DESIGN OF A ROBOTIC TOY AND USER INTERFACES FOR AUTISM SPECTRUM DISORDER RISK ASSESSMENT

by

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# ABSTRACT

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**Keywords:** Autism spectrum disorder, interface design, product design, risk assessment, robotic toy

Autism Spectrum Disorder (ASD) is an umbrella term for a spectrum of complex developmental disorders resulting in deficits in social communication and repetitive and stereotyped behaviors. According to research conducted in 2014, one in every 68 children in the United States is diagnosed with ASD. Despite this observation, there is no national screening system in Turkey, and screenings are not conducted systematically. Research in the area revealed that individuals with ASD are more interested in interact with technology (e.g. computers, iPad, robots, etc.) than human beings. This thesis includes research into how to design and use technology to create suitable products for deficits of ASD. With all of the concern over the high prevalence ratios of ASD, this thesis presents the methodology and design of a risk assessment device, which aims to capture the interest of children with ASD aged 3-4, and direct children who score low on the tests towards a diagnosis. In particular, the tests in the device focus on Theory of Mind (ToM) development and designed to detect differences with ToM tests between ASD and Typically Developing (TD) children. In the scope of the thesis, 2D illustrations, interface design, and outer shell design of the device are created in compliance with the research data in the field. Finally, outer shell design is 3D printed, and then surface is sanded and spray-painted.

# ÖZET

OTİZM SPEKTRUM BOZUKLUĞU RİSK DEĞERLENDİRMESİNE YÖNELİK ROBOTİK OYUNCAK VE KULLANICI ARAYÜZÜ TASARIMI

DENİZ UNCULAR

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**Anahtar Kelimeler:** Otizm spektrum bozukluğu, arayüz tasarımı, ürün tasarımı, risk değerlendirmesi, robotik oyuncak

Otizm Spektrum Bozukluğu (OSB) hafiften şiddetliye kadar karmaşık gelişimsel bozukluklar için kullanılan yelpaze terimidir. Bu gelişimsel bozukluklar sosyal iletişimde yetersizlik, tekrarlayıcı ve sterotipik davranışlara neden olmaktadır (APA, 2013). 2014 yılında yapılan bir araştırmaya göre, Birleşik Devletler'de her 68 çocuktan biri OSB tanısı almaktadır (Baio, 2014). Bu gözleme rağmen, Türkiye'de ulusal tarama sistemi bulunmamakta ve taramalar sistemli yürütülmemektedir (Rakap et al., 2017). Alandaki araştırmalar OSB'li bireylerin teknolojiyle (ör. bilgisayarlar, iPad, robotlar, vb.) etkileşime geçmekte insanlarla etkileşime geçmeye kıyasla daha istekli olduklarını ortaya çıkarmıştır (Fong et al., 2003). Bu tez OSB'nin yol açtığı eksikliklere uygun ürün yaratmak için tasarımın nasıl yapılması ve teknolojinin nasıl kullanılması gerektiği araştırmasını kapsamaktadır. OSB'nin yüksek yaygınlık oranları göz önüne alındığında, bu tez bir risk değerlendirme cihazının metodolojisini ve tasarımını sunmaktadır. Bu cihaz 3-4 yaş aralığındaki çocukların ilgisini çekmeyi ve testlerde düşük puan alan çocukları teşhise yönlendirmeyi hedeflemektedir. Cihazın içindeki testler özellikle Zihin Kuramı gelişimine odaklanmaktadır ve OSB'li çocuklarla tipik gelişim gösteren çocuklar arasındaki farklılıkları Zihin Kuramı testleriyle saptamaya yönelik tasarlanmıştır. Tez kapsamında cihazın prototipinin 2 boyutlu illüstrasyonları, arayüz tasarımları ve dış kabuk tasarımı alandaki araştırma verilerine uygun olarak yapılmıştır. Son olarak, dış kabuk tasarımı 3 Boyutlu yazıcı ile basılıp yüzeyi zımparalanıp sprey boya ile boyanmıştır.

# DEDICATION

*Bana her zaman inanan ve destek olan annem, babam, ablam ve Çağrı'ya…*

*Çok sevdiğim ve çok özlediğim canım babaannem Gülay Uncular'a…*

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# INTRODUCTION

According to the American Psychological Association (APA), Autism Spectrum Disorder (ASD) is an umbrella term for a spectrum of complex developmental disorders resulting in deficits in social communication and repetitive and stereotyped behaviors (APA, 2013). Individuals with Autism spectrum disorder (ASD) experience impairments in social communication and social interaction. These impairments include issues in social exchange, gestural behaviors in communication, and difficulties in building, preserving, and comprehending relationships. In addition to these impairments, behavior and interests appear to be limited and are marked by repetitive patterns (APA, 2013). Moreover, children with ASD suffer from impairments in communicating verbally and nonverbally, particularly with actions involving motor control, facial expression of emotions, and eye gaze attention (Dautenhahn, 2002). The diagnosis of ASD relies on behavioral criteria determined in a diagnostic handbook named the DSM-V (APA, 2013).

According to research conducted in 2014 (U.S.), one in every 68 children in the United States is diagnosed with ASD (Baio, 2014). According to research conducted by Autism Platform and their predictions from previous years, it is assumed that there are 550.000 children with ASD in Turkey and approximately 150.000 children with ASD aged between 0-14 years. Despite this observation, there is no national screening system in Turkey, and screenings are not conducted systematically. Also, despite the importance of early diagnosis, it is hard to say that early diagnosis has been achieved at a necessary level in Turkey (Rakap et al., 2017). Research into how to design and use technology that would increase diagnosis rates for ASD diagnosis is increasingly important. With all of the concern over the high prevalence ratios of ASD, this thesis aims to make a prototype of a risk assessment device as a supplementary tool for supporting screening systems in Turkey.

Research in the area revealed that individuals with ASD are more interested in interact with technology (e.g. computers, iPad, robots, etc.) than human beings (Fong et al., 2003). In accordance with this, in the last decade researchers have performed numerous studies that have used technology in therapy, diagnosis, and collecting data from the behavioral responses of individuals with ASD (Feil-Seifer, 2005; Cabibihan, 2013). This thesis presents the methodology and design of a risk assessment device, which aims to capture the interest of children with ASD aged 3-4, and direct children who score low on the tests towards a diagnosis. In particular, the tests in the device focus on Theory of Mind (ToM) development and designed to detect differences with ToM tests between ASD and Typically Developing (TD) children.

Chapter One begins with a brief description of ASD in infancy and early childhood, continues with the background about Theory of Mind (ToM) and ToM tests, ends with the findings on emotion perception and face processing strategies in ASD and cultural differences in emotion perception. Chapter Two includes, literature review on implementation of technological systems for ASD, principles and methodologies for designing for children with ASD, and shell designing robotic interfaces for children with ASD. Chapter Three contains the adaptation of ToM tests to the robotic toy, implementation of the design rules stated in Chapter Two to user interface and user experience design, and finally the shell design of the prototype.

# CHAPTER 1

# LITERATURE REVIEW ON AUTISM SPECTRUM DISORDER

## 1.1. Autism Spectrum Disorder in Infancy and Early Childhood

Abnormality of child's development is recognized by twenty-four months in 90% of the cases (De Giacomo & Fombonne, 1998). Proper gestures such as nodding and pointing appear to be absent after one year. However, the early signs of Autism Spectrum Disorder (ASD) alter with age. Infants with ASD might exhibit restricted eye contact and reduced social attention (Maestro et al. 2002; Sparling 1991). Both motor and vocal imitation may be diminished, and they may have difficulties with arousing or possess abnormal physical reactions (Dawson et al. 2000). According to the study of Maestro et al. (2002), compared to age matched control groups, infants later diagnosed with ASD displayed weaker visual attention to social stimuli. They were also less frequent in smiling, vocalizing, and engaging in object exploration. Their repetitive behaviors, however, did not differ from the control group. The studies of Werner et al. (2000) and Osterling and Dawson (1994), with 8 to 10 month-old infants and 12 month-old infant participants respectively, reported that infants later diagnosed with ASD tend to respond to their names less.

According to research in the area, the early predictors of ASD are as follows: diminished interest in social interaction, impaired social engagement, and communication difficulties starting from the first few months. However, other than social difficulties, dissimilarities from the control group are less prominent. Differences in communication such as the absence of attention toward speech, including their name, appear to be more noticeable by six to twelve months. Infants diagnosed with ASD in the future tend to have a reduced interest in social interaction with people and are less integrated in object exploration compared with typically developing infants (Bates et al. 1979). Social abnormality and communication deficits become prominent by thirty months (Ornitzet al. 1977). Children with ASD diverge from typical age matched children in terms of anticipatory postures, turn taking ability, eye contact level, and joint attention (Wimpory et al. 2000). They also exhibit atypical sensory behaviors and reduced emotional interaction (Hoshino et al. 1982). Below the age of three, children with ASD can be distinguished from typically developing or developmentally delayed children in terms of hindered social development, abnormal gaze, unusual play, and unresponsiveness to verbal communication (Dahlgren & Gillberg, 1989). Early diagnosis and intervention is essential for enhanced long-term results, yet though initial indications of ASD are observable in numerous instances before 12 months of age, infants and young children are challenging to diagnose (Volkmar et al. 1994).

### 1.2. Theory of Mind and Autism Spectrum Disorder

Theory of "mind blindness" has been proposed as the cognitive reason for social and communication difficulties of Autism Spectrum Disorder (ASD). This theory presumes that typically developed individuals are able to "mind read", which means that they are able to understand their own mental state and other people's mental states; this is also called the "Theory of Mind"(ToM) and "mentalizing". However, individuals with ASD have difficulties in social communication and with perceiving mental states (Frith, 2001). Typically developing children's ability to mentalize is believed to start with an innate mechanism and to develop with the child's social environment (Frith, 2001). Early indications of interest regarding the mental states of other individuals are observed through shared attention (Carpenter et al., 1998). Infants in the first year of life instinctively track the gaze direction of another person, meaning they direct their attention to what another person is attending. Referential looking is also present, meaning infants examine their caregiver's emotional manner before getting near or holding back from a new object (Repacholi, 1998). Imitation of complicated and deliberate activities of other people starts at 1.5 years of age (Meltzoff, 1995). Children around 2-3 years old acquire the ability to comprehend and practice mental state verbs such as want, know, and pretend (Bretherton, 1992). Mentalizing is believed to assist with learning word meanings (Bloom, 2000) by following the referential objective of the agent as well (Baldwin et al., 1996). Sophisticated matters such as false belief, deception, white lie, and double bluff are obtained frequently between 5-8 years of age (Frith, 2001).

The theory of mind hypothesis proposes that the innate mentalizing mechanism does not function properly in individuals with ASD. Although they may be able to learn mental states through training, they obtain this ability late and slow, also inclined to making mistakes when it comes to more complex mentalizing tasks, such as second-order false belief tasks (Frith, 2001). The mind blindness hypothesis does not imply that this is the underlying reason for repetitive behavior and the restricted, compulsively followed activities present in ASD, but it might be the reason for certain language deficits. Indeed, idiosyncratic use of language, language delay, muteness, and echoing of speech are common characteristics of ASD. Caregivers report abnormal ways of word learning even in children with Asperger disorder (Frith, 2001).

### 1.2.1. Theory of Mind Tests and Children with Autism Spectrum Disorder

Having a Theory of Mind (ToM) requires being able to comprehend all types of mental states and being capable of reflecting on what is in one’s own mind and the minds of others. In Autism Spectrum Disorder (ASD), the problem of comprehension regarding another person’s mind is a fundamental cognitive characteristic and seems to be universal. To be able to reveal this condition, developmentally appropriate tests should be practiced (Baron-Cohen, 2001). Tests listed by Baron-Cohen (2001) are described in the following paragraphs separately.

The “mental-physical distinction” test contains stories that one character is experiencing mentally (e.g. thinking about a dog) and the other character is experiencing physically (e.g. holding a dog). The child is asked to inspect which character can make diverse actions (e.g. which character can stroke the dog?). Typically developing three to four years old children are expected to answer correctly (only the character having the physical experience can perform this action), thus proving their understanding of mental and physical experiences. Such judgments are challenging for children with severe ASD despite having the requisite four-year-old level mental age (Baron-Cohen, 1989a).

In "understanding the functions of the brain" test, children with ASD (mental age minimum 4-years-old) are unable to state any mental functions of the brain (e.g. dreaming, wanting, thinking, keeping secrets) despite being able to successfully describe physical functions. On the other hand, 3-4 years old typically developing children are successful at both functions (Baron-Cohen, 1989a).

The "appearance-reality distinction" test also reveals differences between typically developing children and children with ASD. Objects may have deceptive identities - for instance an apple-shaped candle's appearance is similar to an apple, but in reality, it is a candle. Typically developing children around the age of four are able to differentiate appearance and reality, which demands keeping track of both the appearance of the object and what it really is. In impulsive explanations, children with ASD may not include the double identity of the object (Baron-Cohen, 1989a).

"First-order false belief" tests, consistent with the name of the test, comprise inferring mental state of one person only. Children with ASD have difficulties in comprehending that people may have diverse understandings about the same setting, and consequently they report only what they know rather than what other person thinks the situation is (Baron-Cohen et al., 1985, 1986; Perner et al., 1989; Reed & Peterson, 1990; Swettenham et al., 1996). However, typically developing children (4 years old) are able to determine other people's thoughts (Wimmer & Perner, 1983).

The "seeing leads to knowing" test is about comprehending the source of the knowledge, and is another keystone for developing a theory of mind. Comprehending the source of knowledge enables the child to differentiate who has which information. This is an essential step for communicating suitably, and for being able to deceive someone. This test includes a story about two characters: one character looks in the box and other character touches the box. Typically developing 3 year old children comprehend the ‘seeing leads to knowing’ norm and are able to identify which character has the information about what is in the box. However, children with ASD decide almost randomly on this test (Baron-Cohen & Goodhart, 1994; Leslie & Frith, 1988).

“Recognizing mental state words” is another sign of theory of mind development. Children with ASD have difficulties in separating mental state words such as think, know, dream, pretend, hope, wish and imagine from non-mental words (e.g. ‘verbs: jump, eat, move’ and ‘nouns: door, school, computer’). Through testing the understanding of mental state words, one may grasp markers of conceptual development in mental state comprehension. Typically developing 4-year-old children are able to distinguish mental state words from non-mental words (Baron-Cohen et al., 1994).

“Use of mental state words in spontaneous speech” is also distinguishably different between typically developing children and children with ASD. Children with ASD are inclined to communicate using fewer mental state words in spontaneous dialogue about picture stories containing action and deception, than are children in the control group. This may be an indication of setbacks, struggles, and diminished attention in understanding mental state concepts (Baron-Cohen et al., 1986; Tager-Flusberg, 1992).

The “spontaneous pretend play” test reveals that pretend play is also limited in children with ASD (Baron-Cohen, 1987; Lewis & Boucher, 1988; Wing et al., 1977). This may be an outcome of difficulties in reflecting on their imagination; in other words, a mindreading problem (Leslie, 1987). Alternatively, it may be a consequence of a problem with comfortably directing attention towards a ‘pretend mode’, correlated with executive function (Russell, 1997).

Emotions can be caused by physical events (falling, getting a present, etc.) or mental states (desires, beliefs, etc.). The “understanding the causes of emotion” test shows that 4-6 years old mental age children with ASD struggle with understanding the causes of emotion when it originates from more complex mental states. By way of contrast, their typically developing peers comprehend both sources of emotion (Baron-

Cohen, 1991; Baron-Cohen et al., 1993).

The test of “understanding the eye-region” relates to when an individual is thinking and to what an individual may desire, and shows that children with ASD are limited in comprehending such representations. Typically developing children (4 years old) can make deductions from gaze direction - for example, a gaze directed upwards and away indicates that a person is thinking about something. Gaze direction also gives clues as to what a person wants. Children with ASD have troubles in producing meaning from such indications. Though they can tell where a person is looking at, they do not make mental judgments from gaze direction intuitively (Baron-Cohen et al., 1995; Baron-Cohen & Cross, 1992).

Children with ASD and typically developing children also perform differently in the “monitoring one’s own intentions” test. Understanding someone’s intentions is crucial to comprehending the underlying reasons of their actions. In a study, 4-year-old children are requested to use a toy gun to hit one of the six aims. Before shooting the gun, they were asked to state which target they were aiming at. The experimenter manipulated the results, producing a miss or a hit for the selected target. Typically developing children were able to answer the question, ‘Which one did you mean to hit?’ correctly, but children with ASD often stated the one they actually hit rather than their aimed target (Phillips et al., 1998).

