Supporting Independence of Autistic Adults through Mobile and Virtual Reality Technologies

Bogoan Kim
Hanyang University
Seoul, Republic of Korea
bogoankim@hanyang.ac.kr

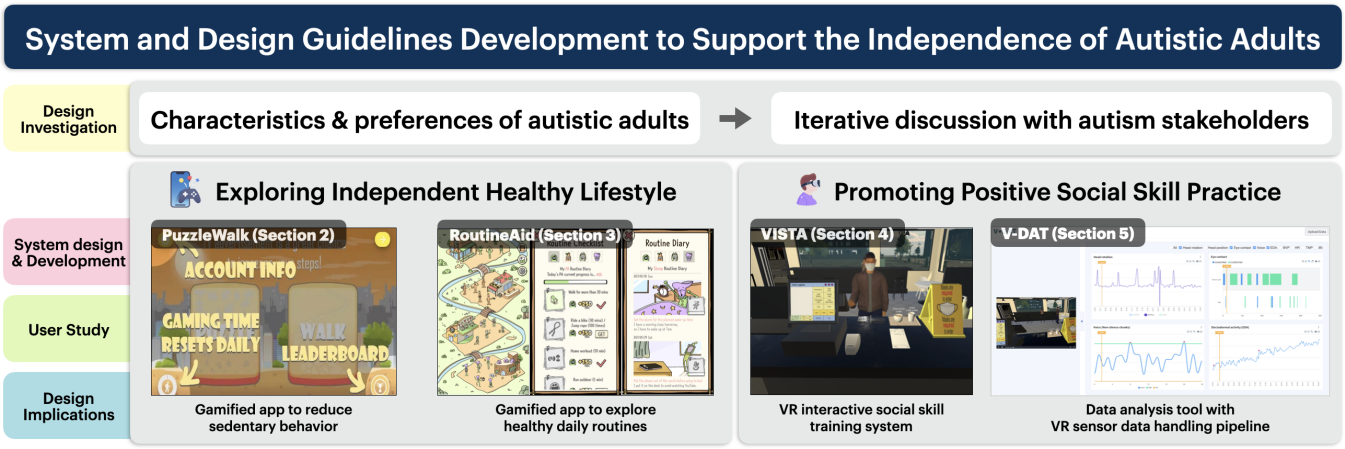


Figure 1: The overview of the dissertation.

ABSTRACT

Pervasive symptoms in autistic individuals, such as facing more frequent challenges in social situations, pose significant obstacles in their pursuit of an independent life in adulthood. Although much research has proposed computer-assisted programs (e.g., smartphone apps and VR-based systems), there is a significant lack of systems designed for autistic adults and their independence, and the preferences or characteristics of autistic individuals are not carefully reflected in the design process. Thus, in my dissertation, I focus on two requirements of autistic adults for supporting their independence: (1) an independent and healthy lifestyle and (2) positive social skill practice. These requirements were externalized in two gamified mobile apps (*PuzzleWalk* and *RoutineAid*) and two VR-based systems (*VISTA* and *V-DAT*). My research aims to design and develop mobile/VR systems and derive design guidelines to support the independence of autistic adults.

CCS CONCEPTS

• **Human-centered computing** → **Accessibility systems and tools**.

KEYWORDS

autism, gamified apps, virtual reality, accessibility

ACM Reference Format:
Bogoan Kim. 2023. Supporting Independence of Autistic Adults through Mobile and Virtual Reality Technologies. In *The 36th Annual ACM Symposium on User Interface Software and Technology (UIST '23 Adjunct), October 29-November 1, 2023, San Francisco, CA, USA.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3586182.3616706

UIST '23 Adjunct, October 29-November 1, 2023, San Francisco, CA, USA

ACM ISBN 979-8-4007-0096-5/23/10.
https://doi.org/10.1145/3586182.3616706

1 INTRODUCTION

Autism is a complex developmental condition involving social interaction challenges with specific patterns of repetitive behaviors [4]. According to a 2020 report by the Centers for Disease Control and Prevention (CDC), approximately 1 in 36 children in the US are estimated to have autism [26]. This number has been steadily increasing over the past 20 years, and it is expected that this trend will continue. For this reason, research on how to best support autistic individuals [1] has blossomed in the past two decades [15].

