 5 to the most negative affect face. The children were asked "How do you feel right now?" and were guided to show their response by pointing one of the faces. Approval studies have shown that it is a suitable measure for assessing the children's strongest expression of pain and fear sensation during the dental procedure, i.e. both in the waiting room and while sitting on the dental chair. Each child gave his/her own response independently although their parents or researchers help them in reading the instructions for children when necessary [3].

Before beginning treatment, the dentist rated the child's behaviour on Frankl's Behaviour Rating Scale (FBRS), which is one of the more reliable and frequently used behavior rating systems in both clinical dentistry and research [48]. The FBRS categorises the child's behaviour as either one of the following: definitely positive (4), positive (3), negative (2) or definitely negative (1). This evaluation was also completed by the dentist at the end of the treatment session. Definitely negative (1) represents refusal of treatment, negative (2) means reluctance to accept treatment, positive (3) shows that the child accepted the treatment but he/she was cautious and definitely positive (4) corresponds to good rapport with dentist, the child was enjoying the dental procedure.

Anxiety level was also recorded before, during and after treatment in terms of physiological pulse rate (bpm) by using a finger type pulse measuring device (Pulse Oximeter) as shown Figure 4.3. In the robot group, apart from measuring the children's anxiety and behaviour, we administered the question, “Would you want to have the robot in your next treatment session?", to the children. Responses were given on a 5-point scale from "not at all (1)" to "very much (5)" [3].

Figure 4.3 : A finger type pulse measuring device has been used to record the child's anxiety level.

4.3 Procedure

The children's treatment plans were determined based on the first inspection carried out by specialist dentists. All children are exposed to the same dental treatment in the same clinic environment. While first patient group has been treated only by the dentist (control group, n=17), the second group has been treated by a robot accompanied by the dentist (robot group, n=16). Both groups will be subject to previously determined standard dental treatment. After clinical setting is introduced in both groups, the treatment phase starts.

Children's treatment type is divided into subgroups, according to predetermined treatment needs: 1) dental treatment of first group will be carried out without local anesthesia (restorative treatment), 2) dental treatment of second group will be applied local anesthesia (endodontic treatment). Treatments are planned to be completed in a single session. According to routine clinical procedures, parents were not allowed near children during treatment. In addition, all sessions will be videotaped with cameras fixed at two different locations.

Treatment of first group also called control group in the study, was performed in the routine clinical procedure. The dentist provided information about the clinic setting, equipments and processes. As a result of feedback received from the child, dentist applied the corresponding therapy using basic behavior techniques as appropriate. In the second group, or robot group, the robot was seated on a platform near the dentist at the child's eye level as in Figure 4.4. The robot chatted with the child, instructed the child before and during the treatment, distracted and encouraged her/him, and played animations favoured by the children.

Figure 4.4 : IRobiQ performs some body movements with face expressions during a child's dental treatment.

In this context, the robot appeared acting naturally even in the lack of autonomy. A web camera together with a microphone transmitted audio and video to the wizard room. The wizard room was away from the clinic setup. As part of the WoZ setup, an expressive verbal interaction is thought to be able to easily involve children in communication. Based on the analysis of captured videos, the majority of the children started to show more natural and expressive behavior after the wizard presented some feelings and emotions in the interaction. Because the wizard's communication skills also affect the children's behavior, we got help from a child psychiatrist about chatting with children [34].

IRobiQ was programmed to help the wizard to execute the commands as distraction strategies (shaking head, swinging arms, face expressions) during the treatment. Once the WoZ system was installed, the wizard did not need to make any adjustment such as re-activate the robot for each phase. Figure 4.4 shows some body movements with different face expressions performed by the robot. This way, the robot played a role as a member of both the welcoming and the treatment team. In this scope, a possible communication scenario between the robot and child is as follows.