“Deception” tests also convey differences between two groups. In order to be convincing, a deception requires a person to be able to understand the thoughts of another person and understand that thoughts can be changed into believing something not true. Around the age of 4, typically developing children begin to demonstrate the ability to deceive other people (Sodian et al., 1992). Deception is a milestone signal of being able to understand other minds. However, both comprehending and creating deception is challenging for children with ASD (Baron-Cohen, 2001; Baron-Cohen, 1992).

Tests of “understanding for metaphor, sarcasm, jokes, and irony” are used to determine theory of mind development as well. As interpreting other people’s intentions is key for comprehending and using figurative speech such as sarcasm and metaphor, children with ASD also tend to differ from normally developing children in these tests. Experimenters used the "false naming paradigm" on 3 year-old typically developing children by saying, "This is a shoe" while pointing at a cup. Children appeared to be sensitive to the option that the statement could be a joke. On the other hand, children with ASD did not recognize the manner behind the sentence compared to typical group; they responded that the experimenter was essentially wrong (Baron-Cohen, 1997). However, according to Happe (1994), figurative speech may be learned without any appreciation of mental states, since they are static expressions.

As "pragmatics" comprises mindreading and the use of context, tests of pragmatics display difficulties for the ASD group (Baron-Cohen, 2001). Some of the aspects of pragmatics include: adapting speech, and the content of speech, to a specific audience according to what they previously know or what they should know; regarding codes of verbal communication such as being honest, appropriate, to the point, and well mannered; turn-taking suitably in the dialogue; caring for the input of the other party in the dialogue; distinguishing between appropriate and inappropriate things to say in a specific conversation; not moving away from the particular subject; and assisting the other person to keep track of when moving to another subject (Baron-Cohen, 2000). Studies suggest that children with ASD struggle with conversational relevance and recognizing when someone says the wrong thing (Baron-Cohen, 1988; Tager-Flusberg, 1993).

"Second-order false belief" tests are generally matched to a mental age of 6 years old whereas the first-order false belief tests mentioned above match to a 4-year-old's mental age. First-order tests related to figuring out the thoughts of just one person; second-order tests include being aware of someone's thoughts about another person's thoughts (Baron-Cohen, 2001). Despite the argument regarding the universality of first-order false belief tests, there are no reports on children with ASD passing first order false belief tasks at the appropriate age (Happe, 1995). Delay in accomplishing first-order tests of the theory of mind, seems to invariably result in failing second-order false belief tests later on (Baron-Cohen, 1989b).

Together with these ToM tests, children with ASD show differences in emotion perception and face processing as well. The following section explores the emotional perception and the abnormal face processing strategies of individuals with ASD.

**Table 1** Theory of Mind Tests

| Author(s) | Test | Age (TD*) | Ability/Difference |
|---|---|---|---|
| Baron-Cohen, 1989a | The “mental-physical distinction” tests | 3- to 4-year-old | Demonstrating good grasp of the ontological distinction between mental and physical entities and events. |
| Baron-Cohen, 1989a | The “understanding the functions of the brain” tests | 3- to 4-year-old | Knowing that the brain has a set of mental functions, such as dreaming, wanting, thinking, and keeping secrets. |
| Baron-Cohen, 1989a | The “appearance-reality distinction” tests | 4 years old | Distinguishing between appearance and reality, that is, they can talk about objects, which have misleading appearances. |
| Baron-Cohen et al., 1985, 1986; Perner et al., 1989; Reed & Peterson, 1990; Swettenham et al., 1996 | The “first-order false belief” tests | 4 years old | Understanding that different people can have different thoughts about the same situation. |
| Baron-Cohen & Goodhart, 1994; Leslie & Frith, 1988 | The “seeing leads to knowing” tests | 3 years old | Comprehending the source of the knowledge and who knows what |
| Baron-Cohen et al., 1994 | The “recognizing mental state words” tests | 4 years old | Picking out from a word list words that refer to what goes on in the mind or what the mind can do |
| Baron-Cohen et al., 1986; Tager-Flusberg, 1992 | The “use of mental state words in spontaneous speech” tests | Preschool | Producing fewer mental state words in their spontaneous descriptions of picture stories involving action and deception, and in their conversational discourse, compared to their normal counterparts |
| Baron-Cohen, 1987; Lewis & Boucher, 1988; Ungerer & Sigman, 1981; Wing et | The “spontaneous pretend play” tests | 3-5 years old | A lower frequency of pretend play in the spontaneous play of children with autism |

| | | | |
|---|---|---|---|
| al., 1977 | | | |
| Baron-Cohen, 1991; Baron-Cohen et al., 1993 | The “understanding the causes of emotion” tests | 4- to 6-year-olds | Normal 4- to 6-year-olds understand all types of emotional causation. In contrast, studies show that children with autism with this mental age have difficulty with mental states as causes of emotion |
| Baron-Cohen et al., 1995; Baron-Cohen & Cross, 1992 | The “understanding the eye-region” tests | 4 years old | Making deductions from gaze direction - for example, a gaze directed upwards and away indicates that a person is thinking about something. Understanding that gaze direction also gives clues as to what a person wants. |
| Phillips et al., 1998 | The “monitoring one’s own intentions” tests | 4 years old | Keeping track of people's intentions |
| Baron-Cohen, 2001; Baron-Cohen, 1992 | The “deception” tests | 4 years old | Understanding and accomplishing deception. A deception requires a person to be able to understand the thoughts of another person and understand that thoughts can be changed into believing something not true |
| Baron-Cohen, 1997; Happe, 1994 | The “understanding for metaphor, sarcasm, jokes, and irony” tests | 3 years old | Understanding figurative speech through story comprehension. Figurative speech requires an understanding of the speaker's intentions, in order to move beyond the literal level of simply mapping words onto their referents. |
| Baron-Cohen, 1988; Tager-Flusberg, 1993 | The “pragmatics” tests | Preschool | Understanding conversational relevance and recognizing when someone says the wrong thing |

| | | | |
|---|---|---|---|
| Baron-Cohen, 1989b; Bowler, 1992; Happe, 1993; Ozonoff et al., 1991 | The “second-order false belief” test | 6 years old | Being aware of someone’s thoughts about another person’s thoughts |

*TD: Typically Developing

## 1.3. Emotion Perception and Face Processing in Autism Spectrum Disorder

Typical social interactions require the understanding of facial expressions and the ability to gather social information from faces. Even typically developing newborn infants are highly attentive to faces. They tend to fixate more on images that consist face-like patterns than on wrongly configured facial features or an arrangement of a face without such features (Morton & Johnson, 1991). Typically developing individuals usually depend on the spatial arrangement of the eyes, nose, and mouth to detect emotions and recognize faces. Face processing is generally holistic or organized. On the other hand, object recognition is based on a segmental process that requires features to be detected individually (Diamond & Carey, 1986; Farah et al., 1998; Gauthier & Tarr, 1997; Valentine, 1988). Inverting and changing the typical configuration of facial features makes face processing more difficult (Haxby et al., 1999; Valentine, 1988), which generates key evidence for holistic face processing. It also pushes individuals more towards a segmental strategy of face processing to reduce the impact of inversion (Farah et al., 1998; Valentine, 1988).

Studies have shown that typically developed adults attend to the core features of the face rather than to the outer features (Pelphrey et al., 2002). Instead, individuals with Autism Spectrum Disorder (ASD) tend to focus more on facial features separately such as the mouth area (Hobson, Ouston, Lee, 1988; Langdell, 1978), which perhaps is a sign of relying on a segmental strategy to process faces (Pelphrey et al., 2002). Consistently, individuals with ASD are influenced less by the inversion of faces than typically developed individuals. Furthermore, they have better performance with object perception than face perception (Boucher & Lewis, 1992; Davies et al., 1994; Langdell, 1978).

Perphery et al. (2002) investigated the visual strategies of individuals with and without ASD when met with face stimuli. The study revealed that individuals with

ASD spent significantly more time observing the outer features of the face, and spent less time viewing the inner (primary) features such as the nose, mouth, and especially the eyes when compared with typically developed individuals. Face processing strategies of individuals with ASD appeared unpredictable, disordered, and aimless, usually processing unimportant features such as the ears, chin, and the hairline region. On the contrary, the scanning pattern of typically developed individuals indicate tactical and organized processing, usually scanning the eyes, nose, and mouth, creating a triangular shape with their gaze pattern (Perphery et al., 2002).

Impaired social communication is one of the diagnostic characteristics for Autism Spectrum Disorder (ASD) (APA, 2013), and which is often discovered through the atypical eye contact that individuals with ASD display in social interaction. Individuals with ASD display an unusual gaze pattern when observing at facial features. They tend to spend longer period of time at the mouth area and less at the eye area, whereas normal developing individuals follow the opposite strategy (Pelphrey et al., 2002; Klin et al., 2002). Despite this unusual gaze pattern, high-functioning adults with ASD are generally able to identify individuals and their basic emotions from their faces (Adolphs et al., 2001). However, more complex tasks such as comprehending social intents and mental states from eye expressions are impaired in individuals with ASD (Baron-Cohen et al., 1997).

Perphery et al. (2002) observed that individuals with ASD tend to perform worse when identifying the five basic emotions (anger, disgust, happiness, sadness, and surprise) than the control group even they were statistically equivalent, and performed statistically poorer in identifying fear. Differences in face scanning strategies from typically developed individuals may be the core reason for the poor face perception and emotion recognition abilities among individuals with ASD (Perphery et al., 2002).

The understanding that eye gaze is an indication for visual attention is impaired in children with ASD, although children with ASD are able to perceive gaze direction correctly (Baron-Cohen et al., 1999; Leekam et al., 1998). There are several hypotheses concerning these impairments. One hypothesis suggests that individuals with ASD become distressed due to eye contact and this results in making less eye contact (Dalton et al., 2005). Another hypothesis proposes individuals with ASD are attracted to the mouth area due to its motion and sound making. A final hypothesis suggests that individuals with ASD are interested in the mouth because it compensates for the lack of ability to gather social clues from the eyes.

According to findings from the research conducted by Neumann et al. (2006), individuals with ASD focus the eyes when there are saliency signs, but they focus on the mouth whether or not there are saliency signs. Visual attention models combine two distinct sources for gaze. Plain features, such as high contrast, or actions, impact eye movements in a bottom-up manner. On the other hand, meaning, learned connections, and prospects operate in a top-down manner that results in a deliberate search for the stimulus. The bottom-up model relies purely on signals in the image, whereas the top-down model is based on learned associations or prior knowledge about the stimulus (Neumann et al., 2006). Neumann et al. concludes that individuals with ASD use a bottom-up process of attention for the eyes like the normally developed control group, however they use an abnormal top-down process for the mouth. Results are consistent with the findings, suggesting individuals with ASD have deficits in comprehending complex social information from the eyes, and thus they depend on clues they gather from the mouth for emotional deductions. Neumann et al. (2006) suggests behavioral interventions might gain an advantage from low-level visual cues, and from top-down directions to train eye gaze.

### 1.3.1. Abnormal Face Processing Strategies in Children with Autism Spectrum Disorder

Deficits in social and emotional interaction are believed to be an explicit attribute of Autism Spectrum Disorder (ASD), although the spectrum is immensely heterogeneous. Initial signs of the ASD, such as deficits in shared attention, indifference to the human face, and favoring inanimate items, may reveal itself as immediately as the first year (Cohen & Volkmar, 1997; Baron-Cohen et al., 2000). Starting from early infancy human faces are crucial in terms of social and emotional communication, and thus deficits in face processing in ASD are being intensively investigated. Healthy newborns direct visual attention to the human face. They prefer a representational drawing of a face rather than other drawings, even if the internal parts of the face are scrambled (Johnson et al., 1991). Furthermore, the direct gaze is more favorable than an averted gaze or no gaze (closed eyes) for newborns (Farroni et al., 2002). The underlying principles of these preferences are not definitively known. A hypothesis proposes that these inclinations are due to an instinctive mechanism and that this mechanism believed to be facilitated by subcortical neural systems (Morton & Johnson, 1991). On the other hand, another hypothesis suggests that these preferences are a consequence of the immaturity of the visual system and high contrast between the pupil of the eye and sclera (white region), which attracts that the infant's attention (Cassia et al., 2004). The interest in human faces is believed to be an essential element of typical development, and this prevails for either of these hypotheses. The lack of shared eye contact is a primary and salient indication of ASD. Abnormal social behaviors that are prominent in ASD include a lack of eye contact and the absence of mutual gaze (Volkmar et al., 2005).

Infants affected by congenital cataracts are not able to acquire high-resolution visual input for in average 199 days. As a result, they suffered from deficiencies in face recognition an average of 17 years later (Le Grand et al., 2003). This evidence suggests that interferences in primary visual input might cause enduring face processing complications. Correspondingly, early abnormal gaze patterns in individuals with ASD cause decreases in experience with internal face features, and may increase face-processing deficits in the long-term. On the other hand, problems in facial information processing may be the cause of the lack of eye contact (Golarai et al., 2006).

Abnormal visual scanning pattern is a substantial sign of ASD. However, significant differences in gaze behavior are known between age groups. Between the ages of 9-14 children with ASD interpret and adjust to averted gaze suitably, however identifying direct gaze occurs slower than in the control groups (Senju et al., 2003). Research has revealed that compared to the control groups, adults with ASD look less at the inner parts of the face, and especially the eyes. The ASD group focused on the outer features of the face and their visual scanning patterns seemed irregular and inconsistent. By contrast, the focus of the control group was between the eyes, nose and mouth, and their scanning formed a triangular visual pattern (Pelphery et al., 2002).

The improvement in recognizing facial identity in children begins to develop very early in life. Indications of face recognition are there even for newborn infants at three to four days (Pascalis & Schonen, 1994). Infants are capable of recognizing the facial identities of humans starting from six months. Two-year-old children develop the ability to identify numerous human faces (Pascalis et al., 2002). Although face recognition skills start to emerge early in life, its development continues through adolescence. In childhood the recognition abilities for new faces is enhanced extensively. Research suggests that visual experience from various faces develops perceptual skills and enables face recognition (Carey, 1992). Children with ASD show deficiencies in face recognition and their ability to memorize new faces starting from 2 years old (Klin et al., 1999). Abnormal face scanning patterns have been suggested as the underlying cause for impaired face recognition memory as well (Langdell, 1978). Besides these abnormal processing strategies resulted from ASD, cultural differences considered to be an influential factor for societies in terms of their visual strategies. For this reason, the next section focuses on cultural differences in emotion perception.

### 1.3.2. Cultural Differences in Emotion Perception

The perception of emotion states is essential for social interaction and communication, which makes faces very attractive for humans, and even for newborns. Whether culture has an impact on the perception of emotion states is a valid and an ongoing research question, and recent studies indicate that there are significant differences between various cultures. Recent research has shown that emotion perception is influenced by patterns of attention to social context. Apparently, both Western and Eastern cultures are attentive to contextual elements, but the result of this attention seems to be different across cultures (Masuda et. al, 2008). For instance, Masuda et al. (2008) has suggested that Eastern perceptions are more likely than Western perceptions to be attentive to contextual elements. In contrast to Western participants, Eastern participants in Masuda et al. (2008)'s research integrated the emotions of the contextual figures with the central person's facial expressions when the task was evaluating the central person's emotion. The differences between these attention patterns may have a relation with the participant's cultural background, in the sense that Western cultures are generally considered individualistic and Eastern cultures collectivist. Recent research suggests that individualist cultures are prone to displaying an analytic (contrasting context) pattern of attention by construing elements in sight according to their attributes, whereas collectivist cultures are more prone to displaying a holistic pattern of attention by comprehending elements in sight in terms of their associations with other elements (Stanley et al., 2013).

Senju et al. (2013) have focused on the role of culture and gaze directions of the emotion-encoder on the development of face scanning in young children whose ages vary from between one and seven years old. To investigate this subject, Senju et al. (2013) recorded the eye movements of British and Japanese participants while they were observing dynamic faces with direct and averted gazes. Stimuli (dynamic faces) were generated from four female actors (two Eastern Asian, two Caucasian); thus, gender difference in stimuli was not considered. Senju et al. (2013) stated, however, that they did not find any impact of gender. In contrast to the previous studies which utilized gaze direction as stimuli (Krämer et al., 2013; Krämer et al., 2014), Senju et al. (2013) used real models. Six-second video stimuli were created; all videos began with an averted gaze for one second and then gaze was shifted towards the participant or away from the participant, and after two seconds from the start the model smiled. Finally, the model remained still for three seconds.

