A Social Robot for Improving Interruptions Tolerance and Employability in Adults with ASD

Rebecca Ramnauth, Emmanuel Adéníran, Timothy Adamson,
Michal A. Lewkowicz, Rohit Giridharan, Caroline Reiner, Brian Scassellati
Department of Computer Science, Yale University
rebecca.ramnauth@yale.edu

***Abstract*—A growing population of adults with Autism Spectrum Disorders (ASD) chronically struggles to find and maintain employment. Previous work reveals that one barrier to employment for adults with ASD is dealing with workplace interruptions. In this paper, we present our design and evaluations of an in-home autonomous robot system that aims to improve users' tolerance to interruptions. The Interruptions Skills Training and Assessment Robot (ISTAR) allows adults with ASD to practice handling interruptions to improve their employability. ISTAR is evaluated by surveys of employers and adults with ASD, and a week-long study in the homes of adults with ASD. Results show that users enjoy training with ISTAR, improve their ability to handle various work-relevant interruptions, and view the system as a valuable tool for improving their employment prospects.**

***Index Terms*—human-robot interaction, autism spectrum disorder, socially assistive robotics, interruptions**

I. Introduction

Individuals with Autism Spectrum Disorders (ASD) exhibit social skill deficits such as difficulties with reciprocal social interaction, interpersonal communication, and insistence on behavioral and environmental sameness [3]. These individuals show a broad spectrum of challenges and (dis)abilities, and vary greatly in their levels of social functioning [30].

ASD is an impairing and costly disorder in both dollars and human experience. An estimated 85 percent of adults with ASD currently experience chronic unemployment or underemployment [48], a significantly higher proportion than adults with other developmental disabilities [4]. Creating an inclusive workplace by improving the employability of adults with ASD would result in financial independence and higher quality of life for the individual. Furthermore, many individuals with ASD have unique strengths and abilities, such as attention to detail and consistent work ethic, that are underutilized and in high-demand in numerous employment sectors [29], [43].

Finding and maintaining employment is complex and involves several stages from submitting a job application or participating in an interview, to navigating the responsibilities and expectations once employed. Each stage demands an ability to adapt to unforeseen circumstances and recover effectively from interruptions. Empirical research demonstrates that commonplace interruptions can result in significant lost work, costly errors, or safety violations [13], [16]. We are motivated to study interruptions due to their frequency in the workplace [15] and their measurable effect on workflow [8].

Fig. 1. The *Interruptions Skills Training and Assessment Robot* (ISTAR) is designed to help adults with Autism Spectrum Disorders (ASD) practice handling interruptions in their home, therefore providing workplace-relevant skills training in an intuitive and organic way. The collage on the left illustrates typical interactions between the system and an adult with ASD in four home deployments. On the right is a depiction of the system in a user's home.

Unfortunately, existing methods to mitigate the effect of interruptions mainly focus on restructuring the workplace environment to limit the frequency of interruptions [55]. Understanding how interruptions impact current workflows, characterizing an individual's capacity to regulate attention effectively between tasks, and training individuals to support better error-free interruptions recovery are desirable for any person that experiences interruptions.

However, interruptions can be especially challenging for people with ASD. The effects of handling workplace distractions, unpredictability, and uncertainty are emphasized by the social skills deficits exhibited by many employees with ASD [25]. Aaron Likens, an Easterseals national representative and adult with ASD, reports: "That's the way my brain is; once at speed I can focus with perfect clarity but that one interruption can bring about a complete change in ability to focus or achieve a task, hence why the unsuspecting interrupter is going to get what sounds like an angry answer." [7]. Likens describes that individuals with ASD are more likely than others to experience not only the personal and emotional but also the social implications of interruptions.

Social robotics has the potential to address the critical gap of job-relevant interruptions training for this unique and understudied population [33], [39]. Compared to other technologies, a robot provides a physical component to the training experience that makes it difficult for users to ignore or silence its prompts for interaction. Furthermore, we consider socially assistive robotics (SARs) because it merges traditional robotics and computational methods to improve access to personalized, socially situated, and physically co-present interactions [31]. In other words, a SAR for social skills training demands that its users respond socially appropriately.

Research has established that SARs for ASD interventions can result in positive and productive outcomes [40]. A recent study indicates that robot-assisted therapy may be effective for improving interruptions tolerance in adults with ASD [33]. Preliminary work find that aspects of face-to-face communication can be supported with robot interactions [54] and in-home robot-led training can be applicable to the workplace [33].

Leveraging these previous successes in the development of SARs for ASD interventions [41], we developed the *Interruption Skill Training and Assessment Robot* (ISTAR), an in-home autonomous training system that helps adults with ASD to practice handling workplace-relevant interruptions. This system targets social skills development in a familiar environment and can provide valuable support for adults with ASD as they find and maintain employment.