(C: the child, R: the robot, D: the dentist)

————— *(Acquaintance)* ————

- *D: Hello ..., how are you?*
- *C: I am fine. / I am not good, I have a toothache.*
- *D: My name is Yelda, (pointing the robot) and this is my robot friend. Can you introduce yourself, Robi?*
- *R: (waving) Hi! My name is Robi. I am 7. How old are you?*
- *C: I am ... years old.*
- *R: Here is where the children's teeth are cleaned. Do you know Caillou?*
- *C: Yes, I know Caillou!*
- *R: Caillou was here, too. He cleaned his teeth. Now is your turn. Let's count how many teeth you have and check how well brushed. (pointing the dental chair) Here, we have a big chair, you can sit comfortably then we can count your teeth afar. 1, 2, 3, 4, ... I wonder the total number of your teeth. If you let us count them we may give you a gift. Can you win the gift?*
- *C: (Sat down the chair)*

  ————— *(Chat on the chair)* ————

- *R: Well done. There is a tooth mirror to count our teeth (the dentist shows the mouth mirror to the child), and we need a sun to see our teeth better (the dentist turns the reflector lamp). Now, let's see your teeth (the dentist check the child's teeth using the mouth mirror). 1, 2, 3, 4, .. Wow! You have so many teeth. (referring to tooth decay) But, did I see a microbe on your tooth? What should the color of our teeth be normally?*

- *C: It should be white.*

- *R: I think you may sometimes have forgotten to brush your teeth and black microbes were propagated and stuck on your teeth, anymore your toothbrush at home can not remove stains. We have an electric toothbrush, it is more powerful. A jet engine is put inside of it so that it can remove the stains that you were not able to clean, it makes noise like an aircraft (the dentist runs aerator). Oh! It is really like an aircraft. (the dentist bring the aerator closer to her hand) It squirts water, like raining. So what will we do this water? We need someone to drink the water, and it is "Mr. Thirsty". (to suck up the water in her hand the dentist uses a saliva ejector) Look! Mr. Thirsty is drinking water like an elephant. (the dentist gives the saliva ejector to the child) You can hold Mr. Thirsty too.*

- *C: (The child holds the saliva ejector, the dentist runs the aerator again and dribbles some water in palm of her hand)*

- *R: Ok! Let Mr. Thirsty drink water. (the child make the ejector suck up the water) Now Mr. Thirsty wants to drink water from your hand. (the dentist dribbles some water in palm of the child's hand)*

- *C: (the child make Mr. Thirsty drink the water in her/his other hand)*

- *R: Bravo! How well you did it. Do you know, Mr. Thirsty actually likes to drink the water in our mouths. Now let him drink the water in your mouth, it is the same as before. (the dentist dribbles some water in the mouth of the child)*

- *C: (the child make the ejector suck up the water in her/his mouth)*

- *R: You did that too, you are great! Our brush is also funny, it likes tickling while removing microbes, let's try tickle a microbe once. (the dentist touches the edge of the tooth with the aerator) Were you tickled too?*

- *C: Yes, I was tickled so much!*

- *R: Then, let's count to 5 and tickle a microbe.*

- *C: (opens her/his mouth holding the saliva ejector)*

- *R: (the dentist starts to clean the tooth decay) One! Very good, we tickled one. Let's continue. Two! Three! Four! Five! I see that microbes start to run away. Yes! They are running! Very nice, your teeth has become white. Now let me sing a song until microbes vanishes. (the robot play movies during the procedure) Hooray! we got rid of all microbes. But microbes made a hollow on your tooth we should fill that with dough. I want this dough stick your tooth well so open your mouth larger. (the dentist places the filling) ... That's all! Your teeth whitened and microbes vanished.*

  ——— *(End of treatment)* ———

- *R: Congratulations for your help to fight with microbes. We can not do it without your help. I am sure that you were going to brush your teeth very well. Today's hero is you, so Doctor Yelda will give you a small gift (the dentist gives a toothpaste and a brochure). Would you want to come here?*

- *C: Yes, I would. / No, I would not.*

At the end of the treatment, the robot thanked the child, encouraged to visit again and waved goodbye.

