StarRescue: the Design and Evaluation of A Turn-Taking Collaborative Game for Facilitating Autistic Children's Social Skills

Rongqi Bei
University of Michigan
Ann Arbor, Michigan, USA
rbei@umich.edu

Yajie Liu
Peking University
Beijing, China
1801214935@pku.edu.cn

Yihe Wang*
University of California Santa Cruz
Santa Cruz, California, USA
ywan1125@ucsc.edu

Yuxuan Huang*
City University of Hong Kong
Hong Kong, China
yhuang573-c@my.cityu.edu.hk

Ming Li
Duke Kunshan University
Suzhou, China
ming.li369@dukekunshan.edu.cn

Yuhang Zhao
University of Wisconsin-Madison
Madison, Wisconsin, USA
yuhang.zhao@cs.wic.edu

Xin Tong†
Duke Kunshan University
Suzhou, China
xin.tong@dukekunshan.edu.cn

ABSTRACT

Autism Spectrum Disorder (ASD) presents challenges in social interaction skill development, particularly in turn-taking. Digital interventions offer potential solutions for improving autistic children's social skills but often lack addressing specific collaboration techniques. Therefore, we designed a prototype of a turn-taking collaborative tablet game, StarRescue, which encourages children's distinct collaborative roles and interdependence while progressively enhancing sharing and mutual planning skills. We further conducted a controlled study with 32 autistic children to evaluate StarRescue's usability and potential effectiveness in improving their social skills. Findings indicated that StarRescue has great potential to foster turn-taking skills and social communication skills (e.g., prompting, negotiation, task allocation) within the game and also extend beyond the game. Additionally, we discussed implications for future work, such as including parents as game spectators and understanding autistic children's territory awareness in collaboration. Our study contributes a promising digital intervention for autistic children's turn-taking social skill development via a scaffolding approach and valuable design implications for future research.

*Both authors contributed equally to this research
†Corresponding author

CHI '24, May 11–16, 2024, Honolulu, HI, USA

ACM ISBN 979-8-4007-0330-0/24/05
https://doi.org/10.1145/3613904.3642829

CCS CONCEPTS

• **Human-centered computing → Human-computer interaction (HCI)**.

KEYWORDS

Autism Spectrum Disorder, Games, Turn-taking, Social Skills

ACM Reference Format:
Rongqi Bei, Yajie Liu, Yihe Wang, Yuxuan Huang, Ming Li, Yuhang Zhao, and Xin Tong. 2024. StarRescue: the Design and Evaluation of A Turn-Taking Collaborative Game for Facilitating Autistic Children's Social Skills. In *Proceedings of the CHI Conference on Human Factors in Computing Systems (CHI '24), May 11–16, 2024, Honolulu, HI, USA.* ACM, New York, NY, USA, 19 pages. https://doi.org/10.1145/3613904.3642829

1 INTRODUCTION

Autism spectrum disorder (ASD) has been recently perceived by researchers and self-identified by individuals as a type of neurodiversity [1]. Individuals on the autism spectrum demonstrate a broad array of communication and social abilities, which are reflected in their understanding of social cues and norms, responses to social stimuli, initiation of conversations, etc. [16, 21] Specifically, navigating social interactions can present challenges for autistic children[1], impacting their approach to communication and collaboration — skills that are essential in their daily, academic, and future professional lives [57, 61].

Studies have shown that turn-taking is one of the most fundamental and primary social skills in forming sociality at children's early developmental stage [15] since it involves interchangeable

[1]Our work adopts the identity-first language, referring to the population as "autistic children," in alignment with the preferences expressed by the broader autism community and recent advocacy in academia [2, 9, 13, 33]. This choice respects the perspective that autism is an integral part of an individual's identity rather than a condition to be distanced from, thereby embracing neurodiversity. We recognize, however, that language preferences are personal and context-dependent, and we are committed to respecting individual choices and using inclusive language in writing.

interactions with others [59]. Thus, a wide variety of interventions, including non-digital games and digital interventions, along with extensive research, have focused on training autistic children's social skills, including turn-taking skills, to support them in developing the back-and-forth flow in social interactions and collaborations. For instance, early research projects evaluated how traditional jigsaw and puzzle games allowed children to collaboratively move pieces and solve puzzles, e.g., [5, 50]. Moving forward, researchers started to design storylines and let autistic children practice social skills (e.g., joint attention, understanding social cues, and turn-taking) [7, 20] and communication skills [28] with scenarios. Wu et al. [67] also elaborated on the player-audience interaction that happened among autistic children playing digital games in co-located settings. In addition to exploring various game genres and mechanics in these digital interventions, recent studies have also explored children's collaboration models in scenario-based or role-play games to guide the design of social tasks and interactions, such as Silva et al.'s four-stage model [42] and Giusti et al.'s four collaboration patterns [22]. In Silva et al.'s work [42], the authors proposed a scaffolding collaboration process with four stages based on autistic children's social behaviors and evaluated their framework with a table game, where two children shared joint efforts in putting away toys.