II. Related Work

Our review of recent literature highlights common obstacles to gainful employment for adults with ASD. We emphasize the role of interruptions training to improve employability. Last, we discuss the potential role of SARs in addressing the critical gap of accessible social skills training for adults with ASD.

A. Job Skills Training for Adults with ASD

Few individuals with ASD have been trained in the vocational skills needed to find and maintain gainful employment. The number of under- and unemployed adults with ASD is exceptionally high, even compared to those in similar disability groups [45]. Most job training for adults with ASD that have been demonstrated effective target specific on-the-job tasks such as mail sorting, photocopying, and stocking shelves [44]. Consequently, traditional job training overlooks many of the soft skills essential to job maintenance, including time management, organization, and customer or co-worker interactions. These skills are often the most difficult for persons with ASD.

In all, interventions for ASD do not yet capture the heterogeneity of impairment [30], the demographic [6], or the range of services needed to help adults function with purpose in their communities [20]. Although employment interventions for ASD have been developed, many are not clinically meaningful and lack clear evidence concerning their efficacy [47], [51]. Due to the vast heterogeneity of ASD, a "one size fits all" approach is insufficient and counterproductive [42].

B. Interruptions Training

It is commonly understood that the more people practice performing a particular task, the better they are able to perform that task (i.e., the practice effect; [19]). It reasonably follows that the more an individual practices with interruptions, the better they will become at recovering from interruptions. Research examining the effects of repeated exposure to interruptions supports this view [11], [23]. Two standard behavioral metrics are used to measure the disruption caused by an interruption and to evaluate the success of interruptions training: interruption lag and resumption lag. *Interruption lag* is the time needed to address an interruption once it has happened. Similarly, *resumption lag* is the time needed to "collect one's thoughts" and resume the original task after an interruption is over [1]. Performing a task while experiencing interruptions over several sessions reduces interruption and resumption lags to improve overall performance [11]. However, the source of improved performance is not yet understood. It remains unclear whether improvement arises from repeated exposure of the primary task alone, from reduced cognitive demand due to the practice effect, from experiencing the co-occurrence of the primary and interrupting tasks, or from a more general learning process where exposure to specific interrupting tasks leads to improvement at handling any interruption [11], [38].

Yet, to minimize the disruptive effects of interruptions, it is not sufficient for people to gain expertise at specific primary tasks [11], [24]. Instead, they must also gain expertise at performing tasks with interruptions. As a result, individuals who work in environments subject to many interruptions benefit from practicing workplace-relevant primary and interrupting task pairs. As it is difficult to account for all possible interruptions when developing an interruptions training platform, both task-analytic and observational techniques must be applied to identify the types of interruptions most prevalent in a given environment. For example, in the safety-critical environment of the flight deck, the most common interruptions are radio contact with air traffic controllers, requests from flight attendants, and alerts from the aircraft itself [11]. Incorporating these common interruptions into flight simulation for pilot training has reduced disruptions on the flight deck where error tolerance is at or near zero percent [18], [27].

Nevertheless, it is an ambitious task to compile a comprehensive and continuously relevant set of task pairs that will manifest in the real-world. Job training programs should incorporate general workplace interruptions into the practice of primary work tasks to ensure that individuals will be able to recover effectively when faced with real-world interruptions.

C. Social Robotics for ASD Skills Training

Recent evidence suggesting that technology-driven interactions enable better social understanding for adults with ASD [10], [40] has encouraged researchers to explore technology for workplace interventions [33]. Emerging "Inclusion Engineering" efforts [14] create environments where marginalized individuals can master various everyday tasks that are key to productive employment. Virtual environments have been developed to role-play common employment scenarios such as job interviews. These role-playing scenarios have demonstrated long-term post-intervention improvements [46]. Leveraging the advantages of an embodied system [40], human-robot interactions have the potential for effective skills training for improving the employability of adults with ASD.

SARs have been shown to increase both compliance [5] and learning gains [28] in similar applications. Well-grounded evidence increasingly pervades the literature to affirm that interaction between individuals with ASD and embodied artificial agents encourages prosocial behaviors [17], sustains attention, induces spontaneous and appropriate social behavior, decreases stereotyped and repetitive behaviors [49], optimizes cognitive learning gains [37], and enhances social engagement [36], [40]. In all, a robot that engages its users in social-skills training can be a valuable tool for adults with ASD.

III. Design Goals

Designing ISTAR was an iterative process. We first examined responses to interviews assessing the state of employment of adults with ASD and the potential for interruptions training. These interviews suggested that an in-home social robot training platform would be applicable to improving users' resiliency to workplace interruptions. We describe here our design goals inspired by the recommendations gathered from these interviews. Later, we improved our prototype based on survey assessments from adults with ASD and employers (Section V). The improvements directly addressed our design goals and made ISTAR more autonomous, robust, and responsive for a home environment. Ultimately, the final system was ready for deployment into homes of adults with ASD (Section VI).