5. RESULTS

In this study, we designed a socially engaging robotical setup to support children so that they feel less anxiety and fear in a dental clinics. We allow the robot to talk with children, perform expressive facial expressions and body gestures. Even though, these results are preliminary considering the fact that in clinical surveys large amounts of patients need to be treated to obtain significant results, they provide an important trend in terms of anxiety assessment.

5.1 Changes in Physiological Pulse Rates

Figure 5.1 shows the change of children's average levels of pulse rate for each group. We have observed that based on the outcomes of pulse rates of the children in control group as well as the video analyses, these children were more anxious and stressful during the treatment than before the treatment. As expected, after the treatment finished, they became calmer and their pulse rates reached even lower than the pre-treatment levels. On the other hand, the patients in the robot group had similar pulse rates before and during the dental procedure, which indicates that the robots were effective in the reduction of the patients' anxiety. Moreover, after the treatment has been completed, these rates have returned to lower levels compared to the pre-treatment pulse rates.

By investigating the quantitative pulse rate changes of individual patients, as shown Table 5.1, we observed that 70.58% of the participants in the control group suffered from increased pulse rate in the time interval between pre-treatment and during treatment, defined as *Phase 1*, whereas only 23.52% of the patients had decreased pulse rate. If the change of pulse rate stayed within a limit of $\pm 3\%$ of the original pulse rate during the phase, we defined this case as *No change*, and only 5.88% of the patients in the control group experienced this effect. The transition from the treatment time to the post-treatment is defined as *Phase 2* and 64.70% of the patients were relieved from their dental stress, while the pulse rate of the 29.41% of the patients did not change.

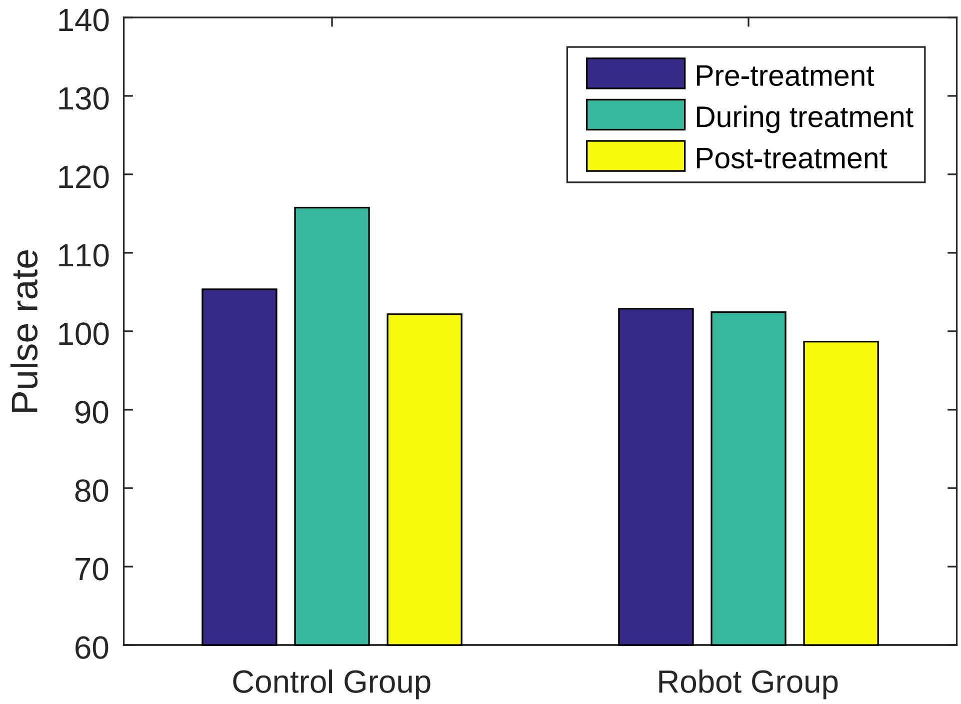


Figure 5.1 : Children's pulse rates before, during and after dental treatment.

Table 5.1 : The change in the children's pulse rate.