A growing body of computer-assisted programs has been proposed to enhance the physical, emotional, and social well-being of autistic individuals [19, 24]. In particular, smartphone-based programs have proven effective in establishing and maintaining healthy habits. These programs assist users in setting behavioral goals, monitoring target behaviors, and planning actions in a timely manner. More recently, VR content has been developed to support, without the fear of social consequences that can be overwhelming in real-life situations, self-help skills (e.g., activities of daily living

[1] I use identity-first language due to a reported preference of autistic individuals [18] and recent movement in academia [8].

skills [1, 25, 30], driving [13], road crossing [29]) or social skills (e.g., job interview [31], facial expression recognition [6, 12], and social interaction [17, 28, 32]) that are necessary for one's daily life.

However, autistic adults have not received similar attention when compared to autistic children, and relatively little research on the prognosis, outcomes, or effective interventions for autistic adults has been conducted [11]. Many medical experts specializing in autism (e.g., developmental pediatricians) stop seeing autistic individuals once they reach adulthood, and only few physicians receive training to care for autistic adults [10]. The lack of attention in research, treatment, and care could be one reason for the significantly poorer health and well-being of autistic adults [16]. The majority of autistic individuals experience comorbid psychological disorders, such as anxiety [4], and these disorders mainly occur or worsen during the transition to adulthood, since many autistic adults tend to face more frequent challenges in social situations and lack the resources to successfully achieve their desires, such as participation in employment and social relationships [7]. Recent priorities in autism research [5] have highlighted the critical need for more effective interventions for health conditions associated with autistic adults in real-world settings [16, 33].

Moreover, the design and development of the existing computer-assisted programs have been conducted with somewhat inadequate consideration for autistic individuals. To develop a program suitable for the autism population, it is necessary to involve more consideration of characteristics such as preference for visual reasoning processes and expected interfaces, as well as iterative discussions with autism stakeholders (e.g., autism professionals involved in diagnosis advice and support, autistic adults, and parents of autistic children). According to key design guidelines for mobile/VR system development for autistic individuals [2, 9], autism stakeholders' input and considering autism characteristics into account is crucial to the program's usability, effectiveness, and sustainability.

To address this gap, in my dissertation, I focus on two requirements of autistic adults for supporting their independence – (1) **an independent and healthy lifestyle** and (2) **positive social skill practice** (Figure 1). These requirements were externalized in four systems, with careful consideration of their preferences and characteristics through iterative discussions with autism stakeholders. Among them, two systems were designed to explore an independent and healthy lifestyle as gamified smartphone apps: (1) *PuzzleWalk* [23], a gamified smartphone app to promote physical activity, and (2) *RoutineAid* [22], a gamified smartphone app designed to break down daily routines into smaller steps and celebrate the accomplishment of each. The others were designed to promote positive social skills practice using VR technology: (3) *VISTA* [20], a VR-based interactive social skills training system for autistic adults, and (4) *V-DAT* [21], a web interface integrated with a pipeline for handling and analyzing multimodal VR sensor data collected from autistic adults.

2 [PLOS ONE'20] PUZZLEWALK: A GAMIFIED APP TO PROMOTE PHYSICAL ACTIVITY

The first system designed to support the independence of autistic adults is *PuzzleWalk* [23], a gamified app that reduces their sedentary behavior. *PuzzleWalk* was developed through an iterative design approach, integrating key aspects of user-centered design, such as surveys, interviews, and prototyping, involving autism stakeholders. The system development was guided by behavior change techniques (BCTs) including self-monitoring, visual rewards, performance feedback, user instruction, and goal-setting, along with gamification. *PuzzleWalk* incorporates a variety of user interfaces that are both predictable and sustainable. These interfaces were specifically designed to cater to the preferences and needs of autistic adults with cognitive function, based on insights gathered from a series of design studies.