Our collaborators [9] conducted individual and focus group interviews with employers, service providers, and adults with ASD to achieve a first-hand account of their perceptions of employment and the current workforce. In these interviews, individuals with ASD highlighted that interruptions in the workplace from other people were ”problematic” and considered a barrier to maintaining employment. Employers reported that successful employees with ASD are part of peer support programs that encourage socialization and role-playing situations as an effective form of preparation. The design requirements of our robot prototype address these insights by providing role-based interruptions training to its users.

To improve tolerance to real-world interruptions, the system should provide workplace-relevant interruptions training through role-playing. With efficient and relevant training, we expect users will improve their tolerance for workplace interruptions where, over time, the interruptions will become less disruptive, allowing them to return to their primary task quickly. There are four primary design goals for ISTAR:

1. Embodied. The system should be embodied as a robot. A social robot can produce measurable learning outcomes [28], provide a physical component to the training experience that improves compliance [5], and express realistic cues that encourage socially appropriate responses from users [22].

2. In-the-home. The system should be designed to provide training in the home. Therefore, users can interact with ISTAR to avoid potential stigma from colleagues, and without needing approval from or declaring a diagnosis to their employers. Although similar systems for studying interruptions [33] have been designed for clinical or laboratory settings where environmental conditions can be controlled or planned for [41], the home is a dynamic, unstructured environment that demands more complex sensing and behavioral decisions.

3. Autonomous. Training should be fully autonomous; it should not be necessary for someone with technical expertise to adjust or control the system once it is given to the user.

4. Realistic. ISTAR should provide realistic interactions that are appropriate and similar to interruptions that occur in the workplace, respond in real-time, and express human-like behaviors such as naturalistic gaze, movement, and speech.

IV. System

In this section, we illustrate ISTAR-given interruptions as well as the hardware and software components that address our design goals of a fully autonomous robot system that simulates these interruptions in the homes of adults with ASD.

A. Interaction

ISTAR is designed to be an in-home interruptions training robot. Frequent and brief robot-led interactions should capture the attention of its user. After each interaction, users exercise their resiliency to interruptions by resuming their original activities. Figure 2 illustrates an example of ISTAR giving its user an interruption. The user is engaged in his primary task of reading while ISTAR sits on the desk beside the user. ISTAR is configured to initiate an interruption only when its user is within its camera's view. The first frame (A) shows the user focusing on a primary task. In frame B, ISTAR initiates an interruption by asking the user a question to capture his attention. Then, in frame C, the user shifts his attention, diverting his focus away from the primary task to respond to ISTAR's interruption. The time between when ISTAR initiated the interruption and when it captured the user's attention is the interruption lag. ISTAR thanks the user for his response in frame D. Frame E depicts the completion of the interruption as ISTAR resumes its idling behavior. Frame E also shows the user resuming his original task. The resumption lag is computed from the completion of the interruption interaction to when the user resumes his original task.

B. Hardware

To achieve these interruption interactions, our system is comprised of six main hardware components as shown in Figure 3. We used the robot Jibo [35] which stands 11 inches tall and has 3 full-revolute axes designed for 360-degree movement. Jibo's hardware capabilities allowed us to program personified behaviors such as naturalistic gaze, pose, and movement. We included a compact PC that communicates with other hardware, monitors the overall system, and serves as the local data storage during our in-home system evaluation.

Survey evaluations by adults with ASD and employers (Section V-A2) suggest implementing interruptions that require a physical response. We included a numeric keypad to facilitate interruptions that prompt users to complete a mental task and enter their response into the keypad. Jibo and the keypad are

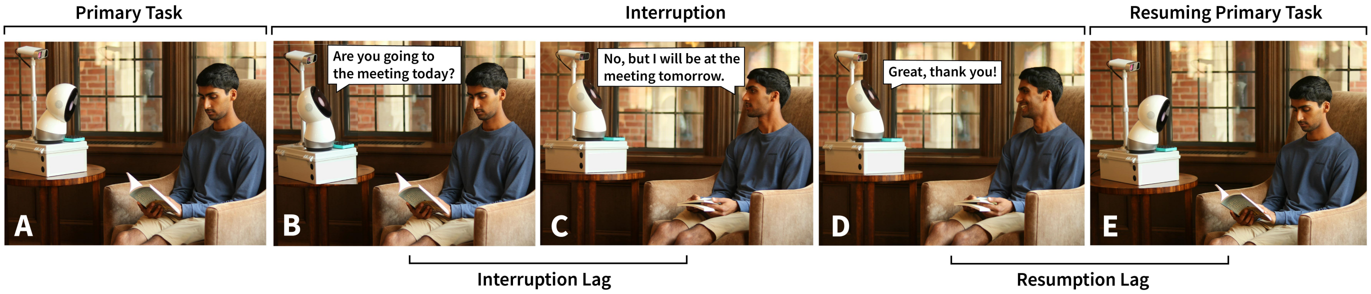

Fig. 2. **ISTAR interruptions**: (A) the participant is occupied with a primary task while the robot is performing idling behavior; (B) the robot interrupts the user by asking them a work-related question; (C) the user responds to the robot's interruption; (D) the robot thanks the user for their response; finally, (E) the user resumes their original task. We define two primary metrics in Section IV-A to measure resiliency to an interruption: interruption lag and resumption lag.