		Increased(%)	Decreased(%)	No change(%)
Control	Phase 1	70.58	23.52	5.88
Group	Phase 2	5.88	64.70	29.41
Robot	Phase 1	31.25	43.75	25.00
Group	Phase 2	12.5	43.75	43.75

However, the results of the robot group indicate an important trend of reduction in dental anxiety both in *Phase 1* and *Phase 2*. The total percentage of the patients having either no change or decrease in their pulse rate was 68.75% compared to 29.40% in the control group. Furthermore, the relaxation from stress after the treatment continued: a total of 87.00% of the patients had lower or equal pulse rates. Additionally, Figure 5.2 shows the amount of change in each of the subject pulse rates.

5.2 Facial Image Scale Scores

According to the Facial Image Scale scores in Figure 5.3 from pre- and post-treatment session, the percentage of children in control group having a negative or equal affect (indicating dental fear and anxiety) after the treatment (35.29%) was drastically higher than the percentage of children feeling the same way in the robot group (6.25%). 93.75% of the patients in the robot group have indicated that they felt better after

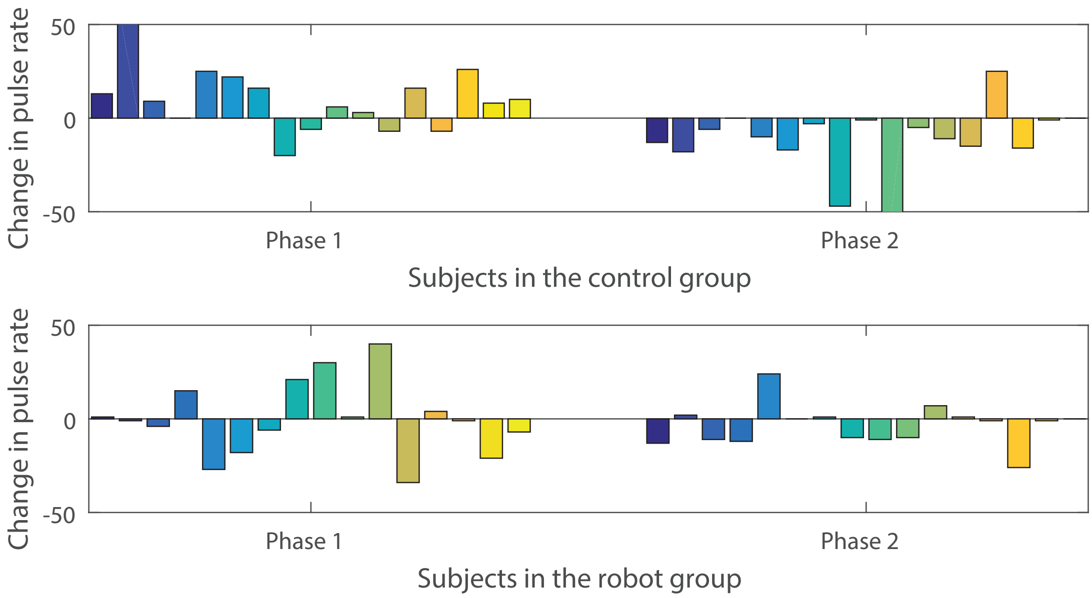


Figure 5.2 : The change of pulse rates of each child in *Phase 1* and *Phase 2*.

the procedure. Based on these results, it is apparent that the level of anxiety of the children increased in control group, though conversely the children in robot group feel less anxiety after the procedure. Moreover, there is a remarkable difference between the levels of both groups.

The mean scores of FIS shows the rate of the intensity of pain before and after the intervention in Figure 5.2. Lower the score was, higher was iRobiQ recognized as a companion. Thus, we had a general score as well as detailed results.