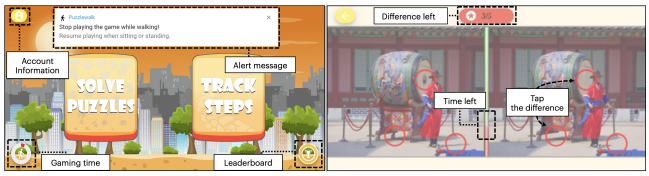


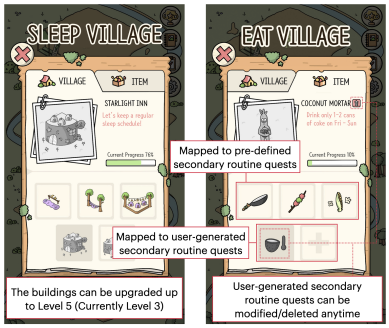
Figure 2: PuzzleWalk, a gamified smartphone app to reduce sedentary time and promote physical activity.

The primary objective of *PuzzleWalk* is to encourage physical activity (PA) using mobile technology-driven behavior change interventions. I employed walking as a means to operationalize PA in autistic adults due to their below-average motor skills [3] and higher susceptibility to obesity compared to the general population [14]. *PuzzleWalk* was developed with the "spot the difference" puzzles (Figure 2). Puzzle images consist of pictures of 100 cities all over the world to incentivize users to increase and sustain PA engagement. The design principle of *PuzzleWalk* is the conversion between walking steps and puzzle-solving time. The accumulated walking steps will automatically be converted to puzzle-solving time so that users will be motivated to increase their walking steps to solve more puzzles.

I recruited 18 participants to evaluate the perception of the use and feasibility of this system and conducted a one-month field study. Overall, the results of the usability evaluations indicate that *PuzzleWalk* was well-received by autistic adults, who found it engaging and entertaining. The satisfactory usability increases the likelihood that *PuzzleWalk* can be used as an effective PA intervention tool for them. This system also reveals useful insights into the ongoing challenges and facilitators of the mobile app-led physical activity intervention, as well as important considerations for flexible and technology-focused game and intervention design for autistic adults focusing on visual communication, gamified motivation strategies, and BCTs.

3 [CHI'23] ROUTINEAID: A GAMIFIED APP TO MANAGE DAILY ROUTINES

RoutineAid [22] is a gamified smartphone app designed to break down daily routines into smaller steps and celebrate the accomplishment of each. Autistic adults can complete primary and secondary daily routines, and develop four types of villages (physical activity, eating, mindfulness, and sleep) by acquiring items and building upgrades based on their routine quest progress (Figure 3). Furthermore, autistic adults can use the routine diary and the leaderboard to track their daily progress and self-reflect. *RoutineAid*'s gameplay aims to help autistic adults independently manage their daily



(a) Buildings (b) Items

Figure 3: RoutineAid, a gamified smartphone app to explore healthy daily routines. In (a) and (b), each building and item is presented with the corresponding image and progress bar.

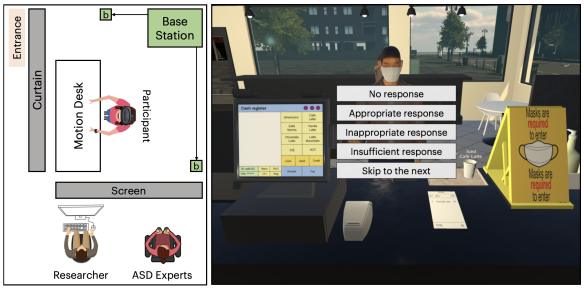
routines and understand the essential components of their own healthy lifestyles.

To develop *RoutineAid*, I conducted a formative study involving 15 autism stakeholders (five autism professionals, five parents of autistic children, and five autistic adults). Through this study, I identified three challenges related to daily routine management for autistic adults: (1) amplified anxiety caused by a broken routine during the Pandemic, (2) insufficient support to balance key components of daily routines (e.g., physical activities, eating habits, mindfulness, and sleep), and (3) frequent difficulties in planning concrete and actionable measures to sustain their routines. To address these challenges, I formulated three design goals corresponding to each challenge: (1) provide opportunities to explore and plan appropriate life rhythms with visual narratives, (2) provide opportunities to achieve sustainable key daily routine management, and (3) provide opportunities to explore actionable daily routine planning.