Eye movements were recorded and visit durations were calculated for each area of interest (AOI). Senju et al. (2013) determined the AOIs as follows: front eye, back eye, bridge, center and mouth. The difference between the front eye and the back eye comes from the tilt of the faces to one side or another, and this makes one of the eyes seem closer to the participants. After conducting a statistical analysis on the visit period data, Senju et al. (2013) reported that the relative visit period of British children was considerably longer on the mouth, whereas Japanese children tended to focus considerably longer on the eyes, at least when compared to one another. These findings replicate the results of the prior studies with adult participants. However, they noted that their observations did not reveal any cultural differences regarding the gaze direction (direct or averted) of the stimuli, which is significantly different from the results reported by Krämer et al. (2013; 2014) which implied that the gaze direction influences interactions with the ethnic in-group and ethnic out-group differently during emotion perception. Senju et al. (2013) also diverged with Krämer et al. (2013; 2014) regarding differences between in-group and out-group interaction; they did not find that the ethnicity match or mismatch of the participants and the stimuli produced a noticeable effect. The discrepancy between these findings indicates that differences of gaze pattern among cultures are present from young childhood, whereas variations among cultures due to gaze direction occur in later stages in life.

Senju et al. (2013) contrasted younger and older children on three AOI (front eye, back eye and mouth) gaze times in order to analyze developmental alterations in culture-related face gaze, and in the process they detected that both the cultural background and the gender of individuals has an influence in this regard. In accordance with their analysis, Senju et al. (2013) noted the younger male children and the older female children revealed significantly more culturally influenced gaze patterns than the other participants. Moreover, British children, and particularly males, tended to show age and sex associated alterations in face gaze more prominently. Thus, this finding may imply that there is a difference in the gaze pattern development of male and female children in terms of the time of development. In general, the findings of Senju et al. (2013) imply that culture-specific face gaze patterns are more prevalent in children than in adults.

In conclusion, throughout the average lifespan, the perception of emotion states is an essential criterion for human beings to communicate and interact with each other; this is true even for a newborn. Researchers have found that while both Western and Eastern cultures are attentive to contextual elements, they differ in their attention patterns in relation to emotional perception (Stanley et al., 2013). These differences may be based on cultural background in the sense that Western cultures are individualistic and Eastern cultures are collectivistic. Indeed, studies have shown that the gaze patterns of Americans has more transitions which include the target face, or target transitions, than do the gaze patterns of Chinese participants. The influence of gaze direction on emotional perception across cultures seems to represent a valid concept in the role of stimuli. In this sense, as these findings have implied, in the direct gaze condition Eastern participants perceived one another's face as angrier, more unapproachable, and more unpleasant than Western participants. Studies have also indicated that anger is perceived as more prominent when it comes from an out-group member in the direct gaze condition, whereas anger is perceived as more prominent when it comes from an in-group member in the averted gaze condition. Direct gaze conditions from in-group members, and averted gaze conditions from out-group members are interpreted as more prominent when interpreting happiness.

# CHAPTER 2

# HUMAN-ROBOT INTERACTION

Technological systems that are used for individuals with Autism Spectrum Disorder (ASD) are considered to be a type of human-machine interactive systems. In these systems, the human section consists of one or more participants, and the technology section involves a computer or a robotic system. The technology section is broken down into two groups: output and input. Output is generally comprised of visual and audio material, and input is the data collected from participants by keyboard, mouse, touch-screen, wearable sensors, or eye tracking devices (Liu et al., 2017). Touch-enabled mobile devices, computer monitors, virtual reality, and social robots are the technological systems that are used to deliver serious games or programs for ASD. Each of these device categories has benefits and drawbacks concerning cost, accessibility, and efficiency (Liu et al., 2017). For example, utilizing a mobile device for serious games and programs is beneficial in terms of accessibility, convenience, and interactivity. Moreover, touch screens on mobile devices eliminate the use of a keyboard or mouse and increase interaction (Liu et al., 2017).

## 2.1. Implementation of Technological Systems for Autism Spectrum Disorder

Individuals with ASD exhibit a particular interest in technology. Computer systems provide advantageous settings suitable for addressing the social interaction deficits of ASD, for instance providing a consistent, openly defined goal and usually a single focus of attention without any interruptive stimuli (Grynszpan et al., 2014). Also, individuals with ASD generally experience difficulties when facing social expectations.

Since computer systems are able to deliver instant, anticipated, and stable feedback, they appear to be more favorable than human interaction (Moore et al., 2000). Considering that real-world experiences contain uncontrollable variables, researchers in the area have created interactive environments mostly in the form of software platforms for children with ASD (Heimann et al., 1995; Pares et al., 2005; Lányi & Tilinger, 2004). These platforms are used to convey information in a more engaging manner and embed educational context in an entertaining environment. Moreover, progress in information communication technology has enabled the utilization of diverse types of input; the majority of the research in this area is dedicated to touch-screen technologies for gathering input rather than mouse-based systems.

Technological systems are implemented to aim at various intervention purposes for children with ASD, targeting behaviors including imitation (Robins et al., 2004a; Pioggia et al., 2007; Kozima et al., 2007; Robins et al., 2009; Duquette et al., 2008), joint attention (Robins et al., 2004b; Kozima et al., 2007; Robins et al., 2009), turn-taking (Kozima et al., 2007; Robins et al., 2009; Dautenhahn, 2003), eye contact (Robins et al., 2004a; Kozima et al., 2007; Shamsuddin et al., 2012; Robins et al., 2009; Meltzoff et al., 2010), emotion and face recognition (Golan & Baron-Cohen, 2006; LaCava et al., 2007; LaCava et al., 2010; Silver & Oakes, 2001), social skills (Bernard-Opitz et al., 2001; Farr et al., 2010; Mineo et al., 2009; Parsons et al., 2006; Sansosti & Powell- Smith, 2008; Simpson et al., 2004), language and reading skills (Tjus et al., 2001; Williams et al., 2004; Rajendran & Mitchell, 2006), and scheduling daily activities (Cramer et al., 2011; Carlile et al., 2013; Fage et al., 2014).

### 2.1.1. Benefits of Implementation of Technological Systems for Autism Spectrum Disorder

Individuals with Autism Spectrum Disorder (ASD) and their families confront difficulties in acquiring health care. In Turkey, children diagnosed with ASD need to be assessed by "Guidance and Research Center (GARC)" (*Rehberlik ve Araştırma Merkezleri*) in order to access special education services provided by the state (Aksoy & Diken, 2017). However, there are significant limitations concerning qualified and experienced special education personnel in ASD at GARCs. Personnel in these institutions have prior education in mind, hearing, or visual impairment and later receive limited education in ASD (Rakap et al., 2017). Another limitation is a lack of adequate assessment instruments and educated personnel who are able to practice proper evaluation regarding communication, social interaction, and restrictive patterns of behavior (Rakap et al., 2017). Educational assessment can only be conducted at GARCs, yet there are only one or two GARCs in the majority of provinces in Turkey. These circumstances result in families who live far from the city centers travelling great distances to access services. Complicating the picture more, since there are only one or two GARCs in the majority of provinces in Turkey, these institutions are over-occupied. This excessive workload results in hindering an extensive educational assessment process and impacting its quality. Furthermore, educational assessment and diagnosis conducted outside the natural environment of the child hinders the data gathering process about the natural behavior of the child (Rakap et al., 2017).

Autism spectrum disorder diagnosis rates in children have been increasing in recent years. A child is born with ASD one in every 68 births (Baio, 2014). However, according to a recent study conducted in Turkey by Tohum Otizm Vakfı, only 58% of the citizens answered yes to the question: "*Have you ever heard of a developmental disorder by the name of autism?*" and only 18% answered yes to the question "*Are you aware of the symptoms of autism?*" ("Türkiye'deki Bireylerin Otizm Algısı ve Bilgi Düzeyi Araştırması", 2017). Infrastructural drawbacks accompanied by low awareness rates lead to difficulties in diagnosis. Complementary implementation of technological systems may increase the awareness of citizens about ASD risk and early diagnosis.

Individuals with ASD are generally greatly attracted to and motivated by technology: therefore, technology-facilitated education is suitable to assist them in concentrating on academic and behavioral development. Professional assistance in the area is expensive and may be unreachable for some caregivers. Technology-facilitated mobile instruments for education and self-management may be beneficial for improving skills of individuals with ASD and their caregivers, which may decrease their dependence on professional assistance (Goodwin, 2008). For example, wearable sensors that are able to detect and record sensory input enable the interpretation of the arousal levels of individuals with ASD, thus assisting them in comprehending, transferring, and controlling their arousal levels (Goodwin et al., 2006). A growing body of research has been conducted to evaluate the benefits of implementation of technological systems for

ASD. A high proportion of the research in this area focuses on social interaction and communication difficulties (Grynszpan et al., 2008). Advantages of implementation of technological systems include adaptability, manageability, and supportiveness. Since individuals with ASD generally experience difficulties while interacting with other individuals, human-computer interaction appears to be more comfortable, attractive, and pleasant for children with ASD (Boucenna et al., 2014).

According to Moore and Calvert (2000), computer-based vocabulary lessons provide better motivation, attention, and vocabulary learning for children with ASD in comparison to lessons provided by a human instructor. Hetzroni and Tannous (2011) explored a computer-based intervention program aiming to improve the communicative abilities of children with ASD. The software program was constructed so as to comprise daily life activities about play, hygiene, and food. Research revealed that the program succeeded in enhancing communication and that children were able to adapt these improvements to the classroom environment (Hetzroni & Tannous, 2011). Leonard et al. (2002) developed a single-user virtual reality environment that recreates real-life scenarios such as finding a place to sit in various settings. Adolescents with high functioning autism exhibited a significant enhancement in managing social scenarios appropriately (Leonard et al., 2002). Golan et al. (2010) evaluated an educational animated series named "The Transporters" developed by the Autism Research Centre. The Transporters consisted of toy vehicles running on tracks or cables (e.g. trams, cable cars) to restrain movement possibilities in order to simplify variables. Into the vehicles were inserted real-life faces of actors expressing emotions in a social context between the toy vehicles. By depicting social interactions between emotionally expressive toy vehicles, The Transporters aims to improve the emotion recognition ability of children with ASD. After the children watching The Transporters every day for four weeks, Golan et al. (2010) observed that children with ASD significantly improved in emotion recognition. In another important study focusing in social deficits, Bernard-Opitz et al. (2001) presented different animated social problems on a computer screen and asked for solutions. Subsequently, training sessions were conducted. In the training sessions, a person explained the solutions of the problems, and then the solutions were demonstrated through animations. After the training sessions, Bernard-Opitz et al. (2001) observed a stable increase in the success of children with ASD in solving social problems.

Despite various advantages of computer-aided systems, researchers have also suggested that individuals with ASD could experience difficulties in generalizing knowledge obtained through computers to everyday life (Bernard-Opitz et al., 2001; Lord & Bishop, 2010; Ricks & Colton, 2010; Cabibihan et al., 2013). Additionally, researchers express concern about dependence on computer-aided systems and the possibility of isolation (Moore & Taylor, 2000).

### 2.1.2. Implementation of Technological Systems and Robots in Diagnosis of Autism Spectrum Disorder

Diagnosis of autism spectrum disorder is challenging before a child is 3 years old because behavioral patterns that are observed for diagnosis have not completely developed before that age (Campolo et al., 2008). Nevertheless, early diagnosis and intervention is essential for enhanced long-term results (Volkmar et al. 1994). Diagnosis of autism spectrum disorder relies on behavioral observations (APA, 2013). Individuals are evaluated based on behavioral criteria determined in a diagnostic handbook DSM-V (APA, 2013); however, evaluation processes are subjective and differences of opinion may arise between clinicians (Klin et al., 2000). To deal with such limitations, an objective and quantitative method for measuring behavioral criteria may be accomplished through implementation of technological systems. Research has indicated that gaze patterns of infants may be evaluated using a robotic system to early diagnose Autism Spectrum Disorder (ASD) (Scassellati, 2007). Social robots may be utilized to reproduce uniform actions and coherent evaluations (Scassellati et al., 2012). Since robots are able to deliver consistent stimuli and stable performance, they may aid in the development of more standardized diagnosis processes. Additionally, camera systems on robots able to identify the type of behavior (positive or negative) may offer objective evaluations for diagnosis (Feil-Seifer & Mataric, 2012). Several technology-facilitated systems have been developed to achieve this purpose (Hashemi et al., 2015; Duda et al., 2016; Cho et al., 2016; Scassellati, 2005; Petric et al., 2014).

Hashemi et al. (2015) developed a mobile application for assessing ASD risk in young children by quantifying social referencing and affective behaviors. Behaviors that are quantified include social referencing, social smiling, pointing, and directing facial expression to others. In the study, 16-30 month old children watched visual stimuli (e.g. bubbles and a social scene featuring a mechanical bunny) on an iPad and their behaviors were recorded via iPad camera. Hashemi et al. (2015) utilized an iPad with a simple stand, and the child was on his/her parent's lap 1 meter away from the iPad. Automated computer vision algorithms are employed to quantify ASD risk behaviors by coding emotions and social referencing of the child. Hashemi et al. (2015) suggest that the application may measure the possible risk for ASD and may increase access to ASD screening. However, they have not established a group difference on a large sample, and they indicate that further enhancement of the application is required. Moreover, they intend to collect data at home and school environments since they expect variances in children's performance in different settings (Hashemi et al., 2015).

Duda et al., (2016) created an ASD screening tool named the Mobile Autism Risk Assessment (MARA), which is a caregiver questionnaire about the communication skills, behaviors, and social abilities of the child. The MARA aims to distinguish children with ASD from those with other developmental disorders. The MARA is conducted on an electronic platform and is able to score the questionnaire results automatically, which eliminates additional scoring time and the need for a trained clinician to score the test results. The questions of the MARA are listed below:

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"1. How well does your child understand spoken language, based on speech alone? (Not including using clues from the surrounding environment)
2. Can your child have a back-and-forth conversation with you?
3. Does your child engage in imaginative or pretend play?
4. Does your child play pretend games when with a peer? Do they understand each other when playing?
5. Does your child maintain normal eye contact for his or her age in different situations and with a variety of different people?
6. Does your child play with his or her peers when in a group of at least two others?
7. When were your child's behavioral abnormalities first obvious?" Duda et al., (2016)

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For each question, caregivers are required to choose from 4-5 answers and a "non-applicable" option. The test can be completed at any device that is connected to the Internet. Through a machine-learning model, the set of answers is converted into a final score that varies between -10 and 7. Based on the clinical evaluation of the MARA, researchers claimed that it is able to detect children with ASD with 89.9% sensitivity. Duda et al., (2016) suggest that if the results are established on a large sample, the MARA could be used to determine children with the highest risk of ASD among children with behavioral and/or developmental concerns.

Cho et al. (2016) utilized eye-tracking technology to analyze gaze patterns for ASD screening. The screening technique that Cho et al. (2016) developed is called Gaze-Wasserstein (due to the computation method that is utilized), and it can be adapted to every mobile device with a front camera. Visual stimuli that they have presented for eye tracking consisted of four social scenes (comprising more than one human figure) and four non-social scenes (containing few non-human figures). Images with plain backgrounds are chosen in order to avoid distraction. Each visual stimulus is presented for five seconds and the changing period to the next visual stimulus was 2 seconds (Cho et al., 2016). Based on the research conducted with 2-10 year old children, Gaze-Wasserstein claims to be 93.75% precise in screening ASD. Cho et al. (2016) claim that their research demonstrates the capability of Gaze-Wasserstein and should leads to the implementation of mobile technologies into ASD screening.

Scassellati (2005) employed passive social cue recognition systems and social robots to deliver quantitative data for ASD diagnosis. Passive social cue recognition systems detect gaze direction, prosody from human voices, and the position of the participants (Scassellati, 2005). However, Scassellati (2005) believes that social robots enable distinctive conditions for inspecting social responses more comprehensively. Scassellati (2005) listed the benefits of utilizing interactive robots as follows:

1. Autonomously gathering data independent from clinic environments, improving quantity and quality of the data without the need for additional fieldwork by clinicians.

2. Producing stimuli to obtain certain responses from the participants, especially eliciting infrequent behaviors or behaviors that are difficult obtain in diagnosis at clinic environments.
3. Robot's actions can be rearranged particularly to explore responses to interaction variables.
4. Producing uniform stimuli and providing consistent recording procedure without bias, thus simplifying the diagnosis process. Also, robots may be used to evaluate the outcomes of therapy and may set a standard for assessing social skills.
5. Motivating participants for social interaction, especially participants who are not willing to interact with humans.
6. Robots enable interaction to be gradually developed by offering levels of complexity to adjust the abilities of the user. According to Scassellati (2005), this continuous development may enable clinicians to focus on individual abilities and may enable incremental training.