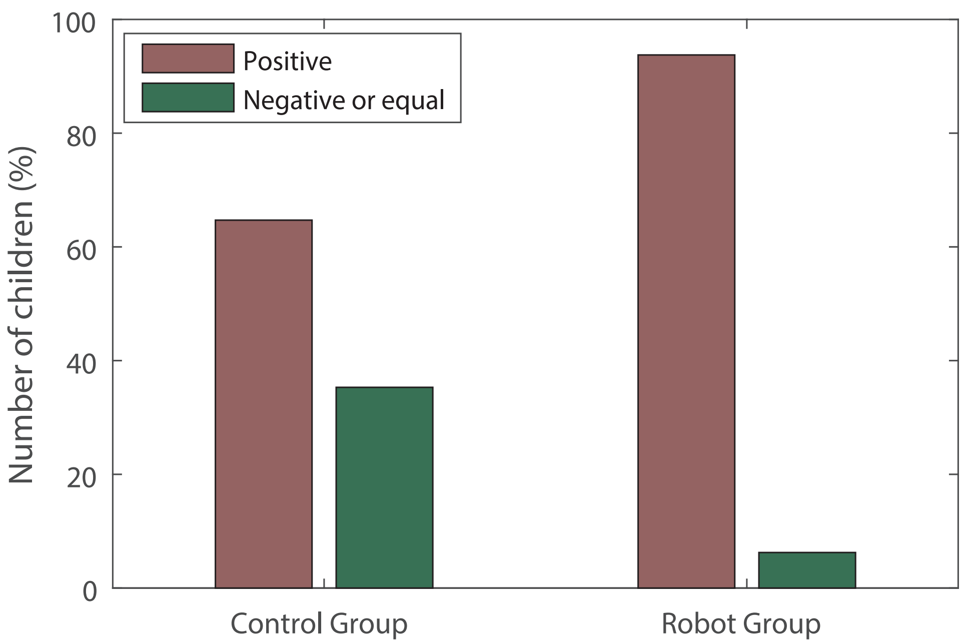


Figure 5.3 : The change of children's affect in Facial Image Scale.

Table 5.2 : Facial Image Scale scores.

	Pre-treatment	***Post-treatment***
Control Group	2.52	2.59
Robot Group	1.87	1.68

5.3 Frankl's Behavior Rating Scale Scores

Figure 5.4 shows the change of the children's behavior towards dental treatment with respect to Frankl's Behavior Rating Scale. Comparing the children's treatment willingness, which was evaluated by the dentist, it can be seen that the half of the control group (50%) showed more positive attitude between the pre- and post-treatment relatively. However, the children in the robot group had more positive attitude after the treatment than they did have before the treatment (93.75%).

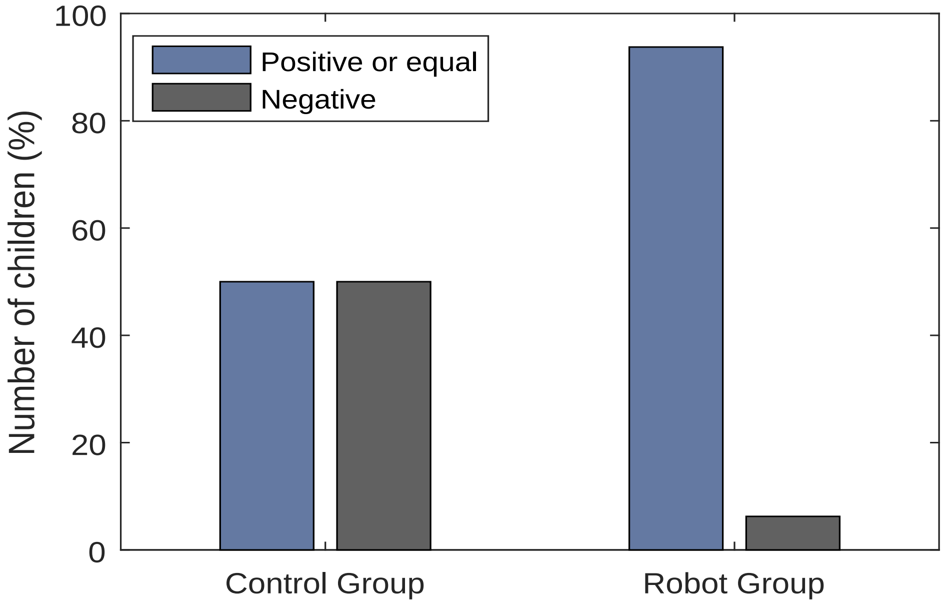


Figure 5.4 : The change of willingness of treatment according to Frankl's Behavior Rating Scale.