Based on these design goals, I developed *RoutineAid* and conducted a two-month field study of 10 autistic adults. The results of the study highlighted that they showed high engagement through micro-planning, strategically managing their daily tasks, reflecting them in routine reports, and celebratory interactions. In addition, these results provided researchers, designers, and developers with insights (i.e., enhanced user engagement via visual elements of the main screen, information-sharing support through a leaderboard, and visual support via loss aversion) into how mobile technology should be used and designed to help improve the daily lives of autistic adults.

4 [VRST'22] VISTA: A VR INTERACTIVE SOCIAL SKILLS TRAINING SYSTEM

VISTA [20], a VR-based interactive social skills training system for autistic adults, is designed to reflect insights and feedback from autistic professionals and stakeholders as well as to comply with design guidelines for autistic adults [9]. *VISTA* provides training content that puts autistic adults in an environment where they have to understand a given scenario as barista assistants and interact with others. In particular, one of *VISTA*'s key designs is to provide training scenarios with incremental complexity that were considered effective training methods for autistic individuals and had not been used in previous studies. In addition, *VISTA* was designed to collect various types of sensor data (i.e., eye movement, head



(a) Experiment environment (b) Unity game view on a researcher's side

Figure 4: Experiment setting of VISTA. Depending on the participant's response, the researcher selects the response type (only visible to the researcher), and the avatar (e.g., a customer) shows the subsequent reaction.

movement, physiological signals, and voice) from autistic adults. I carefully selected signals that could be collected unobtrusively, taking into account their high sensitivity to wearing additional devices.

The objectives of the user study were to (1) measure the effectiveness of the design of *VISTA* on having autistic adults engage in training and supporting them understand social situations and feel confidence in social interactions; (2) investigate the difference in sensory reactions between the two groups; and (3) discuss the characteristics of autistic adults by comparing the results with those of previous studies and presenting new insights identified in our study.

The results of our study reveal three significant findings. First, the autistic participants exhibited positive perceptions of their training experience and demonstrated an increase in self-efficacy after being trained through *VISTA*. Second, though there were no significant differences in the variation of sensor signals between autistic and neurotypical participants at the beginning, the differences became more prominent in most sensor signals as the complexity of tasks in the scenarios increased. This indicates that *VISTA*'s design is effective in increasing the engagement and immersiveness of autistic participants. Lastly, our study findings were interpreted in relation to previous studies, reaffirming the importance of some key sensor signals while also identifying other signals that have been somewhat neglected as indicators for understanding autistic adults.

5 [UIST'23] V-DAT: VR DATA ANALYSIS TOOL

The last system designed to support the independence of autistic adults is *V-DAT* [21], a web interface integrated with a pipeline for handling and analyzing multimodal VR sensor data collected from autistic adults (Figure 5). *V-DAT* has been developed to accommodate four primary types of data (i.e., head position and rotation, eye movement, audio, and physiological signals) that are commonly employed in previous studies focusing on autistic adults [6, 20, 28]. Beyond its role in facilitating the collection and storage of data, *V-DAT* has been designed to support comprehensive visualization and analysis of the collected data.

V-DAT is a web-based system integrated with pipelines to process data collected from autistic adults. To support this, the pipeline consists of two modules: (1) data collection considering different collection methods for each sensor modality, and (2) data processing

Figure 5: The V-DAT web interface for data visualizations, which consists of two sections (left: training video, right: visualizations). The timeline flag (yellow vertical line) on the graph is synchronized with the video.

considering appropriate processing and synchronization methods for each sensor modality of different data types. *V-DAT*'s web interface synchronizes the data processed through the pipeline between data forms and provides a visualization appropriate for each data characteristic.

To examine how autistic adults can review and perceive their training outcomes with autism professionals through *V-DAT*, I conducted a user study of 20 autistic adults. I then interviewed five autistic professionals for insight and advice on how *V-DAT* could be employed in clinical sessions in hospitals or centers for autistic adults. The study results revealed that *V-DAT*'s comprehensive visualizations considering the autism characteristics could be used to provide potentially meaningful intervention or diagnostic support for autistic adults.