fixed to the top of a plastic case containing the PC and all remaining hardware components that users do not interact with but support ISTAR's functionality. For the sensing required for in-home use, we mount an Azure Kinect [34] camera to a mast behind and 2 inches above Jibo's head to maximize the camera's field of vision. The Kinect also has a microphone array to capture audio during ISTAR training sessions.

We included several accessories to ensure the system is self-reliant in that it maintains power and internet connection once in the user's home. Each system is outfitted with a mobile router with a prepaid internet service plan for continuous WiFi connection. The router also enables automatic cloud-based data synchronization and remote control of the system for troubleshooting and system-monitoring purposes during our in-home evaluations. Additionally, the system is equipped with an uninterruptible battery power supply which serves as ISTAR's main charging station. This pack improves system robustness in the event of power outages.

With these components, ISTAR is a plug-and-play system that only requires connection to a power outlet in the user's home. Our hardware ensures self-reliance and self-containment. Considering rules for ergonomic and accessible design, we reduce the apparent complexity of the system by encasing its non-interfaceable components in the container which the robot and the external camera are mounted on.

C. Software

1) Interaction Components: We used a modular software architecture when creating the system to allow for individual components to be easily updated and improved. To achieve this modularity, we created the different components of our software as nodes in the Robot Operating System (ROS) [50].

The scheduling node determines when the system will capture an image. The images are captured on the system's Azure Kinect and then used as input to a pre-trained YOLO [21] neural network to predict the number of people in the system's field of view. If less than two people are detected, then ISTAR delivers an interruption. If two or more people are detected, the system assumes that this is not a socially appropriate time to interrupt its user and it skips the planned interruption. Yet, the frequency of interruptions incrementally increases such that the number of interruptions within the designated time window remains the same. The time between interruptions is selected from a Gaussian distribution to prevent the user from predicting when the next interruption will occur.

When not delivering an interruption, Jibo silently looks at the floor. When it is prompted to deliver an interruption, Jibo looks up and plays a pre-recorded audio file of the interruption from its speakers. For interruptions that require a verbal response, Jibo waits for the user's verbal response which is then sent to the Google Speech-to-Text API so that the user's response can be transcribed. If the user does not respond within ten seconds, Jibo will reprompt them with the original question. After receiving their response, Jibo then thanks the user and resumes silently looking at the floor.

2) Robustness for in-home study: Robots deployed in the home generally require significantly greater robustness than robots used in a lab setting. The unstructured environment of the home comes with many challenges, including the possibility of power outages, variable lighting conditions, and unexpected events that distract the user. To make our system robust to this unpredictable environment, we added software to inform us of the system's performance and the ability to remotely fix whatever problems may arise. This was achieved by using watchdog scripts and remote desktop applications.

The system has two watchdog scripts that run each day. The first script runs at the start of the training session. It verifies that the camera and microphone are successfully capturing images and sound, and that the PC is able to communicate with Jibo. The second watchdog script runs at the end of each day to check the size of the video, audio, and other files recorded to determine if the system turned off during the training session. It also checks the number of times that each type of interruption was delivered and the participant's responses to the interruptions. Each script notifies the research team detailing the success or failure of each of the components.

The system has two remote desktop applications [2], [52] installed to allow for remote configuration and debugging during the in-home evaluation. Remote access allows for remote configuration; the system can be delivered to the user's home and then configured completely without human contact.

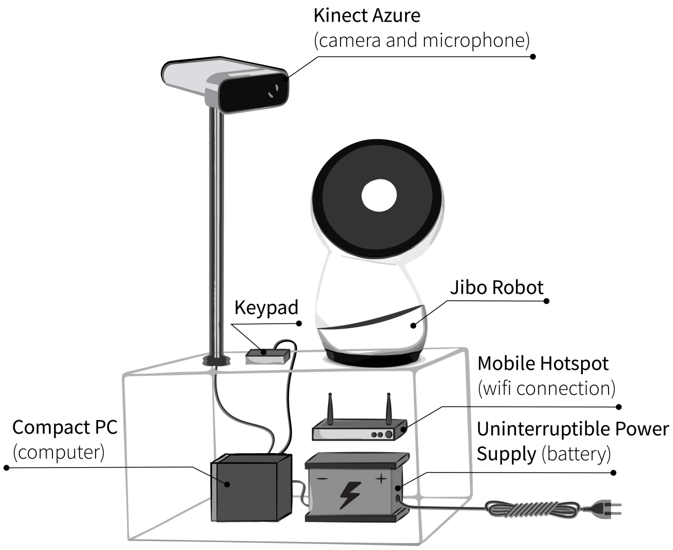

Fig. 3. **ISTAR Hardware**. The system has a battery, compact computer, and mobile hotspot that are contained in a hard plastic case. An external camera and microphone are mounted on a mast above the robot's head. We later include a numeric keypad based on reports of common workplace interruptions experienced by adults with ASD in Section V.