Scassellati (2005) employed a low-cost robot, named ESRA, which can produce limited facial expressions. The robot performs a two-minute script that comprised of actions and audio from speakers adjacent to the robot. The script consists of three parts: waking up, asking questions, and falling asleep. The robot had limited skills; it did not have sensory abilities, and was unresponsive to the child's actions. Despite these limitations, all children (with and without ASD) tolerated the robot well and appeared to enjoy the performance (Scassellati, 2005). Scassellati (2005) suggest that a potential product of the study is a performance-based screening method able to identify ASD risk in newborns and toddlers. Also, the study may enable a detailed analysis of social abilities and increase knowledge about ASD (Scassellati, 2005).

Petric (2014) developed a robot-facilitated diagnostic protocol by modifying four tasks from the Autism Diagnostic Observation Schedule (ADOS) and utilizing an anthropomorphic robot, Nao, which is broadly used for children with ASD. The first task of the protocol is to call the child by name and assess the child's ability to attend to the source of the call. The second task is comprised of demonstrating an action and evaluating the functional and symbolic imitation skills of the child. The third task resembles the first task; the robot calls the child by name; however, this third task requires the child's attention to be focused on another object via the robot's head movements and pointing. The fourth task is bubble play, which aims to investigate the child's ability to communicate on several channels (eye contact, gestures, and vocal expression) at the same time (Petric, 2014). The robot aims to collect gaze pattern and vocal expression data during the protocol to obtain unbiased observation. According to the first clinical tests with preschool children, Nao's observations were mostly consistent with clinicians, and outcomes of the study are considered to be promising (Petric et al., 2014).

**Table 2 Implementation of Technological Systems and Robots in Diagnosis of ASD**

| Author(s) | Technology | Age Group | Method |
|---|---|---|---|
| Hashemi et al., 2015 | Mobile application, iPad | 16-30 month old | Assessing ASD risk in young children by quantifying social referencing and affective behaviors. |
| Duda et al., 2016 | Software that can be operated at any electronic platform | 16 months-17 years | A caregiver questionnaire about the communication skills, behaviors, and social abilities of the child. The MARA aims to distinguish children with ASD from those with other developmental disorders. |
| Cho et al., 2016 | Eye-tracking, can be adapted to every mobile device with a front camera | 2-10 year old | Analyzing gaze patterns for ASD screening. |
| Scassellati, 2005 | Passive social cue recognition system and a low-cost robot | Newborns and toddlers | Passive social cue recognition systems detect gaze direction, prosody from human voices, and the position of the participants. |
| Petric et al., 2014 | Anthropomorphic robot Nao | Preschoolers | A robot-facilitated diagnostic protocol by modifying four tasks from the Autism Diagnostic Observation Schedule (ADOS). |

Overall, robots are beneficial for ASD therapy because they are less complex and more predictable compared to human beings, which enables children with ASD to follow instructions more easily. Since interacting with robots is simpler than interacting with humans, children are less intimidated by the intricacies of verbal or non-verbal communication, and can communicate with robots more conveniently (Michaud, 2003; Kozima, 2007). Therefore, utilizing robots as instruments for diagnosis and therapy embraces beneficial opportunities (Cabibihan et al., 2013). Also, in order to facilitate interaction, robots may be designed as appealing little toys so they can perform as playmates for children (Michaud et al., 2003; Dautenhahn, 2003). Robots can provide customizability of therapy by modifying their attitude according to each child (Robins et al., 2007). Another advantage of utilizing a robot is the enabling of embodied interactions; physical motion and tactile contact allow robots to be more appealing and attractive for children (Billard et al., 2007). Virtual environments do not provide tactile interaction, which makes utilizing robots more advantageous (Dautenhahn et al., 2003).

## 2.2. Designing for Children with Autism Spectrum Disorder

Serious games are computer-based intervention programs that aim to improve target skills (Fridenson-Hayo et al., 2017). The design principles set for serious games are applied to the potential risk assessment tool that is developed in the scope of this thesis. Some of the design principles for serious games are; including a storyline or a narrative, gradually increasing levels of difficulty, defining clear task goals, providing clear instructions, delivering feedback and rewards, ensuring repeatability and predictability of game tasks, presenting smooth transitions, minimalistic graphics, simple sound, and dynamic stimuli (Bartoli et al., 2014; Whyte et al., 2015). Including a storyline or a narrative contextualizes game tasks, increases enjoyment, and provides motivation to pursue the game. Providing increasing levels of complexity in the game enhances engagement and motivation since games require less effort at first and become progressively challenging. Task objectives should be clear for participants to follow easily. Instructions should be clear and text should be supported via sound and visuals for better comprehension of the goals. Alongside continuous feedback, rewards with visuals, animation, or sound should be presented to encourage children with Autism Spectrum Disorder (ASD) (Whyte et al., 2015).

Repeatability and predictability of game tasks is another important aspect since unpredictability may cause anxiety for children with ASD. The transition between levels of the game should be easy, and transition time should be minimized to avoid losing the attention of the child. All visuals should have a purpose in the game. Otherwise, the abundance of graphical elements might cause anxiety and loss of concentration. Audio should give feedback to the child, and there should be background music or music during transitions. Also, audio should be joyful, clear, and purposeful. However, using too many audio stimuli should be avoided as well because this might cause stress for children with ASD. Visuals should be animated to grasp attention; long static stimuli without dynamic stimuli might provoke abnormal behaviors such as repetitive patterns of movements (Bartoli et al., 2014; Whyte et al., 2015).

### 2.2.1. User Interface and User Experience Design

User interfaces contain both input and output mechanisms. Since users interact with a device through a user interface, design decisions are very important. Some of the best practices and design guidelines that are listed by Lal (2013) include providing minimum design, simplicity, accessibility, consistency, and feedback principles. The *minimum design principle* requires utilizing the 80/20 rule (which denotes that the proportion of significant features is around 20 percent) and use of visually appealing layout and colors. The *simplicity principle* involves clear and simple design, focusing on the main task to prevent loss of attention, and preservation of simplicity and functionality. The *accessibility principle* entails designing for convenient user experience. The *consistency principle* refers to layout and terminology similarity for the whole work, utilizing similar navigation and interaction methods, and continuing in a consistent user interface throughout the framework. The *feedback principle* includes giving feedback instantaneously and informing the user about the present state of the background actions.

Additional to the guidelines stated by Lal (2013), principles chosen based on utility and evidence by Lidwell et al. (2010), including general design considerations and human psychology are considered in the design process. Principles overlapping with the scope of this thesis are listed below;

1. Users perceive aesthetic designs as being more convenient to use, which increases the likelihood of usage independent of its actual convenience (Lidwell et al., 2010).
2. Aligning elements conveys an impression of harmony and consistency that enhances the perception of design as being more aesthetic and stable (ibid).
3. Characters that are designed to have features similar to baby-faces (rounder, larger eyes) are more appealing to children due to the baby-face bias (ibid).
4. Colors should be implemented carefully by maintaining the number of colors used to around five, so that the human eye can comprehend the scene at first glance. Colors should be combined consciously to attain aesthetic appeal (Lidwell et al., 2010). Lidwell et al. (2010) describe the appropriate use of color to attain aesthetic appeal as following;

   "*…using adjacent colors on the color wheel (analogous), opposing colors on the color wheel (complementary), colors at the corners of a symmetrical polygon circumscribed in the color wheel (triadic and quadratic), or color combinations found in nature*".
5. Consistent interfaces are more user-friendly and facilitate easier and more focused learning. Representing similar elements with similar methods contributes to the consistency of an interface (Lidwell et al., 2010).
6. The distinction between the figure and background should be well defined and stable for the figure to grasp attention and be remembered more than the background (ibid).
7. Iconic symbols enable users to recognize, find, remember, and learn easier. Also, they make the interface easier to understand across cultures (ibid).
8. "*Performance load is the degree of mental and physical activity required to achieve a goal*." (Lidwell et al., 2010). Performance load reduces the possibility of achieving a task, so the interface design should decrease the load of performance as much as possible (ibid).
9. Proximity enables the perceiving of close elements as a group. Grouping elements increases clarity and imposes relatedness. Elements should be organized in close proximity if they are related to each other (ibid).
10. Young children's preference for savanna-like or park-like landscapes is strong and persistent across cultures. Thus, utilizing savanna-like natural environments while designing for young children should be considered (ibid).

11. Similar elements are assumed as being more related, and similarity of elements results in grouping. Since grouping diminishes complexity and strengthens relatedness, elements should be represented similarly only if they are related (ibid).
12. Symmetry delivers a sense of stability, harmony, and balance. Symmetric forms should be used as figure images instead of background images since symmetric forms are remembered better and gather more attention (ibid).
13. Uniform visual assets that are used to connect elements enable the grouping of elements; thus, elements are perceived as more related. Common regions and connecting lines are strategies, which can achieve uniform connectedness. The strategy of common regions is achieved if elements are grouped in a bounded visual area. The connecting lines strategy is attained if elements are grouped with an explicit line. Uniform connectedness should be used to link and cluster elements visually (ibid).
14. Visibility of status and methods enhances usability. Reducing complexity and maintaining stability can be achieved through hierarchical organization and context sensitivity (ibid).

The graphical user interface is an essential component for gathering and maintaining the attention of the user. The graphical user interface enables users to interact with the interface via icons, elements, and graphics on a two-dimensional screen. Best practices and design guidelines that are listed by Lal (2013) include the following; the visual features of a user interface element should suggest its behavior, theme and user interface elements should be consistent, images and actions should be familiar in order to be understandable, the interface should provide feedback concerning actions of the user in a pleasant, expectable and common manner. Since this thesis contains a survey assessing potential risk for ASD, the principles of designing a survey by Lal (2013) are considered in the design process as well. Online surveys allow the gathering of data from users, and Lal (2013) suggested a set of best practices and design guidelines to prepare an appropriate survey. Lal (2013)'s principles for online surveys that are applicable for the thesis project are; utilizing accessible content guidelines, displaying a finish button prominently, randomizing answers to prevent border answer bias, utilizing a progress bar for multiple page surveys that includes information about the time of completion before starting, preserving the layout consistently, and providing a simple first survey page. Additionally, concerning user experience in surveys, Lal (2013) suggests that questions should be one line long and that users should be informed about the number of questions in the survey.

User engagement is also crucial for user interfaces, and entertainment facilitates this. Game play might be used to modify naturally boring tasks such as filling out surveys so that they become enjoyable (Pratt & Nunes, 2012). Pratt and Nunes (2012) defines "gamification" as follows: "*Gamification is the integration of game dynamics or game mechanics into any nongame experience, application, or website*." (Pratt & Nunes, 2012, p.122) Gamification can be achieved by utilizing the following steps: At the time of completion users are given points, badges, or achievements, and levels might be used to give an impression of status (Pratt & Nunes, 2012). Since this thesis includes a survey assessing potential risk for ASD, achieving gamification could be beneficial in terms of engaging users. Since the gamification process is followed, principles to design electronic game applications for mobile devices are considered as well. Mobile game applications offer users entertainment anywhere they prefer. Best practices and design guidelines provided by Lal (2013) to design an electronic game application for mobile devices are; maintaining easy access to play/pause options, offering a full-screen option without any bald user interface controls, and designing pause and volume controls to be transparent. For enhancing user experience in mobile game applications, Lal (2013) proposes that the loading process of the game should be fast, an easy way should be granted to reach pause and save options, and auto save should be included.

Moreover, a touch user interface should be employed since touch-based systems ensure improved usage performance compared to mouse-based systems for children with ASD (Sitdhisanguan et al., 2012). Touch user interfaces adopt tactile input on a hardware surface via two methods: capacitive touch and resistive touch. Capacitive touch employs electric signals to determine the location of the touch where a finger acts as a conductor, which also allows multi-touch. On the other hand, resistive touch employs pressure for this purpose. The project completed in the scope of this thesis utilizes a 7-inch 1024x600 pixels resolution Capacitive Touch Screen LCD Screen HDMI Interface display. Accordingly, Lal's (2013) set of best practices and design guidelines for user interface technologies based on the sense of touch is considered. For the implementation of capacitive touch, Lal (2013) advises having smooth interactions via finger touch, maintaining scrolling smoothness, and permitting content interactions. Regarding user experience, Lal (2013) suggests constructing coherent interaction and balance of assets to achieve an enhanced user experience.

### 2.2.2. User Interface and User Experience Design for Children with Autism Spectrum Disorder

User-centered design principles suggest that an interface should be established concerning the cognitive capability of target users (Darejeh & Singh, 2013). Cognitive impairments such as Autism Spectrum Disorder (ASD) lead to certain design concerns in producing suitable human-computer interfaces. Providing visual aid is a successful way of easing communication and learning for children with ASD. Children with ASD are stated to be visual thinkers (Frauenberger, Good, &Alcorn, 2012). Visual sensory stimuli produce more reaction from children with ASD than from any other sensory type (Milley & Machalicek, 2012). Implementing interactive visuals in mobile devices has been found to be beneficial to assist learning for children with ASD (Kamaruzaman et al., 2016).

Grynszpan et al. (2008) researched the influence of multimedia output modalities by using text, voice, and image to create a rich multimedia interface, and compared it to a simple multimedia interface that consists merely of text. The results indicated that adolescents (Age Average: 12 years 10 months) with high functioning autism performed better when they were presented the simple multimedia interface (Grynszpan et al., 2008). Russell (2013) suggests that individuals with ASD tend to have difficulties when they encounter "open tasks", which requires them to consider multiple possibilities in order to reach an answer. According to Russell (2013), open tasks are challenging for individuals with ASD to solve due to executive function difficulties. Thus, Grynszpan et al. (2008) claim that the poor performance on rich multimedia interfaces of adolescents with ASD may be connected to executive function difficulties associated with ASD. Also, Grynszpan et al. (2008) suggest using simple non-human characters to show emotions, since individuals with ASD avoid the eye region when looking at social scenes.

On the other hand, based on the questionnaire data and participant images that Fletcher-Watson et al. (2016) collected, their team established the following principles of design for children with ASD:

1. Characters in the game should be designed to look like children. Vehicles, animals, plants, and toys might be utilized as well. Backgrounds of the game should be familiar to children.
2. Classical music or nursery rhymes should be selected as game music; however, experts suggest that music should be optional. Common classroom phrases could be used, such as "*good listening!*"
3. A reward token system should be utilized, and there should be no reaction in case of a wrong answer.
4. The loading screen should not comprise any sound or animation to prevent fixation behavior; it should be simple and clear.

Moreover, Pavlov (2014) proposed the subsequent principles for user interface design for individuals with ASD:

For presentation;

- Font and background should be contrasting.
- Soft and mild colors should be used.
- The text box should be noticeably disconnected from other elements.
- Text should be displayed in a single column.
- Simple graphics should be utilized.
- Clear sans-serif fonts should be used.
- The background should be plain without any images.
- Transparent surfaces and text should not overlap.
- Pop-ups should not be used.
- Scrolling should be vertical.

For navigation and page loading;

- Navigation should be simple and easy to understand.
- The interface should inform the user about current position on every screen.
- Pages should not load slowly.
- The interface should contain a Help button.

- Menus should be simple and clear.

For interaction;

- The screen should not contain too many elements.
- One toolbar should be used if possible.
- Buttons should be big and clear, containing both text and icons.
- Instructions should be brief at each stage.
- Use of multi-colored icons should be avoided.

The principles established above should be considered in design decisions, and proper evaluation methods should be utilized to assess the product subsequently or during the design process. There are two categories of evaluation methods: summative evaluation and formative evaluation (Nielsen & Molich, 1990). Summative evaluation is utilized to evaluate the success of completed systems. On the other hand, formative evaluation is used while a system is under development because it aims to determine and solve usability problems at an early stage of the system's development (Nielsen & Molich, 1990). Heuristic evaluation is a formative evaluation technique based on expert knowledge. Experts employ their knowledge of end users and assess the system based on established usability principles called heuristics to identify usability problems in a system (Nielsen & Molich, 1990).

Khowaja and Salim (2015) developed a set of heuristics to evaluate interactive systems for children with ASD, which are listed below:

1. System status should be constantly visible to inform users concerning the duration, context, and current condition of the activities. System status should be presented via suitable feedback at sensible time intervals (Khowaja & Salim, 2015).
2. The system should be easily comprehensible by the user. The system should use familiar words, phrases, and concepts with the user. The conventions in the system should be similar to those in every day life, and information should be provided in an ordinary and rational way (ibid).
3. Language should be plain and coherent so as not to distract the user by using different words for the same meaning or using a word for multiple meanings

(ibid).