6 FUTURE DIRECTIONS AND CONCLUSION

In my dissertation, I investigated the challenges to the independence of autistic adults and the limitations of previous studies and specified two requirements: (1) an independent and healthy lifestyle and (2) positive social skill practice. Based on this, I designed and developed four mobile/VR-based systems.

As a future direction, I aim to not only verify the effectiveness of the systems developed through larger-scale or longitudinal user studies but also to explore additional research opportunities. While the number of participants and study duration in the conducted studies are comparable to those of previous studies [17, 28, 29], conducting larger-scale or longitudinal studies would also enable data-driven analyses (e.g., user interaction patterns analysis), using the collected logs and sensor data. Through this future research, I expect to be able to provide more generalizable mobile/VR system design guidelines that can support the independence of autistic adults by expanding the design implications presented in my previous research.

Furthermore, I will employ the multimodal VR sensor data collected from two systems (VISTA, V-DAT) that carefully reflect the requirements of autistic adults and comply with the VR system design guidelines for them [9], to develop deep learning models. Recently, research on multimodal representation learning methodologies enables various downstream tasks, and prominent methodologies like CLIP [27] and TCL [34] have successfully performed zero-shot or few-shot tasks using limited data after representation learning. Similarly, I will employ the model trained on benchmark datasets as an encoder and retrain it on data from autistic adults collected during VR training to develop a prediction model for anxiety/tension displayed in social interaction situations. I expect the VR systems equipped with the developed model will provide autism professionals with a quantitative basis for better understanding autistic adults and evaluating their training more effectively.

At the UIST Doctoral Symposium, I would love to discuss the overall framing that ties together the main themes and objectives surrounding the four introduced systems, as well as the feasibility of future directions.

ACKNOWLEDGMENTS

I am grateful to my advisor Kyungsik Han and my collaborator Hwajung Hong, as well as my co-authors for their support, feedback, and contributions in inspiring and framing my dissertation. I also want to express my great appreciation to the autistic participants who made my research possible.

REFERENCES

[1] Ali Adjorlu, Emil Rosenlund Høeg, Luca Mangano, and Stefania Serafin. 2017. Daily living skills training in virtual reality to help children with autism spectrum disorder in a real shopping scenario. In *2017 IEEE International Symposium on Mixed and Augmented Reality (ISMAR-Adjunct)*. IEEE, 294–302.

[2] Yuska Paola Costa Aguiar, Edith Galy, Anaïs Godde, Maëla Trémaud, and Carole Tardif. 2022. AutismGuide: A usability guidelines to design software solutions for users with autism spectrum disorder. *Behaviour & Information Technology* 41, 6 (2022), 1132–1150.

[3] Katarina Ament, Amanda Mejia, Rebecca Buhlman, Shannon Erklin, Brian Caffo, Stewart Mostofsky, and Ericka Wodka. 2015. Evidence for specificity of motor impairments in catching and balance in children with autism. *Journal of autism and developmental disorders* 45, 3 (2015), 742–751.

[4] American Psychiatric Association. 2013. Diagnostic and statistical manual of mental disorders. *BMC Med* 17 (2013), 133–137.

[5] Autism Speaks. 2013. Strategic Plan for Science 2018 - 2020. https://bit.ly/2kwA7vX. Last accessed 05 September 2019.

[6] Esubalew Bekele, Zhi Zheng, Amy Swanson, Julie Crittendon, Zachary Warren, and Nilanjan Sarkar. 2013. Understanding how adolescents with autism respond to facial expressions in virtual reality environments. *IEEE transactions on visualization and computer graphics* 19, 4 (2013), 711–720.

[7] Amanda E Bennett, Judith S Miller, Natalie Stollon, Raghuram Prasad, and Nathan J Blum. 2018. Autism Spectrum Disorder and Transition-Aged Youth. *Current psychiatry reports* 20, 11 (2018), 103.

[8] Kristen Bottema-Beutel, Steven K Kapp, Jessica Nina Lester, Noah J Sasson, and Brittany N Hand. 2021. Avoiding ableist language: Suggestions for autism researchers. *Autism in Adulthood* 3, 1 (2021), 18–29.