V. Evaluation 1: Surveys of the Prototype

We conducted surveys of adults with ASD and employers to rapidly assess user acceptance of the system. We used the insights gathered from these assessments to improve the system before carrying out the more extensive in-home evaluations.

We showed three videos demonstrating ISTAR's operation. In the first video, ISTAR interrupted a user who was playing video games to ask if they would be willing to switch work shifts. In the second video, ISTAR interrupted a user watching a sports game on TV to ask if they had completed a work report. In the third video, ISTAR interrupted a user washing dishes to ask where it would find an item in a grocery store.

Survey respondents were presented these demonstrations of ISTAR interrupting three different users. They evaluated the characteristics of the interruption, robot, and the overall interaction. Finally, participants were asked whether they would be willing to and how they would use the training system.

A. Results

We collected responses from 35 adults diagnosed with ASD and 13 employers of adults with ASD. A majority of the participating adults with ASD were students (89%). 31% were employed, and 26% were unemployed while 17% were actively looking for work. The remaining student-respondents were not seeking employment at the time surveyed.

1) Surveys of Adults with ASD: Of adults with ASD who were employed ($N = 11$), commonly reported workplace distractions included peer colleagues interrupting on matters unrelated to work (reported by 73%), supervisors interrupting on matters unrelated to work (55%), and environmental noise (e.g., a car honking its horn outside; 73%). When asked if ISTAR's interruptions were similar to those at the workplace, 23% responded that it was similar, 50% reported that it was somewhat similar, and 28% responded that it was different.

We explored how potential end-users would feel about having ISTAR in their home by asking if they would show this system when friends visited. 54% of all adults with ASD surveyed responded that they would show off the system by interacting with it in front of their friends, 23% would just show the system to their friends, without demonstrating its functionality, 14% would ignore the system, and 9% would turn it off and place it out of sight when their friends came to visit. Using a 7-point Likert scale where 1 is *extremely uncomfortable* and 7 is *extremely comfortable*, participants reported they would be roughly equally comfortable interacting with ISTAR in their home ($M = 4.80, SD = 1.80$) as in their workplace ($M = 4.74, SD = 1.70$).

While 66% of adults with ASD did not find ISTAR and the interruptive interactions overstimulating, 13% found the robot's behavior and 8% found what the robot said overstimulating. For example, one respondent mentioned that it "speaks in a fast tone" and another said that "it kept moving and flashing." Several respondents mentioned that the robot distracted the user from their current task. One respondent said, "The information takes you out of and away from the current task." This observation by respondents aligns well with our design goals because we want ISTAR to disengage the user from their task to practice responding to the interruptions.

In all, adults with ASD positively evaluated ISTAR's features and viewed the training interactions as valuable. 40% of participants reported that they would use this in-home system if it improved their prospects of getting a job, 34% of participants said that they would probably use it, and 14% said that they might or might not use it. The remaining 11% said that they would probably not use it.

2) Surveys of Employers: Generally, 80% of employers reported a difference in how adults with ASD handle workplace interruptions as compared to other workers. When asked to describe this difference, employers wrote that adults with ASD experience "difficulty concentrating or returning to [the primary] task" and that many "have adapted protocols on how to stay on or come back to [the primary] task."

Similar to adults with ASD, employers said they expect the most common workplace distractions to be environmental noise (reported by 77%) and peer co-workers on matters unrelated to work (reported by 69%). From employers' experiences, it took adults with ASD approximately 30 minutes and 40 seconds (SD = 38 minutes and 10 seconds) to return to their primary task, once interrupted. Adults with ASD and their employers differ in their perception of how long it takes for an adults with ASD to return to a primary task.

Limited significance should be placed on our survey respondents' estimation of the time it takes to resume tasks. Employers of adults with ASD reported that it took adults with ASD slightly over 30 minutes, on average, to return to their primary task, once interrupted. Whereas, employed adults with ASD reported taking about six minutes, on average, to resume their task. This five-fold difference could be due to employers making estimations based on observations of employee overall performance, recalling employees who took the longest to resume their tasks, and generalizations among employees.

B. Discussion

This evaluation establishes that ISTAR addresses a relevant and pressing problem, and could be accepted and utilized as a training platform. Most employers stated that employees with ASD handle workplace interruptions differently than other workers, and many adults with ASD said they would probably or definitely use our system if it would increase their prospects of getting a job. Survey results also indicate that most adults with ASD felt that they would be comfortable with ISTAR in their homes, even wanting to show off ISTAR and its interactions to a visiting friend. Most adults with ASD viewed ISTAR as friendly, approachable, and not overstimulating.