4. Objects, actions, and options should be visually represented to decrease the memory load of the user. Necessary information should be provided on each screen so that the user does not need to memorize. A user guide should be available and conveniently accessible (ibid).
5. Unrelated or infrequently needed information should not appear on interface screens since it may be a distraction for children with ASD. Only relevant information should be visible on the screen to increase visibility (ibid).
6. Redo and undo options should be added to the system in case of choices by error. The system should contain an easily visible "emergency exit" option to allow the user to leave the undesirable state rapidly (ibid).
7. The system should prevent errors to the extent possible by asking for confirmation before executing an action (ibid).
8. The system should provide customizing actions performed frequently. The system should evaluate the first performance of the user then suggest a proper level to begin with (ibid).
9. The error messages of the system should be clear, including an exact sign of the issue kindly proposing an approach to prevent the error. In case of error, the system should offer a multimedia demonstration to deliver recommendations (ibid).
10. "*Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easily available to the user, focus on the user's task, provide multimedia demonstration of tasks to be carried out, and not be too large*." Khowaja & Salim (2015, p.9)
11. Screen items should be customizable according to the desires, skills, and choices of the user. Screen items should be adequately large to ensure ease of reading and access by children with ASD. The system should permit customizability of color, background, font, and size (ibid).
12. The transitions on the screen should be smooth and gradual in order to avoid dramatic changes so that children with ASD can follow (ibid).
13. Possible latency of an action (e.g. selection) should be avoided since maintaining the attention of children with ASD is challenging, and they could get frustrated quickly (ibid).

14. The actions, answers, time used, and results of the user should be recorded and presented to enable the user to select activities and return to them (ibid).
15. The system should allow different means of input from the user such as text, sound, visual, video, and animation (ibid).

## 2.3. Shell Designing Robotic Interfaces for Children with Autism Spectrum Disorder

The main concern in designing a robotic interface for children with Autism Spectrum Disorder (ASD) is the degree of life-like appearance. Therapeutic robots are designed in various forms; anthropomorphic robots that highly resemble human beings, non-anthropomorphic robots that either appear like animals or cartoon-like characters, and non-biomimetic robots that do not look like any kind of living species (Cabibihan et al., 2013). Social interactions are challenging for children with ASD; therefore, researchers have compared anthropomorphic and non-anthropomorphic robotic designs to observe which design generates more positive feedback. Research has indicated that designs that do not resemble human beings evoke more social responses (Robins et al., 2006). Also, robots that resemble animals or cartoon-like characters lead to more stimulation (Duquette et al., 2008; Michaud et al., 2003). Moreover, experiments have noted that non-biomimetic robots received positive feedback from children with ASD as well (Robins et al., 2007; Michaud et al., 2003). Further work has suggested that non-anthropomorphic and non-biomimetic robot designs may permit the emphasizing of social signals by producing more noticeable cues, and restricting distractions to gather attention for desired social signals (Scassellati et al., 2012). However, anthropomorphic robots may be utilized in particular circumstances, for instance if aiming for a better generalization of acquired skills, because in the case of anthropomorphic robot design, children with ASD may comprehend social interactions more clearly. Besides, the robot should be perceived as a mechanical entity, not as a human being (Cabibihan et al., 2013). On the other hand, extremely machine-like robots may cause attention loss because the child may be interested more in the mechanical aspects of the robot than in interacting with the robot (Kozima et al., 2007). A proper degree of life-like appearance should be achieved to ensure that the robot is not so anthropomorphic that the child is intimidated and that the robot is not so machine-like that the child becomes more attracted to inspecting mechanical components (Kozima & Nakagawa, 2006).

Utilizing robotic systems provides convenient, sheltered, expectable, and consistent conditions, in contrast to everyday social interactions, which are unpredictable and uncontrollable. In robotic systems, interaction complexity can be determined and progressively advanced (Robins et al., 2004c). Considering that individuals with ASD suffer from excessive stimulation (Johnson & Myers, 2007), eliminating superfluous social cues may be beneficial in helping individuals with ASD process social signals (Scassellati et al., 2012). Children with ASD favor simple designs, modest appearance, and foreseeable circumstances while interacting with a toy (Ferrara & Hill, 1980). Robins et al., (2004c) developed interactive robotic systems that support essential communication and social interaction abilities in the Aurora Project. In the scope of the Aurora Project, a robot called Robota is utilized which is a 45 cm high humanoid robotic toy comprised of commercial doll components (head, arms, and legs) (Billard, 2003). Robins et al., (2004c) compared the interaction level and response of the children with ASD while interacting with two separate versions of the robot. In the first version, the robot was clothed to resemble a human, and in the second version, the robot was dressed with a plain white cloth covering all features of its face (Robins et al., 2004c). After comparing these two circumstances, Robins et al. (2004c) observed that children with ASD exhibited a preference to interact with the plain second version of the robot.

Visual engagement is crucial in maintaining the attention of the children with ASD (Cabibihan et al., 2013). A robot containing highly bright components may result in the over stimulation of the child. Moreover, children with ASD are interested in distinctive forms, lights, and spinning mechanical components (Michaud at al., 2003). Also, robot design should not permit sharp corners and the use of ropes (Cabibihan et al., 2013). Interacting with robots is less complicated compared to human interaction, which makes robots more attractive for children with ASD. Thus, the appearance of the robot should not immensely resemble that of a human since the attention of children with ASD may diminish (Robins et al., 2007). Facial expressions of the robot should be simple, and unnecessary forms like eyelashes and eyebrows should be avoided to improve simplicity (Cabibihan et al., 2013). Generally, children with ASD avoid eye contact. However some children have been observed to be interested in making eye contact (Robins et al., 2009), which creates an opportunity to provoke the making and preserving of eye contact. Still, this attribute should be customizable since it highly depends on the child (Robins et al., 2007). In terms of safety, the design of the robot should avoid sharp corners and sudden motions since children with ASD may behave incompliantly or unpredictably. Also, the robot should be designed so as to minimize the possibility of malfunction. The child may have a tantrum and throw the robot, so the robot should be designed to be firm and able to resist strong impacts (Cabibihan et al., 2013).

Numerous robots have utilized motion to gather attention of the children. Objects in motion tend to attract the attention of children with ASD. Therefore, designing robots to be mobile may become highly beneficial (Cabibihan et al., 2013). Children with ASD have exhibited a preference to engage with mobile robots instead of passive robots (Dautenhahn, 2003). Michaud et al. (2003) indicated that children with ASD displayed positive feedback towards mobile robots. Rewards based on achievements are also encouraging for children with ASD; the accurate completion of a task should be rewarded since positive feedback has been demonstrated to be greatly constructive (Robins et al., 2007). Rewards to encourage children may be presented in a sensory form, for example illuminating the robot or playing songs, because children with ASD are encouraged and attracted by these types of rewards (Michaud et al., 2003). Providing options during the child-robot interaction may increase attention and enable sufficient learning. Making choices enables the child to be more in control, and thus more interested in the interaction. For instance, allowing the child decide between illuminating the robot and playing songs as a reward for achievement may increase the engagement of the child (Robins et al., 2007).

Children's perceptions of a robot are highly significant and to comprehend children's opinions about the appearance of robots Woods (2006) conducted a study with 159 children. In the experiment children assessed 40 images of robots via filling a questionnaire about the appearance, personality, and emotions of every robot. Relying on the empirical data gathered from the research, Woods (2006) suggested a set of design rules for the robots that interact with children:

> "Robots should have cartoon-like features, exaggerated facial features, a female gender and be brightly colored for positive behaviors. Robots should have realistic

features, less clear facial features, and be dully colored to depict negative behaviors. The whole appearance of a robot should be considered at the outset of the design phase rather than focusing on specific aspects such as the face. Robots for children should not be designed to look completely human-like, unless they are perfect replicas, indistinguishable of humans." (Woods, 2006, p.1413)

Li et al., (2010) examined the influence of robot appearance and a user's cultural background on the engagement, perceived attractiveness, and response of the user. The results indicated a positive correlation between interaction level and the perceived attractiveness of the robot. The study also revealed cultural differences in approaches and interaction levels of the users when they encounter a service robot. Korean and Chinese users regarded social robots that they have encountered as being more attractive and experienced greater engagement with the robot than German users (Li et al., 2010). Users perceived the machine-like robot to be less pleasant than the zoomorphic (animal-like) robot. According to Li et al. (2010), active interaction increases robots' perceived appeal and trustworthiness. Finally, Li et al. (2010) suggested increasing the time and amount of the human-robot interaction to enhance engagement and likeability.

# CHAPTER 3

# IMPLEMENTATION OF THE PROJECT

## 3.1. Theory of Mind Tests Adaptations for Autism Spectrum Disorder Risk Assessment

Theory of Mind (ToM) proposes that typically developed individuals are able to comprehend their own mental state and other people's mental states. On the other hand, individuals with autism spectrum disorder (ASD) experience struggles in understanding mental states (Frith, 2001). Typically developing children's ToM abilities are considered to begin with an innate mechanism (Frith, 2001). The theory of mind hypothesis proposes that the innate mechanism does not function suitably in individuals with ASD. Individuals with ASD obtain this ability late and develop it slow despite training (Frith, 2001). Considering the differences in ToM development between typically developing children and children with ASD, ToM tests are utilized in order to identify children at risk for ASD. ToM tests that are prevalent and most suitable for visualization are chosen and listed below:

1. 'Inferring from gaze direction' test (Baron-Cohen & Cross, 1992; Baron-Cohen et al., 1995)

   Gaze direction allows normally developing children to understand which of the several objects a person wants. However, children with ASD are unable to retrieve that information as easily. The test of 'Which one does Charlie want?' reveals this difference between normally developing children and children with ASD.

In the test, the child is presented the Figure 1 below, and asked the question: “Which one does Charlie want?” (Baron-Cohen & Cross, 1992). The question is translated into Turkish as: “Çağrı hangisini istiyor?”.

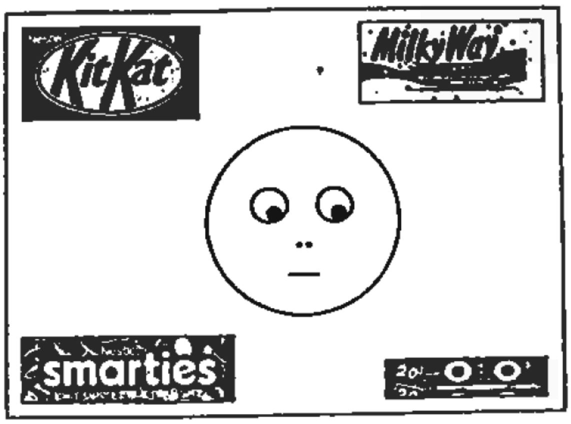


Figure 1. *The test of “Which one does Charlie wants?”*, Baron-Cohen & Cross, 1992

2. ‘Seeing leads to knowing’ test (Baron-Cohen & Goodhart, 1994)

The ‘Seeing leads to knowing’ test by Baron-Cohen and Goodhart, (1994) contains a story about two characters. One of the characters looks into a box and the other one touches a box. Normally developing 3-year-old children are able to comprehend who has the information about what is inside the box (Baron-Cohen & Goodhart, 1994). On the other hand, children with ASD tend to choose a character arbitrarily, when they are asked, “Which one knows what is in the box?” (Baron-Cohen & Goodhart, 1994). The question is translated into Turkish as: “Kutunun içinde ne olduğunu hangisi biliyor?”.

3. The mental-physical distinction (Baron-Cohen, 1989a)

The mental-physical distinction test Baron-Cohen (1989a) conducted comprises four stories; one of the stories is as follows:

> “This is Sam. He likes biscuits. He is hungry, so his mother gives him a biscuit. This is Kate. She likes biscuits. She is hungry, but she is all alone. She is thinking about a biscuit.” (Baron-Cohen, 1989a).

Subsequent to the story a behavioral judgment and a sensory judgment questions were asked, “Which child can eat the biscuit?” and “Which child can touch the biscuit?” correspondingly. (Baron-Cohen, 1989a). The story is adapted and translated into Turkish as following:

> “Bu Selim. Selim bisküvi seviyor. Selim'in karnı aç. Bu yüzden annesi Selim'e bir bisküvi veriyor. Bu Cansu. Cansu bisküvi seviyor. Cansu’nun karnı aç, ama o yalnız başına. Bisküviyi düşünüyor.”

The questions that are asked following the story are translated as “Hangi çocuk bisküviyi yiyebilir?” and “Hangi çocuk bisküviye dokunabilir?” subsequently.

4. First-order false belief task (Frith, 2001)

The Sally-Ann task is utilized as a first-order false belief task. In the Sally-Ann task the following story is enacted for the child:

> “Sally has a basket and Anne has a box. Sally puts a marble into her basket, and then she goes out for a walk. While she is outside, naughty Anne takes the marble from the basket and puts it into her own box. Now Sally comes back from her walk and wants to play with her marble. Where will she look for the marble?” (Frith, 2001).

A normal developing 4-year-old child is expected to answer this question correctly, by giving an answer similar to “Sally will look inside her basket.” However, children with ASD struggle with this task, even though they have a mental age of 4 years and above (Frith, 2001). The story is adapted and translated into Turkish as following:

> “Selin’in bir sepeti ve Aslı’nın bir kutusu var. Selin sepetine bir top koyuyor ve sonra yürüyüş yapmak için dışarı çıkıyor. O dışarıdayken, yaramaz Aslı topu sepetten alıyor ve kendi kutusunun içine koyuyor. Şimdi Selin yürüyüşten dönüyor ve topuyla oynamak istiyor. Selin topu için nereye bakacak?”

### 3.2. User Interface and User Experience Design of the Theory of Mind Tests

Cognitive impairments caused by Autism Spectrum Disorder (ASD) lead to certain design concerns for producing suitable human-computer interfaces. Visual sensory produces more reaction from children with ASD than any other sensory type (Milley & Machalicek, 2012). Since children with ASD are identified as visual thinkers (Frauenberger, Good, &Alcorn, 2012), visual aids are provided to ease communication and learning for children with ASD. Also, the design principles set for serious games are applied to the Theory of Mind tests that are adapted. These design principles contain: gradually increasing levels of difficulty, defining clear task goals, providing clear instructions, delivering feedback and rewards, ensuring repeatability and predictability of the game tasks, presenting smooth transitions, and minimalistic graphics (Bartoli et al., 2014; Whyte et al., 2015). The tests are organized to require less effort at first and become progressively challenging to enhance engagement and motivation. The task objectives are intended to be clear so that they may be followed easily. The instructions are intended to be clear and the text is supported via visuals for better comprehension of the goals. Alongside continuous feedback, rewards with visuals are presented to encourage children with ASD (Whyte et al., 2015). Moreover, game play is used to modify the tests to become enjoyable and engage the users. Game dynamics are integrated into Theory of Mind tests by giving stars and badges to users at the time of completion (Pratt & Nunes, 2012).

Additionally, Lidwell et al.'s (2010) principles overlapping with the scope of the tests are followed. Since baby-faces are more appealing to children (Lidwell et al., 2010), the characters of the tests are designed to have similar features to a baby-face by making their eyes rounder and larger. The number of colors used in the screens is minimized as much as possible, so that the human eye can comprehend them at first glance (Lidwell et al., 2010). The screens are designed to be consistent in terms of their setting, theme, colors, flow, and elements, since consistent interfaces are more user-friendly and easier to focus on (Lidwell et al., 2010). The distinction between the figure and the background is well defined and stable for the figure to grasp the user's attention and be remembered more than the background (Lidwell et al., 2010). Iconic symbols are used in order to enable users to recognize, find, remember, and learn more easily (Lidwell et al., 2010). Performance load is decreased as much as possible to increase the possibility of achieving a task (Lidwell et al., 2010). Related elements are grouped via proximity, similarity, or uniformity to increase clarity (Lidwell et al., 2010). Figure images are designed to be as symmetric as possible in order to deliver a sense of stability, harmony, and balance, and to grasp more attention. Additionally, the status of the user during the game is made visible in all scenes to enhance usability (Lidwell et al., 2010). Practices and guidelines for graphical user interfaces and online surveys by Lal (2013) are implemented as well. The interface aims to provide feedback concerning actions of the user in a pleasant, predictable and common manner. Answers are randomized to prevent border answer bias. Progress bars are utilized for multiple page tests. Information about the number of tests is given before starting.

Moreover, Fletcher-Watson et al.'s (2016) principles of design for children with ASD are employed. Characters in the games are designed to look like children. A reward token system is utilized and there is no reaction in the case of a wrong answer. Furthermore, Pavlov's (2014) principles for user interface design for individuals with ASD are followed closely and listed below:

- Font and background are designed to be contrasting.
- Soft and mild colors are used.
- The text box is noticeably disconnected from other elements.
- Text is displayed in a single column.
- Simple graphics are utilized.
- Clear sans-serif fonts are used.
- The background is designed to be plain without any images.
- Transparent surfaces and text do not overlay.
- Pop-ups are not used.
- Navigation is simple and easy to understand.
- The interface informs the user about the current position on every screen.
- The screens do not contain too many elements.
- Instructions are brief.