Table 5.3 shows the mean scores given by the dentists to the patients in both groups. Whereas the decrease in the average score of the patients in the control group shows a tendency of non-cooperative behavior, the increase in the willingness of the patients in the robot group demonstrates the promising positive effect of the usage of robots in dental treatment.

Table 5.3 : Frankl Behavior Rating Scale scores.

	Pre-treatment	*Post-treatment*
Control Group	2.64	2.21
Robot Group	2.87	3.18

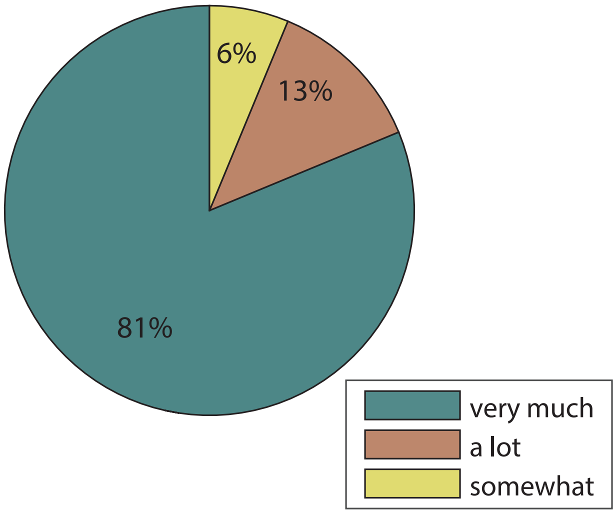


Figure 5.5 : Children's responses to have the robot in next treatment as well.

Another assessment made using the answers from the children in robot group to the question "Would you want to have the robot in your next treatment session?" using the same terminology and notations as in the study of Beran et al. [3], show that the children liked and enjoyed the presence of the robot during their dental procedure. The distribution of the children's answers is given in Figure 5.5: "very much" (81%, n=13), "a lot" (13%, n=2), "somewhat" (6%, n=1).

Thus, all these improvements measured using objective and subjective evaluation criteria demonstrate the fact that the robots may have long-term positive effects on children's behavior in future treatments.

5.4 Discussion

Our project is a clinical research trial that compares the effects of a robot companion in reducing child patients' dental pain, anxiety and stress. We run this project in collaboration with Department of Pediatric Dentistry in Istanbul University and Department of Computer Engineering in Istanbul Technical University. In this thesis, we presented the results from the experiments on 33 subjects who had a dental treatment in the clinic. Because the number of participants is not enough, the analysis of other questionnaires about the fear of the patients, their demographic information, familiarity to technological devices, etc., can not reveal the effect of the study accurately.

We prepared same scenario by executing same series of commands for all children so that every child had the same interaction with the robot. This study is done in a real world setting and the interaction happens in a real clinical environment. Therefore, it was really hard for us to be able to control the whole system and additional challenges in the process were inevitable. Huggable project which aims to help pediatric patients to cope with stress using a social robot, faced similar obstacles due to the hospital environment, variance and severity of the target subjects in their medical conditions and the robot-child interaction which happens in individual subject's bed space. They described the lessons they learned from those challenges in their next study [45].

5.4.1 Challenges in designing the robotic system

Due to the characteristic of the clinic environment, we faced an important challenge during the experiment. The slow wireless network caused some problems in creating a natural social robot interaction. We used a wireless access point that boosts up the signal and tethered the devices to each other. In this way, we aimed to minimize the loss off packets sent among the devices and the number of wires located in the clinic.