However, research gaps still exist in designing effective and engaging collaborative games. In Silva et al.'s [42] game, their social tasks and game mechanics have been specifically designed for Autistic Children with Cognitive Impairment[2] (referred to as AC-CI hereafter). This specific design focus means the social tasks and difficulty levels may not be as motivating or engaging for autistic children without cognitive impairment (AC-NCI). Giusti et al. [22] proposed three mini-games that required more complex social and collaborative skills to train AC-NCI's ability for sharing, mutual planning, and joint performance. Although these games excel in covering more collaboration dimensions, their lack of explicit level progression under coherent game narratives presents challenges in terms of scalability and maintaining player engagement across different content levels. Besides, existing studies aimed at enhancing AC-NCI's turn-taking skills (e.g., [14, 35]) predominantly focused on training autistic children to take actions only within their own turns, overlooking the importance of encouraging AC-NCI to also pay attention to others' turns. These turn-taking training could also be more fun by incorporating gaming elements. Therefore, we designed and developed a turn-taking-based two-player collaborative tablet game, StarRescue [31], especially for AC-NCI. Following Silva et al. [42] and Giusti et al. [22]'s collaboration mode, StarRescue allows pairs of AC-NCI to take turns navigating a ball to eliminate monsters on a planet, directing their attention to collaborate with their partners while fulfilling their own tasks. Besides, StarRescue's cohesive narratives run through all levels, aiming to provide AC-NCI with a purpose for continuous play in training their sharing and mutual-planning skills.

Our study also evaluated the effectiveness of StarRescue along with its scaffolding turn-taking mechanics in improving AC-NCI's social skills. We conducted user studies with 32 preschool-age autistic children (all AC-NCI) and their parents, 20 in the experiment group (10 pairs) and 12 in a do-nothing control group (6 pairs). Each pair of AC-NCI in the experimental group participated in a one-hour play session per day for three consecutive days. During these sessions, we collected changes from their in-game performances, social and mobility skill tests, and self-reported ratings, followed by an open-ended oral survey with their parents. Findings suggested that StarResuce successfully engaged AC-NCI in collaborating with their partners and has great potential to improve autistic children's social communication skills. During playtime, AC-NCI reminded their teammates properly, divided up tasks, and negotiated. Notably, these skills were also transferred to their everyday lives outside of the study, according to parents' feedback. Our study contributes to a promising interactive game prototype, StarRescue, for enhancing autistic children's social skills, which applied a scaffolding collaboration model and integrated sharing, mutual planning, and turn-taking collaborative features. Our evaluation of StarRescue with autistic children not only confirmed its great potential but also uncovered several design implications for future games and research aimed at improving autistic children's social collaboration skills. These implications include building interdependent relationships between pairs, recognizing the critical role of parents as game spectators, and exploring the impact of territory boundaries in the collaborative game environment.

2 RELATED WORK

In this section, we provide a brief overview of the challenges faced by autistic children in social collaboration and motor skills and potential resolutions in training these skills. Additionally, we introduce prior research and digital game interventions that have shown promise in enhancing autistic children's social collaboration and motor skills. We further analyze their design and mechanisms for promoting autistic children's social and motor skills, as well as potential improvement strategies, which further inspire the implementation of our game prototype, StarRescue.

2.1 Understanding Autistic Children and Their Social Interactions and Motor Skills

Autism spectrum disorder (ASD) is recognized as a prevalent and multifaceted form of neurodiversity [1], affecting one in 36 children according to the Centers for Disease Control and Prevention's report in the U.S. [41]. The autism spectrum consists of high variability, making individuals identified as being on this spectrum have varying levels of skills [66]. Many autistic children need different levels of support across various aspects of their daily lives, including social interactions [1], communication [37], and motor activities [26, 40]. Appropriate support can greatly benefit autistic children in engaging in social play with peers, expressing themselves effectively and properly, and enhancing motor coordination [56]. Consequently, efforts to provide these supports are crucial in assisting autistic children to establish deep social connections with their teachers and peers within the school context [6, 57].