[9] Lal Bozgeyikli, Andrew Raij, Srinivas Katkoori, and Redwan Alqasemi. 2017. A survey on virtual reality for individuals with autism spectrum disorder: design considerations. *IEEE Transactions on Learning Technologies* 11, 2 (2017), 133–151.

[10] Mary Beth Bruder, Gerard Kerins, Cynthia Mazzarella, Jessica Sims, and Neil Stein. 2012. Brief report: the medical care of adults with autism spectrum disorders: identifying the needs. *Journal of Autism and Developmental Disorders* 42, 11 (2012), 2498–2504.

[11] Federica Cena, Amon Rapp, and Claudio Mattutino. 2018. Personalized Spatial Support for People with Autism Spectrum Disorder. In *Adjunct Publication of the 26th Conference on User Modeling, Adaptation and Personalization*. ACM, 233–238.

[12] Yufang Cheng, Cheng-Li Huang, and Chung-Sung Yang. 2015. Using a 3D immersive virtual environment system to enhance social understanding and social skills for children with autism spectrum disorders. *Focus on Autism and Other Developmental Disabilities* 30, 4 (2015), 222–236.

[13] Daniel J Cox, Timothy Brown, Veerle Ross, Matthew Moncrief, Rose Schmitt, Gary Gaffney, and Ron Reeve. 2017. Can youth with autism spectrum disorder use virtual reality driving simulation training to evaluate and improve driving performance? An exploratory study. *Journal of Autism and Developmental Disorders* 47, 8 (2017), 2544–2555.

[14] Anna M Egan, Meredith L Dreyer, Cathleen C Odar, Malia Beckwith, and Carol B Garrison. 2013. Obesity in young children with autism spectrum disorders: prevalence and associated factors. *Childhood Obesity* 9, 2 (2013), 125–131.

[15] Christopher Frauenberger, Julia Makhaeva, and Katharina Spiel. 2017. Blending methods: Developing participatory design sessions for autistic children. In *Proceedings of the 2017 Conference on Interaction Design and Children*. ACM, 39–49.

[16] Katherine Gotham, Alison R Marvin, Julie Lounds Taylor, Zachary Warren, Connie M Anderson, Paul A Law, Jessica K Law, and Paul H Lipkin. 2015. Characterizing the daily life, needs, and priorities of adults with autism spectrum disorder from Interactive Autism Network data. *Autism* 19, 7 (2015), 794–804.

[17] Fengfeng Ke, Jewoong Moon, and Zlatko Sokolikj. 2022. Virtual reality–based social skills training for children with autism spectrum disorder. *Journal of Special Education Technology* 37, 1 (2022), 49–62.

[18] Lorcan Kenny, Caroline Hattersley, Bonnie Molins, Carole Buckley, Carol Povey, and Elizabeth Pellicano. 2016. Which terms should be used to describe autism? Perspectives from the UK autism community. *Autism* 20, 4 (2016), 442–462.

[19] Julie A Kientz, Matthew S Goodwin, Gillian R Hayes, and Gregory D Abowd. 2013. Interactive technologies for autism. *Synthesis lectures on assistive, rehabilitative, and health-preserving technologies* 2, 2 (2013), 1–177.

[20] Bogoan Kim, Dayoung Jeong, Mingon Jeong, Taehyung Noh, Sung-In Kim, Taewan Kim, So-youn Jang, Hee Jeong Yoo, Jennifer G Kim, Hwajung Hong, and Kyungsik Han. 2022. VISTA: User-centered VR Training System for Effectively Deriving Characteristics of People with Autism Spectrum Disorder. In *28th ACM Symposium on Virtual Reality Software and Technology*. 1–11.

[21] Bogoan Kim, Dayoung Jeong, Jennifer G Kim, Hwajung Hong, and Kyungsik Han. 2023. V-DAT (Virtual Reality Data Analysis Tool): Supporting Self-Awareness for Autistic People from Multimodal VR Sensor Data. In *36th ACM Symposium on User Interface Software and Technology*. 1–13.

[22] Bogoan Kim, Sung-In Kim, Sangwon Park, Hee Jeong Yoo, Hwajung Hong, and Kyungsik Han. 2023. RoutineAid: Externalizing Key Design Elements to Support Daily Routines of Individuals with Autism. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*. 1–18.