Heuristics by Khowaja and Salim (2015) for evaluating interactive systems for children with ASD are utilized and listed as follows:

- The status of the system is made constantly visible at the bottom of the screens via circles representing the current status to inform users about the duration, context, and current condition of the activities. The status of the system is presented via suitable feedback (collecting stars) between sensible time intervals (end of each task) (Khowaja & Salim, 2015).

- The system aims to be easily comprehensible by the user. The system uses words, phrases, and concepts familiar to the user. The conventions in the system are similar to every-day life and information is provided in an ordinary and rational way (ibid).
- Language used in the screens is plain and coherent to not distract the user by using different words for the same meaning or using a word for multiple meanings (ibid).
- Unrelated or infrequently needed information does not appear on the interface screens since it may be a distraction for children with ASD. (ibid).
- Redo and undo options are added to the system in case of choices by error. The user can undo by tapping the left side of the screen and redo by tapping the right side of the screen (ibid).
- The system tries to prevent errors as much as possible by asking for confirmation before executing an action (ibid).
- The screen items are adequately large to ensure ease of reading and access by children with ASD. A future ambition of the system is to permit customizability of color, background, font, and size (ibid).
- The transitions on the screen are smooth and gradual in order to avoid dramatic changes so children with ASD could follow (ibid).
- Possible latency of an action (e.g. selection) is aimed to be avoided since keeping the attention of the children with ASD is challenging, and they could get frustrated quickly (ibid).

Before starting the theory of mind tests, eight instruction screens (Figures 2-5) are presented in order to provide information about possible actions and the length of the process. Screens have the following texts respectively:

- Hello, I am Zimo. Lets play games together.
- First, I will give you some clues.
- In order to go forward you should touch this (showing right) side.

- In order to come back you should touch this (showing left) side.
- Tap on the picture that you want to choose.
- If you are certain of your decision tap again.
- Congratulations! You have made your choice.
- You are ready now. Lets play four games together. Tap to start.

Also, after the completion of a test the transition screen appears. The user should tap the screen in order to start the next game. When the user has finished all of the tests, the final screen appears to notify them. Screens have the following texts respectively (Figure 6):

- Tap to continue with the next game.
- Congratulations! You have completed all of the games.


Figure 2. *Instructions, screens 1&2*


Figure 3. *Instructions, screens 3&4*


Figure 4. *Instructions, screens 5&6*

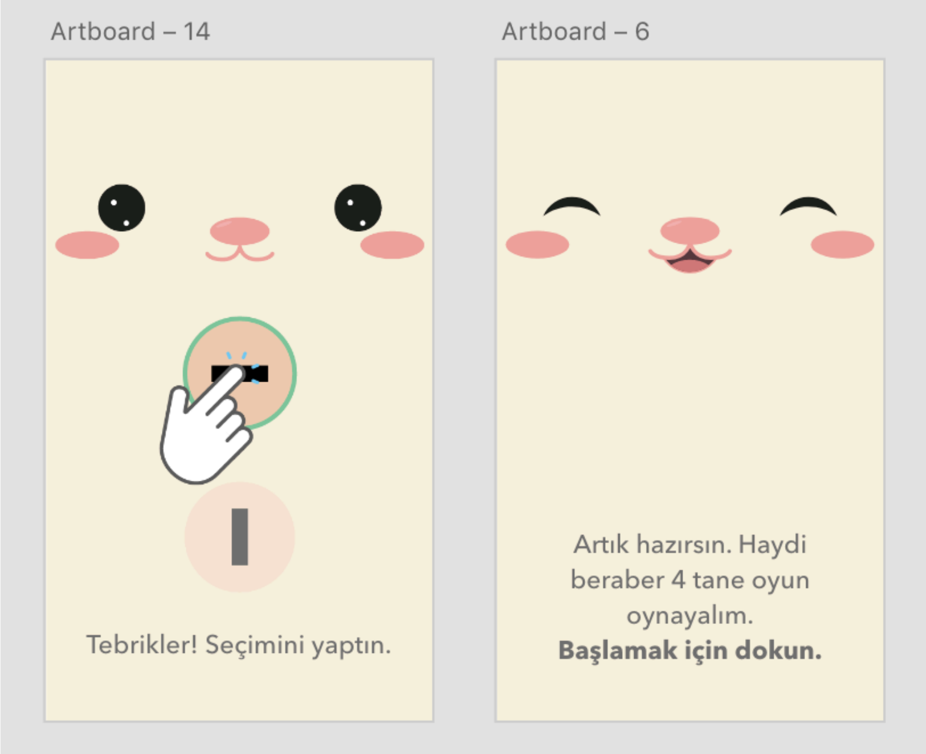


Figure 5. *Instructions, screens 7&8*


Figure 6. *Transition screen & Final screen*

Following the instruction screens, Theory of Mind tests are presented. Interfaces of the Theory of Mind tests that are adapted for the device are listed below (see Chapter 3 section 1 for the details of the tests):

1. ‘Inferring from gaze direction’ test (Baron-Cohen & Cross, 1992; Baron-Cohen et al., 1995)

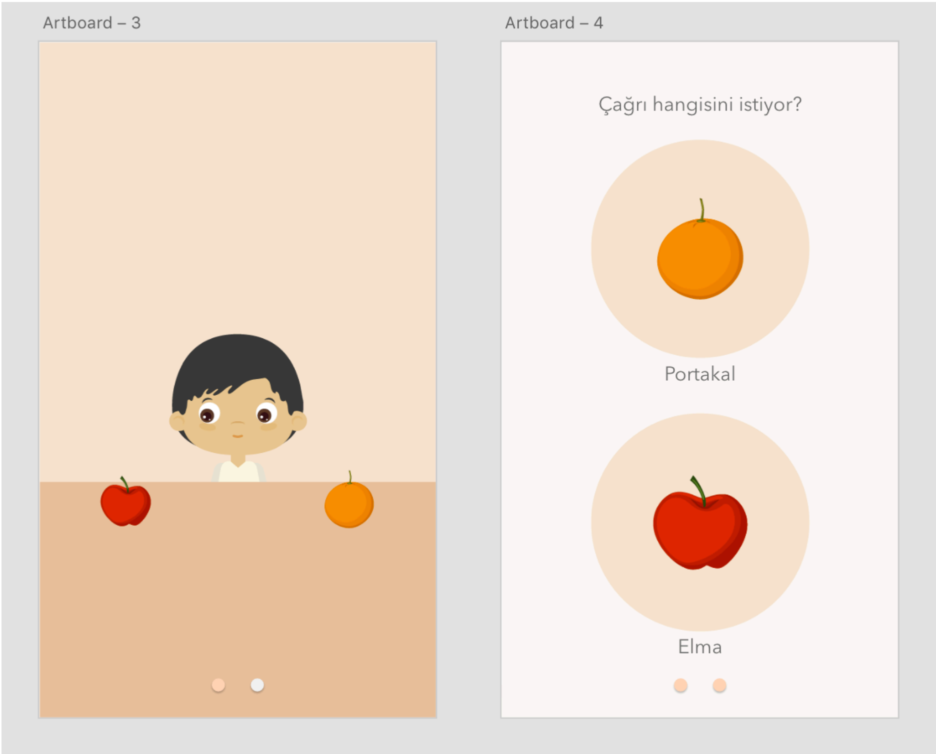


Figure 7. *The 'inferring from gaze direction' test, screens 1&2*

Choice screens (Figure 8) that are presented in this test are repeated in a similar manner throughout all the tests, so they are not repeated for each test in the thesis.

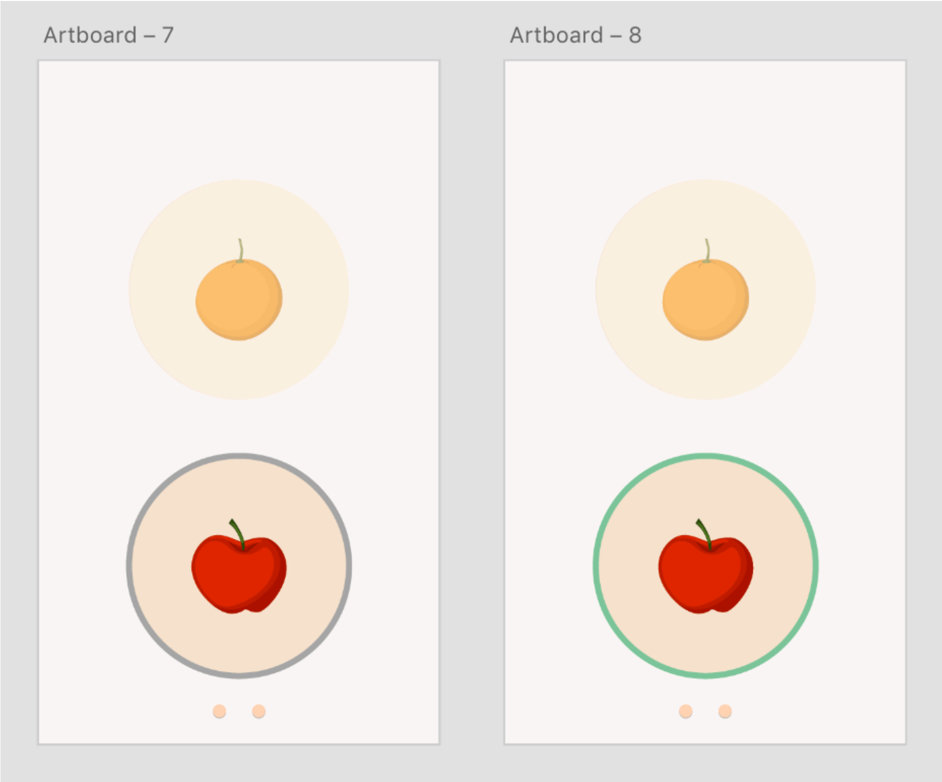


Figure 8. *The 'inferring from gaze direction' test choice screens*


Figure 9. *The 'inferring from gaze direction' test, screen 3*

2. ‘Seeing leads to knowing’ test (Baron-Cohen & Goodhart, 1994)


Figure 10. *The 'seeing leads to knowing' test, screens 1&2*


Figure 11. *The 'seeing leads to knowing' test, screen 3*

3. The mental-physical distinction (Baron-Cohen, 1989a)


Figure 12. *The 'mental-physical distinction test', screens 1&2*


Figure 13. *The 'mental-physical distinction test', screens 3&4*


Figure 14. *The 'mental-physical distinction' test, screens 5&6*

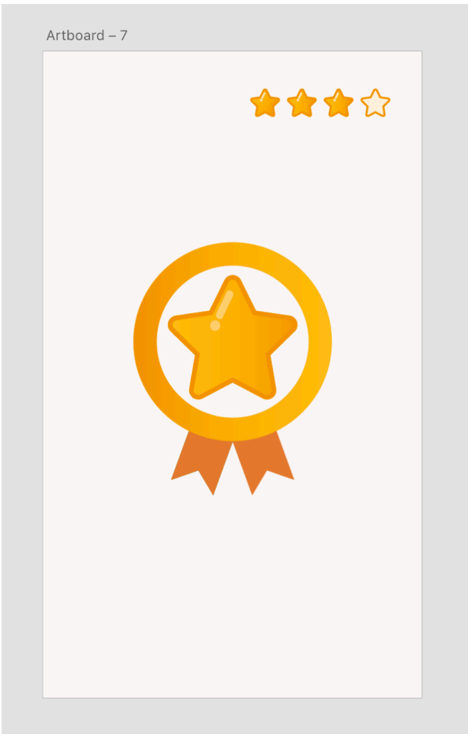


Figure 15. *The 'mental-physical distinction' test, screen 7*

4. First-order false belief task (Frith, 2001)

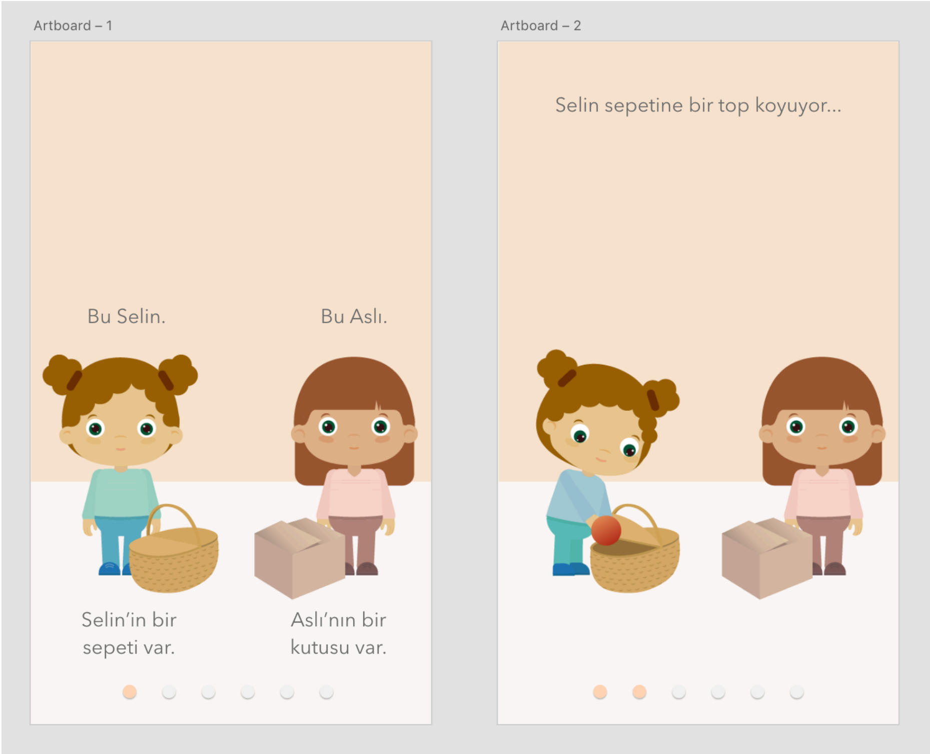


Figure 16. *The Sally-Ann task, screens 1&2*


Figure 17. *The Sally-Ann task, screens 3&4*

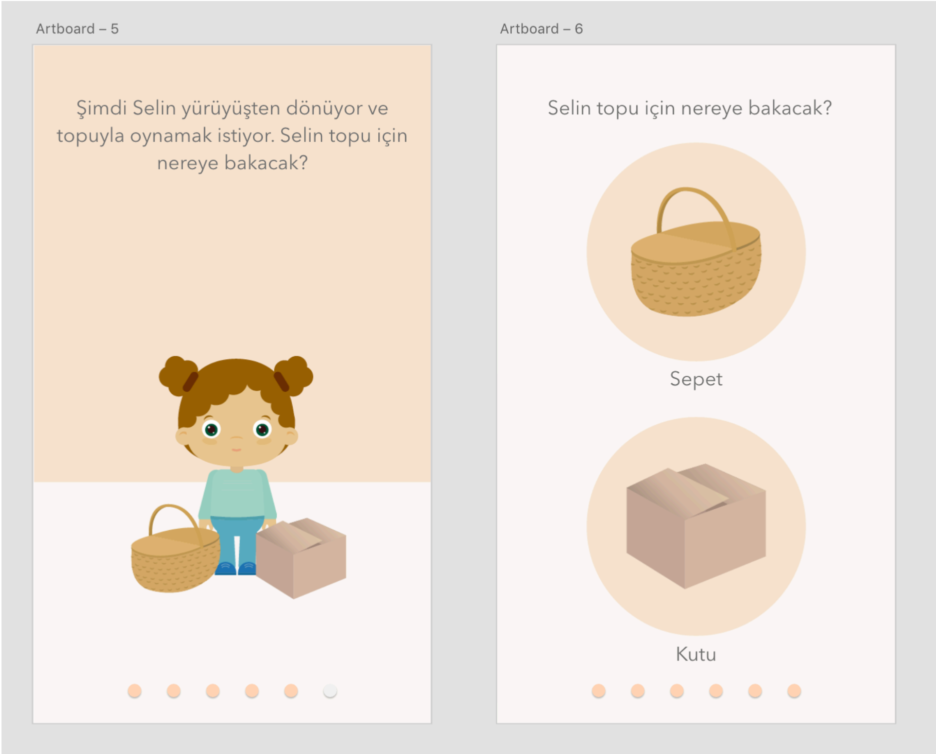


Figure 18. *The Sally-Ann task, screens 5&6*

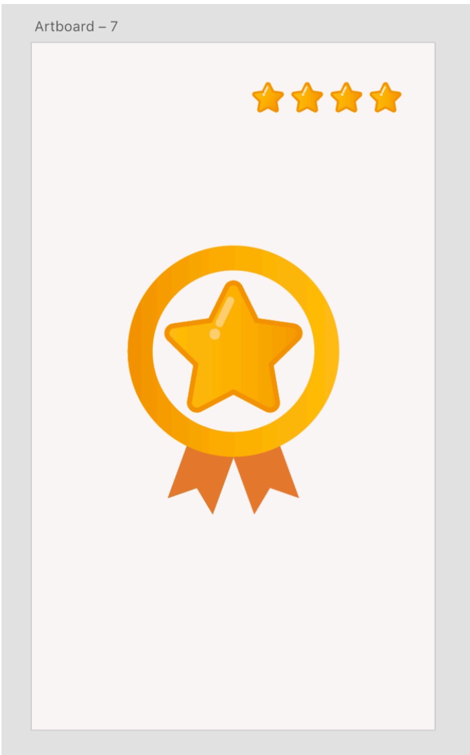


Figure 19. *The Sally-Ann task, screen 7*

### 3.3. Shell Design of the Prototype

Social robots are utilized for facilitating communication, expressing emotions, building social relationships, interpreting natural cues, enhancing social abilities, and diagnosis (Cabibihan et al., 2013). Social robots are used as a medium for diagnosis to elicit required behaviors for the diagnosis, gather and analyze data from behaviors of the child (Scassellati et al., 2012). By creating attractive and meaningful interactions, social robots are able to attract attention and engage with children (Cabibihan et al., 2013). Since social robots are precise, predictable and consistent children with autism are more interested in interacting with social robots than human agents (Pierno et al., 2008).