Insights collected from these surveys suggest that an interruptions training system should provide various types of interruptions to better resemble those frequently experienced in the workplace. We implemented three interruption modes on ISTAR, each of which demand a different skill or form of response. A *social* interruption requires a verbal and behavioral response to a user-directed question (e.g., turning to face the system, maintaining eye contact, and answering a robot-initiated question completely and appropriately). In contrast, a *task* interruption requires the user to physically interact with the system by typing in their response into a keypad. Last, an *environmental* interruption is a sound played through the robot's speakers and the expected behavior is for the user to ignore the entire interruption and continue their original task.

An interaction with ISTAR begins the same for each of these three interruption types. The robot looks up from its sleeping idling behavior and then delivers the interruption. The remainder of the interaction depends on the interruption type. Due to the nature of ASD as a spectrum, our end-users may vary greatly in severity and education. Therefore, ISTAR does not check for the correctness of the users' responses.

For **social interruptions**, the robot asks the user a question and then waits for them to verbally respond. If the user does not respond, it re-prompts the user with the same question. The robot then thanks the user when it receives a response. Examples of social interruptions include, "How do I get to the nearest train station?" and "In which aisle can I find pickles?"

To support task interruptions, we include a numeric keypad as illustrated in Figure 3. For **task interruptions**, the robot asks the user a question and requires them to type their numerical response into its keypad. ISTAR will re-prompt the user if they do not respond. Once the user types their response into the keypad, the robot thanks them for responding. Examples of task interruptions include, "Please enter in your zip code." or "How many days are there until the weekend?"

For **environmental interruptions**, the robot plays a sound that one might typically find in a workplace environment, like the sound of a car driving by or cafeteria chatter. After the interrupting sound is finished, the robot then returns to its idling behavior of silently looking at the floor.

We designed a system that performs robot-initiated interruptions. We validated our design decisions through surveys collecting feedback from potential end-users on a prototype. The majority of survey respondents with ASD stated that they be willing to use ISTAR in their homes. We improved the robot-initiated interruptions to better resemble interruptions commonly encountered in the workplace by implementing several types of interruptions. Based on the frequencies of workplace interruptions reported in our surveys, we configured the final system to interrupt users an average of 8 to 15 times in each two-hour daily training session. We also improved the content of the interruptions to make for more realistic and generalizable interactions.

VI. Evaluation 2: In-Home Deployments

The best evaluation of this system is in the homes of adults with ASD. However, experiencing long-lasting improvement or behavioral change as a result of training would take several weeks to achieve [26]. Before we can fully evaluate the efficacy of ISTAR, we investigate whether adults with ASD will accept the system in their homes and continue to interact with its training prompts throughout a week-long study. The results of this evaluation can support longer-term deployments of ISTAR to explore lasting behavioral improvement in users.

After we received approval by the Yale Institutional Review Board to conduct this evaluation, interested adults with ASD enrolled to participate by signing up via a website highlighted on flyers posted locally. Due to the current COVID-19 pandemic, extra attention was paid to making this system easy to install and use. Each system was delivered to a home and set up exclusively by the user without the research team stepping foot in the home or having any direct contact with the user. Upon receiving their system, participants were encouraged to put their system in a room where they spent most of their time but felt comfortable performing their typical home activities in front of the robot. Participants specified times when ISTAR can engage them a training session. They were told that ISTAR will "wake up" several times during their session to engage them in a short conversation. The study finished when ISTAR has been in the participant's home for seven days.

A. Data Collection

Video and audio data recordings for all training interactions fully captured each ISTAR-given interruption the participant experienced, participant responses to the interruption, and their activities before and after responding to the interruption.

We performed four sets of annotations on each interruption given by ISTAR. Three researchers used ELAN [32] to timestamp when participants first turned their gaze away from their primary task after an interruption is given, then looked at the robot, turned their gaze away from the robot, and finally looked back at their primary task. At the beginning of this process, the transcriptions were evaluated twice for procedural errors. After the process completed, the inter-coder reliability was computed for 25% of all interruptions, randomly selected across participants and annotated by three coders. We evaluated the agreement between annotators because of the inherent ambiguity in assessing participant behavior in the noisy, unstructured home environment. The intraclass correlation coefficient was 0.95 and 0.90 for the time it takes the participant to look at the robot after an interruption is delivered (i.e., interruption lag) and the time it takes to look back at the primary task after an interruption is addressed (i.e., resumption lag), respectively.