Differences in social collaboration among some autistic children may be related to their unique ways of processing social cues, interpreting facial expressions and body language, and initiating or

[2]Following recent research in accessibility and human-computer interaction, we avoid using clinical terms such as "high-functioning" and "low-functioning" that are perceived to be stigmatized by the autistic group [9]. Therefore, we chose to use more diversity-focused language in this paper.

responding to social interactions [29]. These unique interaction styles can influence the development of social skills such as sharing, establishing joint attention, and taking turns [53], which are vital for effective collaboration. Among various types of social interactions, prior work has demonstrated the crucial role of turn-taking in promoting early social engagement among autistic children [15]. Turn-taking entails a dynamic exchange of behaviors between individuals, requiring one participant to both maintain their own turn and attend to their partner's turn [23, 44, 59]. This back-and-forth interaction forms the basis for reciprocal exchanges, which are strongly linked to social acceptance among preschool-aged autistic children [35, 39]. Recognizing the importance and benefits of mastering turn-taking skills in group social settings, we have chosen to design a game that emphasizes this skill, encouraging autistic children to take turns, take responsibility for their own actions, and patiently await their partners' turns.

2.2 Digital Game Interventions for Autistic Children

Computer programs and applications, particularly digital games, have been developed to enrich therapeutic approaches and support the diverse learning and developmental needs of all children, including those on the autism spectrum [8, 25]. This approach is considered reliable because the digital environments created offer predictability, which can provide a comforting sense of security for autistic individuals and reduce the potential for confusion that might arise in the less predictable physical world [45].

2.2.1 Digital Interventions and Games for Social Interactions and Turn-Taking Skills. Several collaborative digital games have been designed to improve autistic children's collaboration skills and social competency [19, 22, 42, 67, 69]. We would like to analyze a few representative studies that proposed generally applicable collaboration models. Giusti et al. [22] created three co-located tabletop games tailored for autistic children without cognitive impairment (AC-NCI). These games incorporated interactive social tasks from three dimensions: *i.e.*, **joint-performances, sharing for common goals, and mutual planning**. All collaborative aspects required simultaneous actions, such as two children jointly moving a basket, taking on different roles to achieve common goals (one moves a container around to pick up what the other one tapped), and negotiating ownership. The authors observed positive social behavior changes in AC-NCI. Later, Boyd et al. [10] went beyond these three dimensions and proposed a game that emphasized not only working towards a shared goal together but also shared memories and emotional experiences. Besides, Silva et al. [42] proposed another collaboration model emphasizing the importance of introducing autistic children to collaborative environments in a progressive way. This model acknowledged that autistic children with cognitive impairment (AC-CI) may initially find it difficult to understand others' mental states, which is an important component of recognizing collaborative relationships. Their progressive collaboration model is designed with four stages: **passive sharing** (children learn to execute their own tasks without necessarily being aware of the collaboration), **active sharing** (children recognize their own role and share information with each other), **joint performance** (children offer help to their partners when needed), and **unrestricted interaction** (children collaborate freely without any constraints or assigned roles). Silva et al. [42] revealed that this progressive collaboration model can motivate both more active and receptive children to understand their partners' intentions and actions. To summarize, Giusti et al.'s [22] collaboration model was designed for AC-NCI and addressed three important social collaboration aspects from three isolated games, without offering explicit level progression or strong narrative connections across levels for sustainable play. Consequently, scaling up the games and maintaining sustained motivation for autistic children with varying content levels may be challenging. In contrast, Silva et al. [42] came up with the progressive collaboration four-stage model specifically for AC-CI. They also simplified the collaborative tasks without high-level collaboration skills that were suitable for AC-NCI, such as conducting negotiations or deciding how to coordinate efforts.

Furthermore, as introduced in Section 2.1, turn-taking is an essential social skill for autistic children. Prior work has developed robot [14] and iPad applications [35] for teaching preschool autistic children turn-taking skills, which sent out audio instructions (*e.g.*, "Sam's turn") to guide children to play with toys [14] or slide pictures in turns [35]. Findings showed that the intervention approaches supported the development of autistic children's abilities in swapping ownership of objects and waiting for others' turns. However, these studies did not implement a progressive collaboration model or address the importance of paying attention to the partners' actions throughout their partners' turns.

Therefore, our game prototype integrated the sharing and mutual-planning collaborative dimensions in Giusti et al.'s work [22] and the four-stage progressive model in Silva et al.'s [42] work into a turn-taking-based collaborative game. Although we did not incorporate the joint performance feature since it required simultaneous input and contradicted the turn-taking concept, our game prototype allowed children to share the same big picture of the game, and they contributed equally to the team's goal. Different from Giusti et al.'s [22] work, where each sub-game only focused on a single collaboration dimension, we embedded sharing and mutual-planning tasks together. Also, each level in our game prototype progressively became more difficult, following Silva et al.'s four-stage collaboration model [42]. Thus, autistic children can learn to collaborate with each other gradually and practice their skills in more complex problem-solving settings with sustained motivation.