Appearance of the Robotic Toy (Outer Shell)

- The robot should be attractive to the child by appearance. The shell is designed to match a non-anthropomorphic appearance since designs that do not resemble humans evoke a more positive response (Robins et al., 2006), cartoon-like characters lead to more stimulation (Duquette et al., 2008; Michaud et al., 2003), and non-anthropomorphic designs received positive feedback from children with ASD (Robins et al., 2007). The appearance of the shell tends to be simple, easy to operate, and toy-like. Kozima et al. (2007; 2009) showed that a very simple robot design (see Figure 20) could retain the attention of children with ASD and enable social interaction.

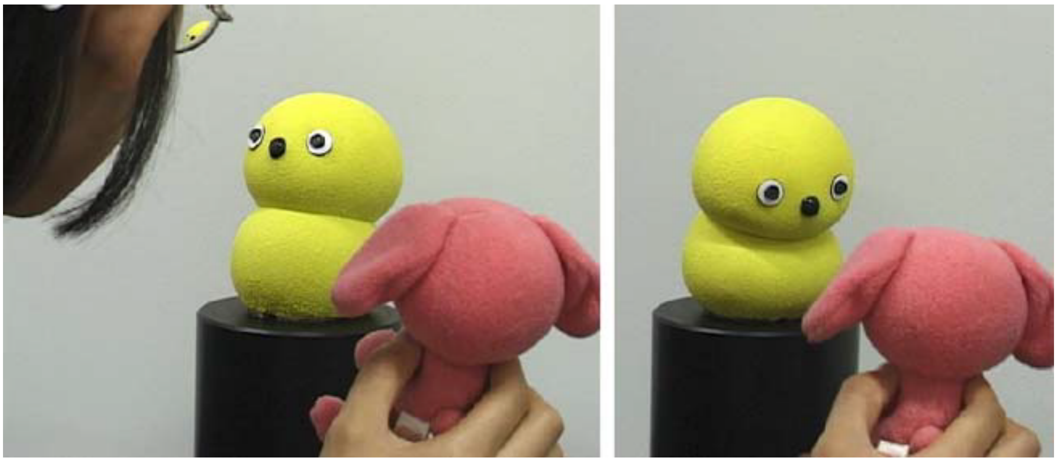

Figure 20. *Keepon, interactive robot,* Kozima et al., 2009

- The outer shell is designed to be simple and appealing. A Raspberry Pi 7-inch touchscreen display is placed vertically on the front side to display facial features, tests, and games. During the use of touchscreen technologies, children with ASD are observed to be more involved and verbal (Hourcade et al., 2012).

- By following Pavlov's (2014) principle of using soft and mild colors, color of the outer shelf is chosen to be light beige in order to eliminate redundant stimuli and reduce distraction.

The first sketch of the outer shell design is presented in Figure 21 below. Figure 23 and Figure 24 represent renders of the finalized solid model designed via Autodesk Fusion 360. Figure 25 demonstrates render of the separated two components that constitute the outer shell. Figures 26-29 exhibit renders from different viewpoints of the attached state of the two components. Figures 30 and Figure 31 presents components in Autodesk Fusion 360 environment, where they are created.

Figure 21. *First sketch of the outer shell design*

The finalized version (see Figure 22) is designed to enable being carried by being held under the arms, which are curved inwards so that the hands may be placed conveniently. The bottom side of the outer shell design is leveled in order to be balanced when it is placed on a table. The front side of the shell is tilted so that the participant can be able to see the screen at a more convenient angle, while sitting on a chair.

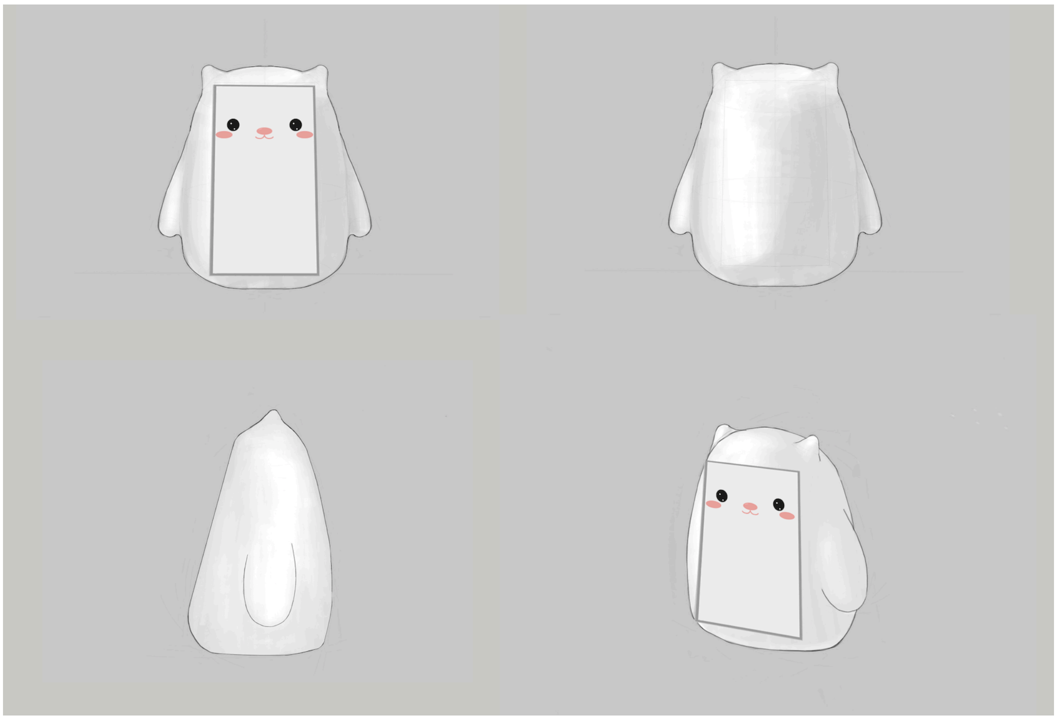

Figure 22. *Final drawings of the outer shell design*

Figure 23. *Finalized solid design of the outer shell*

Figure 24. *Front view of the finalized solid design of the outer shell*

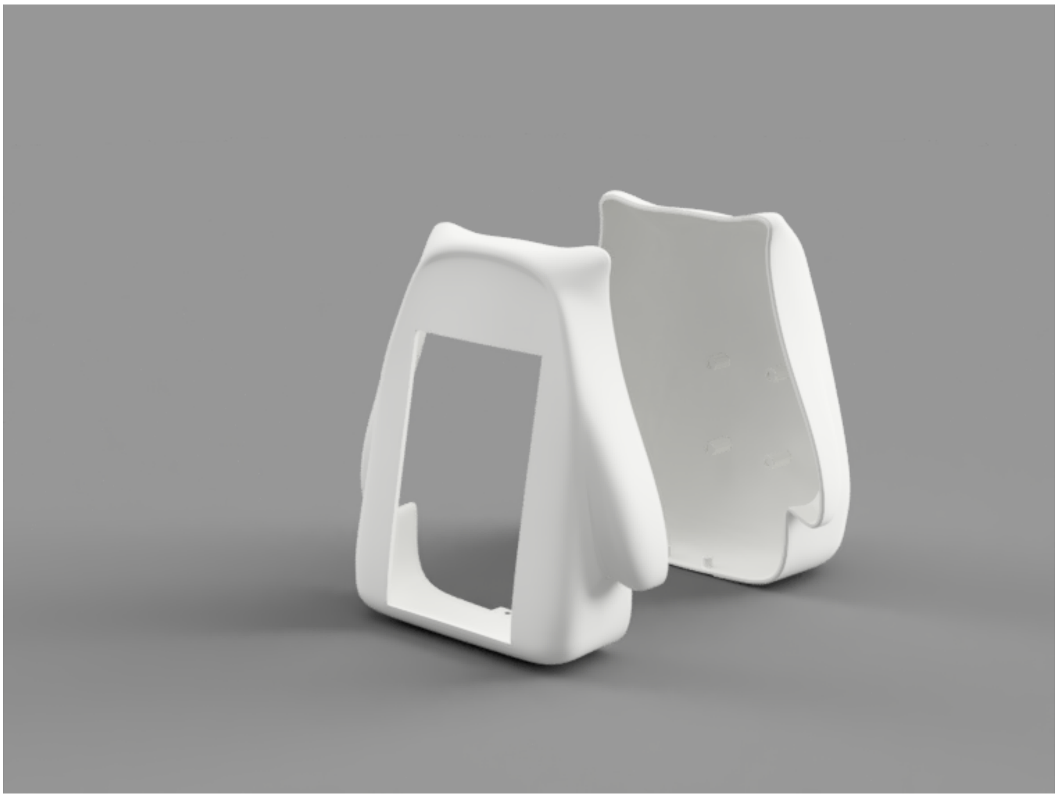

Figure 25. *The separated components of the outer shell*

Figure 26. *The attached state of the components*

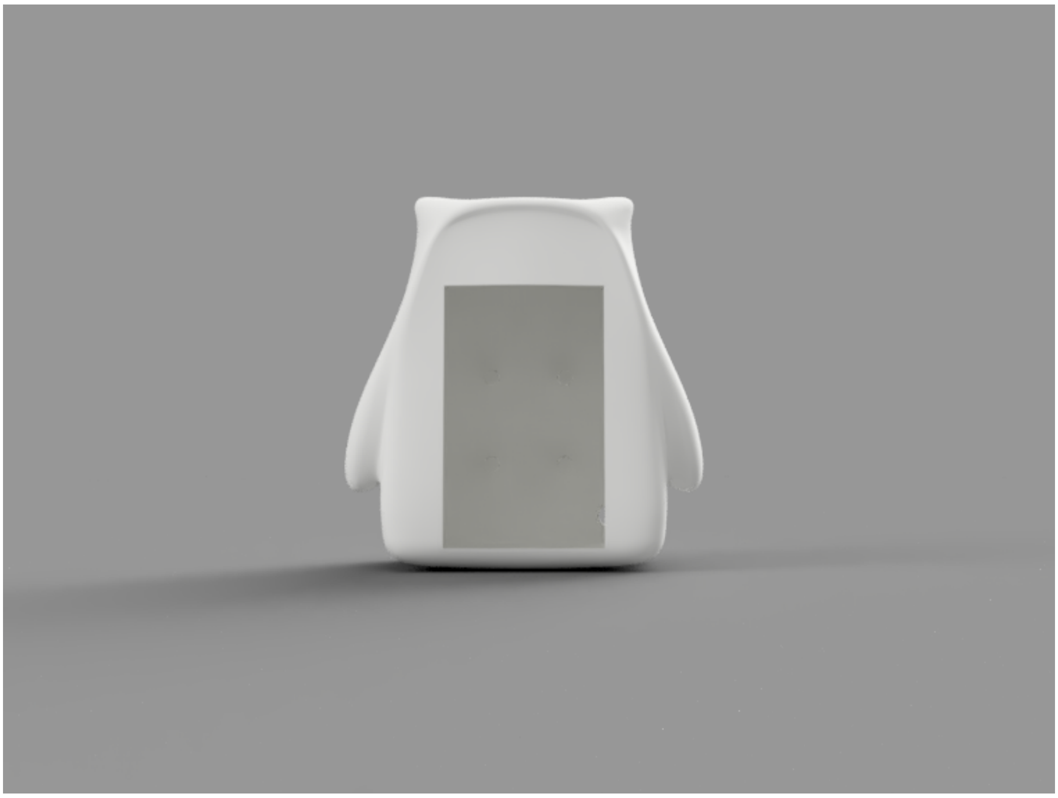

Figure 27. *The attached state of the components, front view*

Figure 28. *The attached state of the components, side view*

Figure 29. *The attached state of the components, back view*

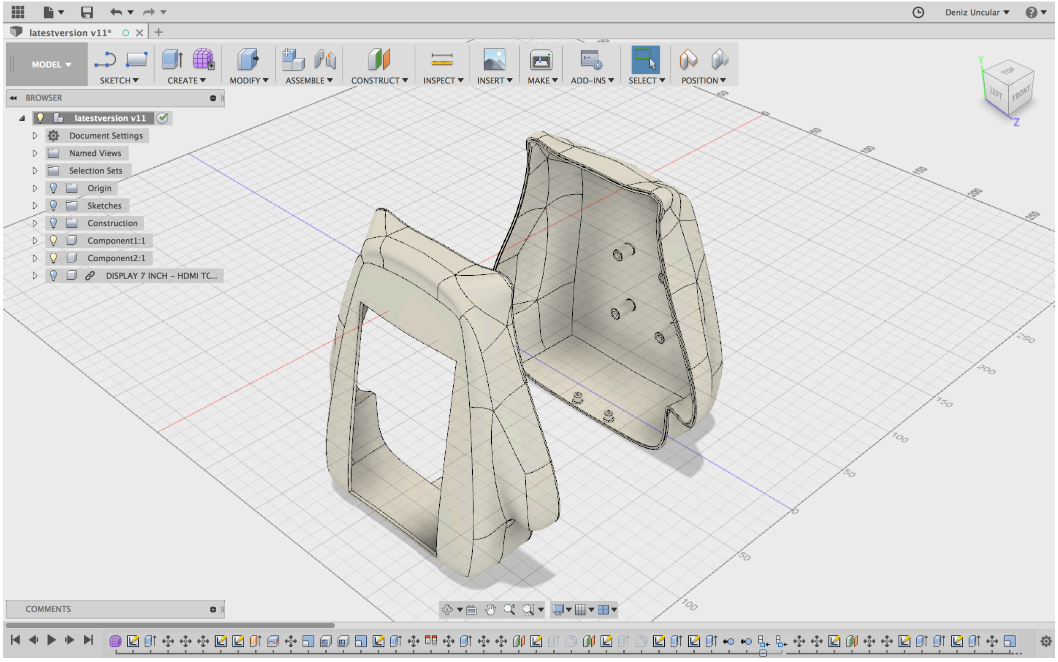

Figure 30. *Components in Autodesk Fusion 360, front*

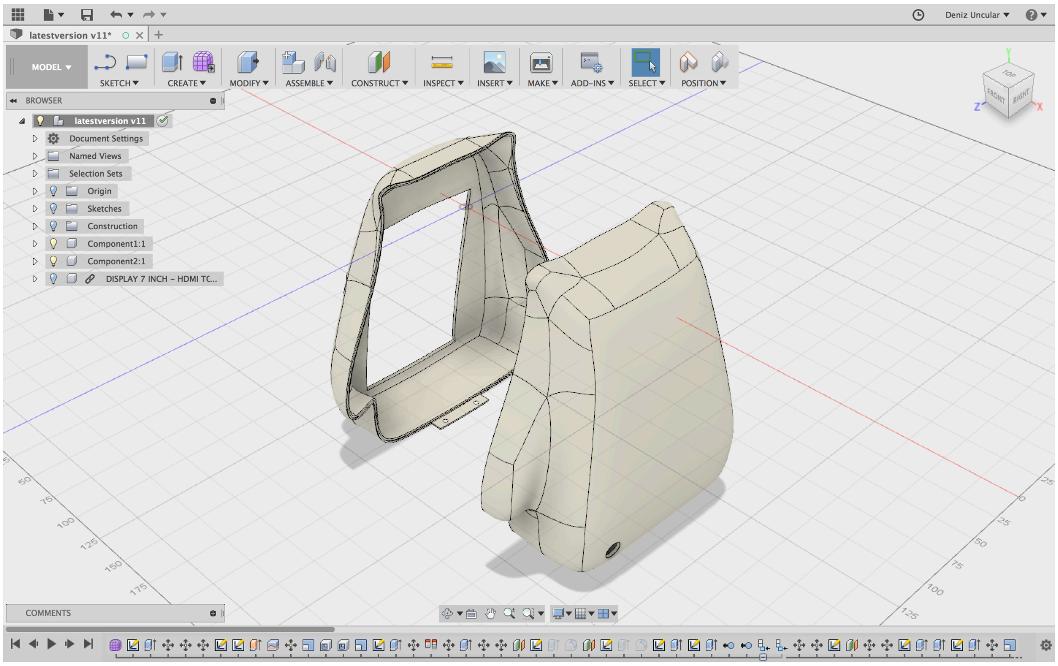

Figure 31. *Components in Autodesk Fusion 360, back*

Finally, outer shell prototype is 3D printed by Raise3D N2 Plus FFF 3D Printer at Collaboration Space, Sabanci University.