To supplement these annotations, one member of the research staff transcribed objective characteristics of the participants' interactions using a survey. These transcriptions assessed the length of the participants' verbal responses to ISTAR, whether the participant resumed their original task or transitioned to a different task after an interruption, and how socially or physically demanding their tasks were before and after an interruption. These transcriptions were made using a series of objective binary questions, so computing agreement and multiple annotators were not necessary.

B. Participant Information

Twelve adults with ASD enrolled in this study. Two participants withdrew because of unrelated personal circumstances due to the current pandemic. 8 males and 2 females, ranging from ages 20 to 42 ($M = 26.3$, $SD = 6.9$) years, completed this evaluation of ISTAR. Participants completed surveys to determine their level of education, employment status, AQ-10 score, and expectations of training with ISTAR using the Flow in Work Scale (FWS) [53]. Among the ten individuals who completed the study, nine participants completed the online survey and one participant required support from a caregiver to navigate the survey website and submit his responses.

Two participants were employed at the time of their study, five were unemployed and actively looking for employment, and three were not looking for employment. All participants had at least a secondary school experience with 80% having attended college or vocational training. Participants were high-functioning adults with a confirmed diagnosis of ASD and an average AQ-10 score of 4.6 ($SD = 1.6$). On a 5-point Likert scale where *1* is *not easily at all* and *extremely easily*, participants reported being "somewhat easily" distracted ($M = 3.1$, $SD = 1.17$) from everyday interruptions. Responses to the FWS show that participants generally expected a medium probability of success, saw interacting with ISTAR to be interesting, not overwhelming, yet a challenge for which they were eager to see how they would perform during training (*fluency of performance*: $M = 24.0$, $SD = 5.89$; *absorption of activity*: $M = 15.0$, $SD = 4.38$; *perceived fit of demand and skills:* $M = 13.0$, $SD = 4.05$).

C. Results

ISTAR delivered 841 interruptions in total. 12% of interruptions were removed from analysis because participants were not in the room to experience them. Each participant experienced an average of 73.2 total interruptions, 12.9 ($SD = 3.4$) interruptions per training session. In a workplace setting, we would define successfully handling *environmental interruptions* as seamlessly performing one's task despite the interruption. For *social interruptions*, we expect an employee to pause their task, maintain eye contact with the interrupter, and address the interrupter's question completely before resuming their task. For *task interruptions*, a verbal response is not necessary, but a complete and relevant response is. We also expect to observe reduced interruption and resumption lags throughout the training. This would indicate that users improve at switching between tasks and interruptions, and that ISTAR would be an effective system for achieving this improvement.

1) Handling Interruptions: According to these criteria, participants responded appropriately to 40% of all environmental interruptions experienced ($N = 237$), 98% of social interruptions, ($N = 250$) and 99% of task interruptions ($N = 245$). Across all social and task interruptions, participants had a high response rate to the interruptions, responding socially to 99% of the interruptions by sustaining eye contact, pausing their original task to attend to the interruption, or speaking to the robot. Interestingly, participants showed similar social behaviors for 60% of all environmental interruptions experienced.

A multiple linear regression calculated to predict interruption lag revealed a significant effect of the interruption type ($\beta = 2.37$, $p \leq 0.001$), AQ-10 score ($\beta = 0.45$, $p \leq 0.001$), and number of interruptions experienced into training with the system ($\beta = -0.01$, $p = 0.01$). The significant decrease in interruption lag as users continued to train with ISTAR shows that they attended more quickly to interruptions over time. A multiple linear regression to predict resumption lag revealed a significant effect of interruption type ($\beta = -11.1$, $p \leq 0.001$) and AQ-10 score ($\beta = -1.02$, $p \leq 0.001$). Estimated coefficients are denoted as β.

Interruption and resumption lags were computed to compare the disruption caused by each type of interruption as measured in seconds (s). Participants' interruption lags were significantly shorter for environmental interruptions ($M = 2.24s$, $SD = 4.02s$) than for social interruptions ($M = 3.18s$, $SD = 3.45s$, $t = 2.66$, $p \leq 0.01$) and task interruptions ($M = 4.66s$, $SD = 4.44s$, $t = 6.00$, $p <= 0.001$). The interruption lags for social interruptions were also significantly shorter than for task interruptions ($t = -4.03$, $p \leq 0.001$).

Participants' resumption lags were significantly longer for environmental interruptions ($M = 15.86s$, $SD = 13.10s$) than for social interruptions ($M = 4.57s$, $SD = 6.82s$, $t = -11.57$, $p \leq 0.001$) and task interruptions ($M = 7.47s$, $SD = 6.89s$, $t = -8.35$, $p \leq 0.001$). The resumption lags for the task interruptions were also significantly longer than for the social interruption ($t = -4.49$, $p \leq 0.001$).

2) Perception of the System: At the end of their study, participants gave feedback on their experience with ISTAR by completing an online survey and interview. Using the Robotic Social Attributes Scale (RoSAS) [12], participants perceived ISTAR as warm, competent, and not discomforting to use. The terms popularly used to describe ISTAR were *social*, *responsive*, *interactive*, *capable*, and *organic*.