[23] Bogoan Kim, Daehyoung Lee, Aehong Min, Seungwon Paik, Georgia Frey, Scott Bellini, Kyungsik Han, and Patrick C Shih. 2020. PuzzleWalk: A theory-driven iterative design inquiry of a mobile game for promoting physical activity in adults with autism spectrum disorder. *PLoS One* 15, 9 (2020), e0237966.

[24] Yiannis Koumpouros and Theodoros Kafazis. 2019. Wearables and mobile technologies in Autism Spectrum Disorder interventions: A systematic literature review. *Research in Autism Spectrum Disorders* 66 (2019), 101405.

[25] Liron Lamash, Evelyne Klinger, and Naomi Josman. 2017. Using a virtual supermarket to promote independent functioning among adolescents with Autism Spectrum Disorder. In *2017 International Conference on Virtual Rehabilitation (ICVR)*. IEEE, 1–7.

[26] Matthew J Maenner, Zachary Warren, Ashley Robinson Williams, Esther Amoakohene, Amanda V Bakian, Deborah A Bilder, Maureen S Durkin, Robert T Fitzgerald, Sarah M Furnier, Michelle M Hughes, et al. 2023. Prevalence and characteristics of autism spectrum disorder among children aged 8 years—Autism and Developmental Disabilities Monitoring Network, 11 sites, United States, 2020. *MMWR Surveillance Summaries* 72, 2 (2023), 1.

[27] Alec Radford, Jong Wook Kim, Chris Hallacy, Aditya Ramesh, Gabriel Goh, Sandhini Agarwal, Girish Sastry, Amanda Askell, Pamela Mishkin, Jack Clark, et al. 2021. Learning transferable visual models from natural language supervision. In *International conference on machine learning*. PMLR, 8748–8763.

[28] Marta Robles, Negar Namdarian, Julia Otto, Evelyn Wassiljew, Nassir Navab, Christine M Falter-Wagner, and Daniel Roth. 2022. A Virtual Reality Based System for the Screening and Classification of Autism. *IEEE Trans. Vis. Comput. Graph.* 28, 5 (2022), 2168–2178.

[29] Mario Saiano, Laura Pellegrino, Maura Casadio, Susanna Summa, Eleonora Garbarino, Valentina Rossi, Daniela Dall'Agata, and Vittorio Sanguineti. 2015. Natural interfaces and virtual environments for the acquisition of street crossing and path following skills in adults with Autism Spectrum Disorders: a feasibility study. *Journal of neuroengineering and rehabilitation* 12, 1 (2015), 1–13.

[30] Marco Simões, Miguel Bernardes, Fernando Barros, Miguel Castelo-Branco, et al. 2018. Virtual travel training for autism spectrum disorder: proof-of-concept interventional study. *JMIR serious games* 6, 1 (2018), e8428.

[31] Matthew J Smith, Emily J Ginger, Katherine Wright, Michael A Wright, Julie Lounds Taylor, Laura Boteler Humm, Dale E Olsen, Morris D Bell, and Michael F Fleming. 2014. Virtual reality job interview training in adults with autism spectrum disorder. *Journal of autism and developmental disorders* 44, 10 (2014), 2450–2463.

[32] Natalia Stewart Rosenfield, Kathleen Lamkin, Jennifer Re, Kendra Day, LouAnne Boyd, and Erik Linstead. 2019. A virtual reality system for practicing conversation skills for children with autism. *Multimodal Technologies and Interaction* 3, 2 (2019).

[33] Roma A Vasa, Amy Keefer, Judy Reaven, Mikle South, and Susan W White. 2018. Priorities for advancing research on youth with autism spectrum disorder and co-occurring anxiety. *Journal of autism and developmental disorders* 48, 3 (2018), 925–934.

[34] Jinyu Yang, Jiali Duan, Son Tran, Yi Xu, Sampath Chanda, Liqun Chen, Belinda Zeng, Trishul Chilimbi, and Junzhou Huang. 2022. Vision-language pre-training with triple contrastive learning. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*. 15671–15680.