3D printing is preferred as the production method due to its numerous advantages over machining and casting methods. 3D printing enables direct production of functional parts in small amounts. Despite 3D printed parts usually have a lower accuracy and surface finish compared to parts produced by machining; some sophisticated systems are able to create high quality parts close to machining quality. 3D printing is advantageous particularly in production times; it can significantly shorten production times, which can be only several hours (Chua & Leong, 2014). Another significant advantage of 3D printing is providing the opportunity to experiment with complex physical models in comparatively short time. According to Chua and Leong (2014), 3D printing is able to reduce the cost and time spent by 50% to 90% depending on the production scale when it is compared to CAD-CAM and computer numerical control (CNC) technologies. Due to its ability to produce more organic and complex forms, it enables designs to be more useful and appealing. Also, 3D printing is able to reduce the amount of parts produced by being able to merge the parts and produce them as a single part. On the other hand, machining imposes parts to be produced separately in order to reduce waste and machining cost (Chua & Leong, 2014). By decreasing the amount of parts produced, time spent on tolerance analysis and detailed assembly drawings are reduced. Moreover, design constraints (e.g. avoiding draft angles, thin walls, and complex shapes) due to machining limitations are eliminated by 3D printing. Finally, fixed costs are lower, part specific setting up and programming is not required, machining or casting labor is decreased, material waste is reduced, unit price nearly becomes independent of production quantity (Chua & Leong, 2014).

Figure 32 and Figure 33 demonstrates the 3D printing process of the front component of the outer shell prototype. Figure 34 and Figure 35 represent the 3D printed components of the outer shell. Figure 36, and Figure 37 represent the attached state of these two components.

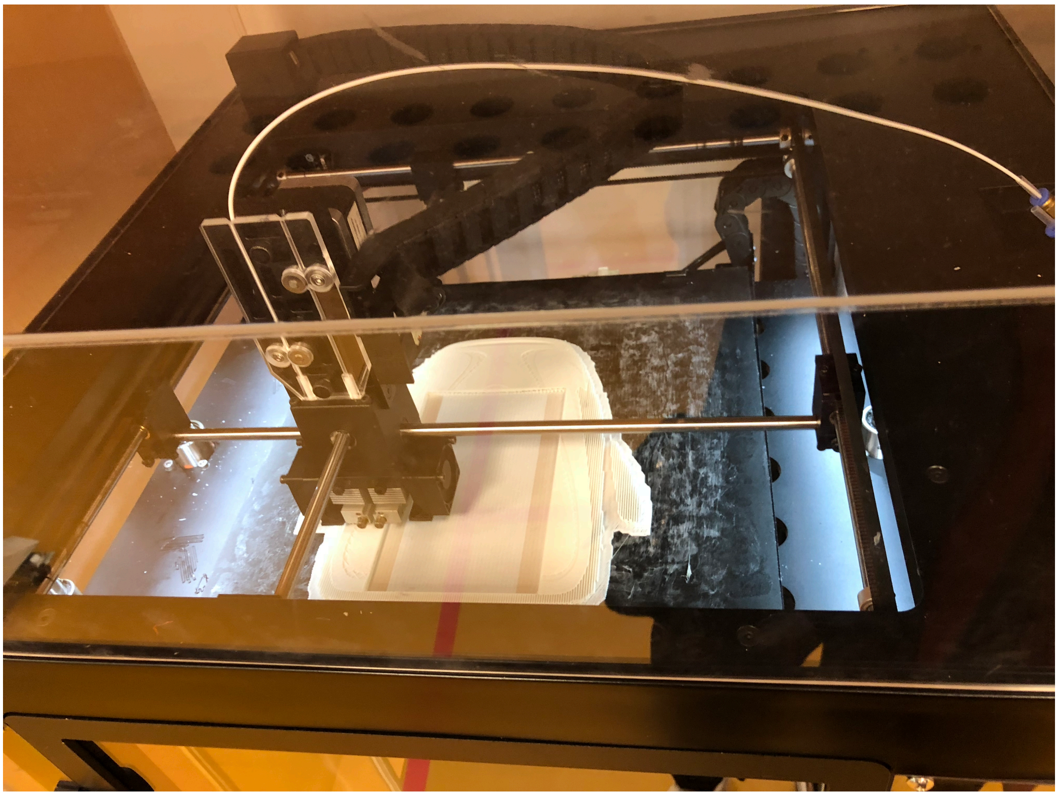

Figure 32. *3D printing process of the shell*

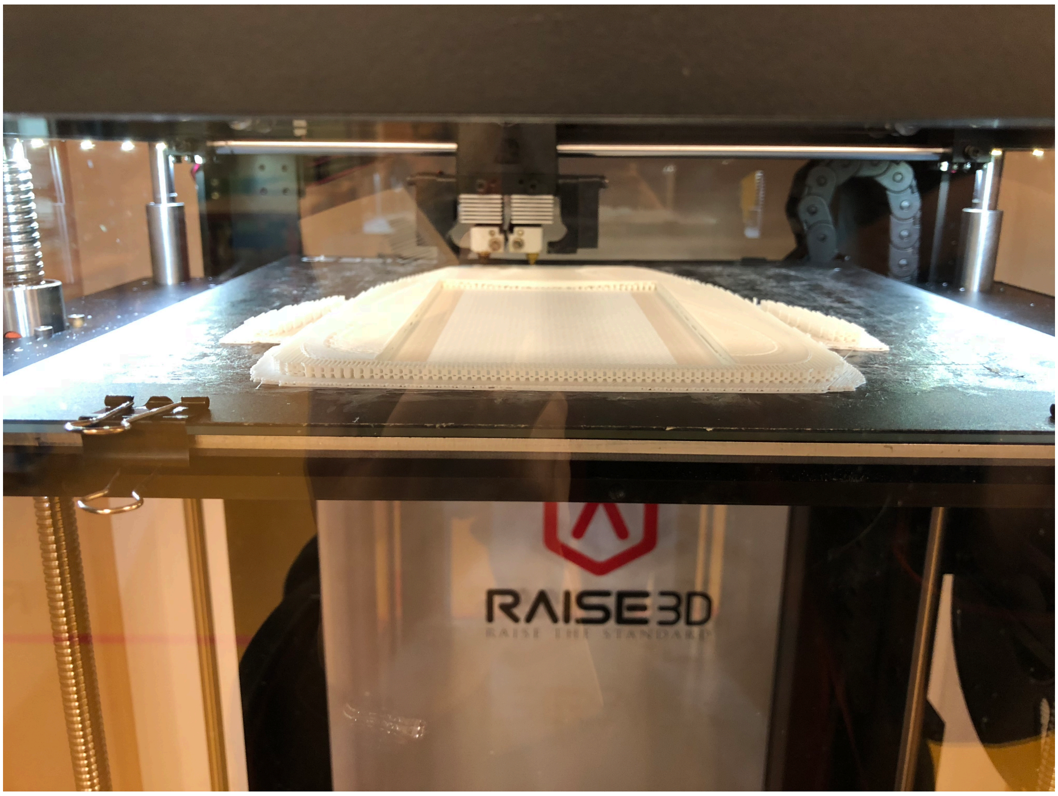


Figure 33. *3D printing process of the shell, front*

Figure 34. *3D printed shell components, front*

Figure 35. *3D printed shell components, back*

Figure 36. *The attached state of the 3D printed components, front*

Figure 37. *The attached state of the 3D printed components, back*

# CONCLUSION

3D printed shell components are sanded to eliminate layer lines and prepare the components for painting. After the sanding process, primer is applied to fill small surface imperfections before painting. Then, components are spray painted for reaching the final appearance of the prototype (see Figures 38-41).

Figure 38. *Final appearance of the prototype, front*

Figure 39. *Final appearance of the prototype, side*

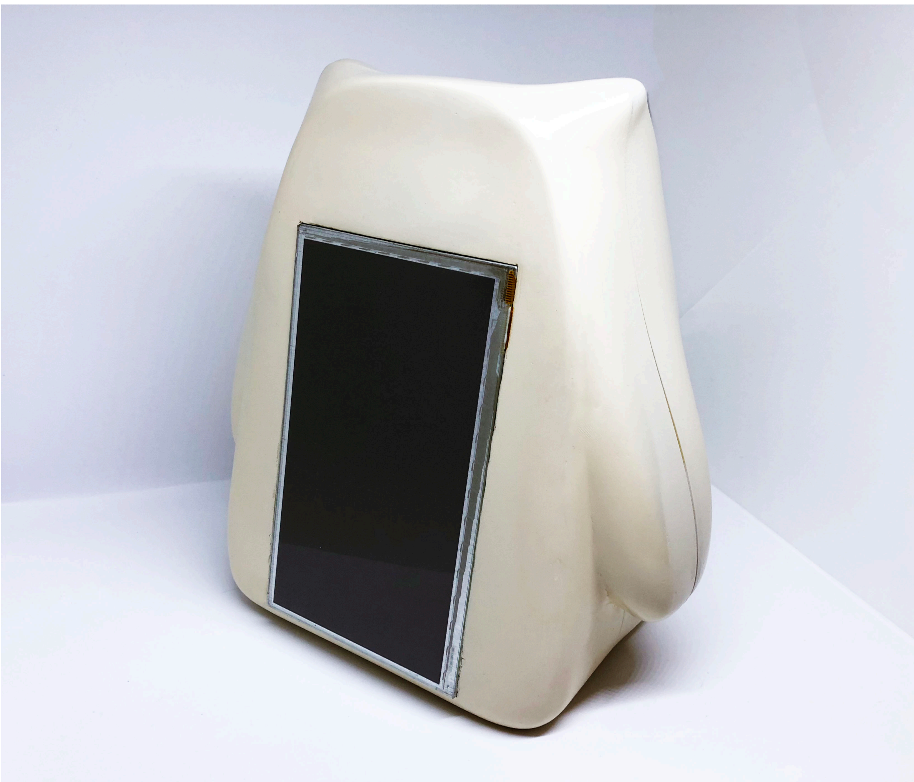

Figure 40. *Final appearance of the prototype, diagonal*

Figure 41. *Final appearance of the prototype, back*

Figures 42-45 shows the device displaying the opening screen and the ‘Inferring from gaze direction’ test.


Figure 42. *Prototype displaying the opening screen*

Figure 43. *Prototype displaying the first test, screen 1*

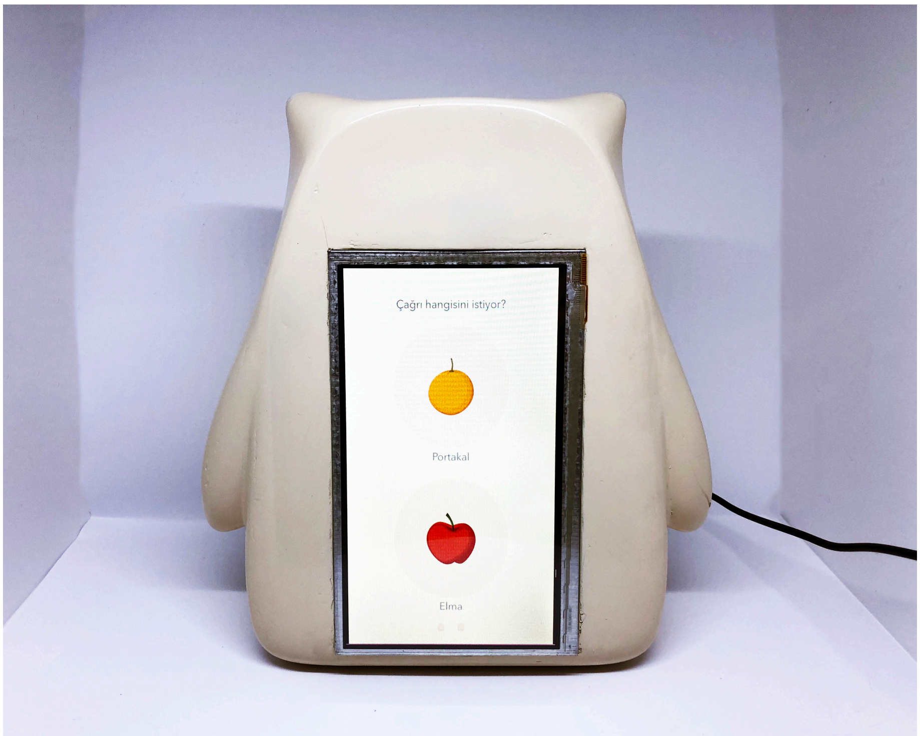


Figure 44. *Prototype displaying the first test, screen 2*

Figure 45. *Prototype displaying the first test, screen 3*

Specifications of the Robotic Toy


Figure 46. *Specifications of the robotic toy*

Mobility of the Robotic Toy

- Size and weight of the device is not exceeding the limits to be carried by caregivers, therapists, and even the child.
- Since mobility adds another aspect that must be controlled during interactions, the device does not have the ability to move around by itself (Scassellati et al., 2012).

Cost of the Robotic Toy

- Cost of the device should be sufficiently low to be highly reachable.
- Raspberry Pi 3 is preferred in order to reduce the cost.
- Actuations are minimized to reduce the cost and to make the device more expectable. Also, having simple equipment reduces hardware failure probabilities, which is an essential aspect for devices to be used long period of times (Scassellati et al., 2012).

Future ambitions for the project include; adding a rechargeable batter unity to provide an option to move the device independently, adding a build-in speaker to provide background music and sound effects, adding LEDs to increase interactivity (child could be given the option to choose the type of sensory rewards from light, audio, and visual), being in communication with external physical objects, providing camera interactions, adding various biosensors (e.g. pulse sensor, ultrasonic sensor, and motion sensor), enabling the use of eye-tracking technologies, and collecting extended data (demographics, time spent to give an answer, heart rate, gaze direction…) from participants. Another future ambition of this thesis is making the robotic toy a home-based device so that assessment can be made in the natural environment of the child (Rakap et al., 2017), since gathering data independent of the clinic environment improves the quantity and quality of the data (Scassellati, 2005). Also, a parent questionnaire can be added to gather more data about the child. A training phase can be added in order to provide the child more time to be accustomed to the software.

Since, abnormal visual scanning pattern is a substantial sign of ASD (Senju et al., 2003) enabling the use of eye-tracking technologies would provide significant data for the research. Perphery et al. (2002) revealed that individuals with ASD spent significantly more time observing the outer features of the face, and spent less time viewing the inner (primary) features such as the nose, mouth, and especially the eyes when compared with individuals without ASD. According to Riby and Hancock (2008) when presented static images of socially interacting individuals, individuals with ASD spend less time looking at faces and spend more time looking at background or body areas compared to typically developed individuals. Another study by Riby and Hancock (2009) revealed abnormal gaze patterns were present for all stimuli types (containing human actor and cartoon images or movies). Besides these abnormal processing strategies resulted from ASD, cultural differences considered to be an influential factor for societies in terms of their visual strategies (Masuda et. al, 2008). Eye tracking has established to be beneficial for revealing the attributes of abnormal visual scanning patterns in ASD. Riby and Hancock (2008; 2009) utilized a Tobii 1750 eye-tracker to record eye movements in their studies. Another future ambition of the project is being able to record eye movements during social scene parsing by connecting a Tobii 1750 eye-tracker to the device and analyzing gaze pattern data considering cultural differences.

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