Participants additionally evaluated ISTAR as a training system. They reported on a 5-point Likert scale, where 1 is *none at all* and 5 is *a great deal*, that training with

ISTAR improved their tolerance for interruptions experienced outside of their training sessions ($M = 3.3$, $SD = 1.3$). In interviews, two participants reported that training with ISTAR was valuable as they continued to look for employment in that "[ISTAR] would remind me of what I'd have to do in anticipation of interruptions, like prioritize [certain tasks]" or "remember what I was focused on before," and "[ISTAR] could help me with situations at work when I'm dealing mainly with frustration, like when handling multiple customers." One participant reports that ISTAR has already helped them in their current job: "Whenever I finished with [training with ISTAR], there have been times where there were interruptions [on the job] where I've gotten right back to work." For another participant, training with ISTAR made him reflect on the interruptions he gave to others: "So I'm a big interrupter. I interrupt in conversations, and it made me think about what I'm doing to others." Finally, on a 5-point Likert scale where 1 is *not relevant* and 5 is *extremely relevant*, participants reported that the training provided by ISTAR was relevant to handling real-world interruptions ($M = 3.9$, $SD = 0.93$).

D. Discussion

Following our results, we evaluated the success of ISTAR's design according to our design goals. ISTAR is **embodied** as a social robot to engage users in a greater capacity than would virtual technology or cellphone applications. Our evaluations suggest that ISTAR's physically co-present interruptions and socially-situated practice are likely to generalize to real-world interruptions. Embodiment allows for ISTAR's naturalistic gaze patterns and body movement that encouraged participants to practice their social responses. A caregiver remarked on the impact the physical presence of the system had on her daughter with ASD: "She absolutely loved it! As soon as [ISTAR] came into her apartment, it sparked her. She liked the way [ISTAR] moved, its personality, and she just came to life!"

As an **in-home** system, we emphasized the importance for individuals with ASD to intuitively and comfortably interact with ISTAR. By minimizing the design and interfaceable components of ISTAR's hardware, we gave users greater autonomy over where, how, and when they interacted with the system. Our results confirmed that users would be comfortable interacting with ISTAR in their homes, even to the extent that they would show off ISTAR and its interactions to a visiting friend. Most participants believed that ISTAR was friendly, approachable, and not overstimulating.

In addition, ISTAR operated **autonomously** for a total of 1680 hours, successfully delivering 70 training sessions. Autonomous interactions present substantial challenges in computational perception and system control to create meaningful social-skills interventions. Yet, our implementation of watchdog scripts and remote software allowed us to ensure participant data is properly collected and stored during the in-home evaluation. Furthermore, due to the current pandemic, the system was designed to be intuitive to install and use. All systems were deployed and setup completely without the research team making direct contact with users or their homes.

Interactions with ISTAR are **realistic**. In designing a system to improve employability through interruptions training, it is intuitive to have only job-specific content. However, not all interruptions are familiar to most jobs or individuals that are not yet employed, and would be aligned with reports of the most distracting interruptions in Section V. Adults with ASD and employers evaluated the interruptions of an ISTAR prototype that produced only work-related interruptions as being only "somewhat similar" to real workplace interruptions. As a result, we vary the physical and social demands of interruptions relevant to most workplaces by implementing three types of interruptions: social, task, and environmental. All employed adults with ASD that participated in the in-home evaluations of the final system reported instances in which they felt they handled real workplace interruptions better due to the interruptions training they experienced with ISTAR. As this work is an early step towards understanding the potential for an in-home social robot for adults with ASD, a longer-term study with a larger sample is needed to investigate whether ISTAR will generalize to workplaces or human-human interactions.

We did not expect significant behavioral change in a week-long study to indicate efficacy of our system. Surprisingly, our in-home evaluation demonstrated that training with ISTAR significantly improved participants' ability to attend more quickly to interruptions over time. Based on computed lags, ISTAR's various types of interruptions produced significantly different disruptions and participant responses. Still, participants practiced appropriate social behaviors to almost every interruption experienced throughout their entire study such as sustaining eye contact, pausing and returning to their original activities, and speaking with the robot. In all, interactions with ISTAR are productive and can be an effective system for improving interruptions tolerance in adults with ASD.

VII. Conclusion

We leveraged previous successes in the development of SARs for ASD interventions [41] to develop ISTAR. The system underwent two primary evaluations: surveys of adults with ASD and employers, and a week-long study in the homes of adults with ASD. Our evaluations demonstrate that users readily accepted this system in their homes, viewed the training provided by the system as relevant, useful, and important, and improved in their ability to handle workplace-relevant interruptions. ISTAR targets realistic practice in a familiar environment, encourages positive and productive behaviors in its users, and provides valuable support for adults with ASD as they find and maintain employment.

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