5.4.2 Challenges in running experiments

Subjects who are eligible for the study are selected among the patients applied to the Department of Pediatric Dentistry in Istanbul University. Our clinic is one of the busiest clinics in patient capacity context in our country, and many patients get appointment to the clinic in a day. However, recruiting subjects for the experiment is not easy as expected. We have to set days and time to run the experiments based on timelines of the patients, clinic staffs and experimenters. We mostly tried to run the experiments except when the clinic is busy.

All of the study sessions happened in a dental unit space in a clinic room. The clinic room where various equipment are installed has three dental units separated from each other with wall panels. Because other clinical staffs who uses the other two unit frequently come in and out of the room and they may perform another child's treatment at the same time, the interaction with the robot could be unpleasant and awkward.

Children were applied to questionnaires before, during and after the session to measure their pain and anxiety. Most of them were observed to have positive experience when interacting with the robot. On the other hand, post-treatment questionnaires were challenging for children who are physically ill or have pain. Few of them did have difficulty to answer the questions after the treatment.

6. CONCLUSION

6.1 Summary

This study has been carried out as part of an ongoing research, with the aim of helping children to reduce their dental anxiety by setting an interaction based scenario using a social robot companion. To our knowledge, no study has reported the application of a social robot in the dental care setting.

In this thesis, we have described a preliminary study, which showed that children's pain and anxiety can be reduced in their dental treatment using robots. We believe that a robot can socially and emotionally aid child patients in their dental procedures to cope with stress and anxiety better than other conventional intervention methods. Moreover, robots have advantages that they are programmable in content and level according children's age, and their usage is simple and eases the work load of health care workers [20].

We presented an experimental platform that will enable Wizard of Oz experiments in which a human experimenter (wizard) teleoperates the robot from a remote laptop device. Prior to the experiment, the script is developed, defining many possible actions for the human and the robot. According to the video record analysis, most of the children showed natural and expressive behavior when the wizard presented some feelings and emotions in the interaction.

6.2 Future Work

In the future, we will continue to recruit more participants and present much quantitative measures relating to patient anxiety and pain. In that sense, the most urgent future work is to obtain the data from all the sessions, i.e. the answers from all questionnaires, and video recordings, and to record a quantitative analysis of each characteristic studied, the causal relationships among these characteristics, and

Figure 6.1 : A humanoid robot Nao, developed by Aldebaran Robotics.

an analysis of the interaction between robots and children based on the children's reactions.

There were not many options available for the children to do with the robot. The subjects engaged with the robot via conversations. We want to create more activities available to engage in for the child and the robot in the future. A play material for the child and the robot can be introduced on the screen of the robot [4].

Furthermore, our next plan is to explore the effects of another robot Nao (Figure 6.1), developed by Aldebaran Robotics, to see whether there will be any differences due to the more human-like appearance and embodiment of this robot [49].

APPENDICES

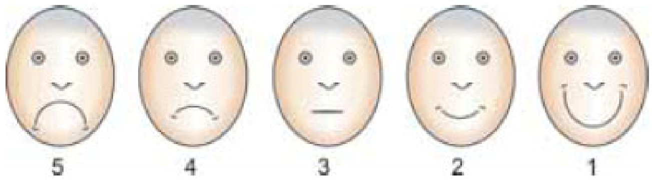
APPENDIX A: Facial Image Scale
APPENDIX B: Frankl's Behavior Rating Scale

APPENDIX A

Kod No:

4-10 yaş grubu çocuklara tedavi öncesi ve sonrası uygulanacaktır.

Soru: Şuanda (diş tedavisinden önce) kendini hangi yüz gibi hissediyorsun?



5: En negatif ifade -> 1: En pozitif ifade

○ 5

○ 4

○ 3

○ 2

○ 1

APPENDIX B

Kod No:

Soru: Bir sonraki diş tedavisi randevunda robotun yanında olmasını ister misin?

○ 1

○ 2

○ 3

○ 4

○ 5

1: Hiç istemem-> 5. Çok isterim

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