2.2.2 Digital Interventions and Games for Fine Motor Skill. As we examined digital interventions aimed at enhancing the social skills of autistic children, we observed the efficacy of game applications [17, 49, 52, 70] in improving autistic children's fine motor skills (i.e., hand dexterity). This is especially noteworthy, as developing fine motor skills is an important area of growth for many autistic children [40]. Among those fine motor skill training games, some were tablet-based [17, 49], providing children with an enjoyable way to engage in hand exercises such as tapping, pinching, and sliding. Whereas other games utilized gesture-sensing technologies and captured hand movement up in the air [52, 70]. Besides games that explicitly target autistic children's fine motor skills, some prior work unintentionally benefited these skills because their interaction interfaces involved touchscreens and/or physical objects. For instance, Hourcade et al. [30]'s drawing game designed to foster creativity inadvertently supports fine motor development, as it necessitates one-finger panning and two-finger zooming. Pang [47]'s social skill intervention introduced LEGO games and also observed children's improvement in fine motor skills.

In addition, a review study shows that fine motor activities, particularly manual dexterity (a sub-type of fine motor skills), could be associated with social skills development, as both require high-level visual-motor integration [46]. Reflecting on our game prototype, StarRescue requires a substantial number of finger-tablet interactions, including sliding along arcs and tapping on the screen, all of which have the potential to contribute to the development of fine motor skills. Moreover, the game demands a high degree of hand-eye coordination, as children must first perceive changes on the screen before executing corresponding actions. Therefore, we explored how such a collaborative mobile game would affect autistic children's hand dexterity and eye-hand coordination and measured their motor skills before and after our experiment.

2.3 Research Gaps

In conclusion, the reviewed literature underscores research gaps in designing effective and engaging collaborative games that facilitate autistic children's social skill development. Although prior research designed collaborative games based on established collaboration models, some games, like Silva et al.'s [42], were tailored for AC-CI, lacking engaging social tasks and game mechanics for AC-NCI. Other games, like Giusti et al.'s mini-games series [22], focused on more advanced social skills but lacked coherent game narratives and progression, which might make it difficult to provide players with a gradually evolving gaming experience and effectively generate interconnected levels. As for the research that primarily concentrated on turn-taking mechanics, most neglected the importance of prompting autistic children to pay attention to and build upon others' turns. To address these research gaps, our study designed and evaluated a turn-taking collaborative game, StarRescue, building upon the integration of prior collaboration models and emphasizing interdependent turn-taking relationships.

3 STARRESCUE: A TURN-TAKING COLLABORATIVE GAME

StarRescue is a turn-taking-based collaborative tablet game designed for two players to enhance social interactions and collaboration among autistic children (particularly those with AC-NCI). The game is designed to help children master the back-and-forth dynamics essential to social interactions. The gameplay revolves around encouraging children to work together towards a shared goal. It assigns distinct roles and unique powers to each player and guides them in leveraging their individual power while coordinating shared resources for effective problem-solving. StarRescue was implemented in Unity and tested on the iPad platform.

In our previous work [31], we conducted interviews with teachers and parents of autistic children to gather feedback on the pilot version of StarRescue. Subsequently, in this work, we iterated and redesigned various aspects of the game, including mechanics, narratives, difficulty levels, and the scaffolding of game levels, and also tested it with AC-NCI. These refinements of level design were based on the integrated collaboration model, as elaborated in Section 3.2. The current version of StarRescue maintains the same narrative setting and core game mechanics, particularly the turn-taking feature, but with improved and well-balanced leveled tasks.

3.1 Game Mechanics & Narratives

StarRescue, as its name suggests, asks a pair of children to work together to rescue stars occupied by monsters. To rescue a star, the two children need to jointly eliminate the monsters by navigating and bouncing the ball using their own paddles and applying superpowers starting from the second level (see Fig. 1 for key game elements and Fig. 2 for game levels). Next, we introduce the core game tasks, which require children's turn-taking and collaborative skills, including navigating balls through paddles, eliminating various types of monsters, and utilizing unique superpowers jointly.

Navigating the Ball through Paddles. The ball navigation in StarRescue embeds collaborative turn-taking. This turn-taking approach draws inspiration from the classic two-player Pong game, which simulates table tennis [34]. In the Pong game, each player controls half of the screen and uses paddles to volley a ball back and forth. Similarly, in StarRescue, children take turns catching the ball from their partners and bouncing it back. They are motivated to ensure that the ball remains within the dedicated circle area while using it to eliminate monsters. The game provides trajectory lines that aid children in predicting and planning the path of the ball (see Fig. 1-c).

Eliminating Various Types of Monsters. There are two kinds of monsters occupying the stars: static monsters and moving monsters (Fig. 1-a). Static monsters remain stationary and can be defeated with three ball hits (Fig. 1-b). Moving monsters take spaceships and travel around within the star, and children need to navigate the ball toward the monster at least twice within 30 seconds. The first time, they applied the freezing superpower to stop it from moving and then used the burning superpower to burn it at the second hit. Eliminating moving monsters requires more advanced collaboration skills compared to static monsters since the pairs need to share their unique superpowers (Fig. 1-e) and coordinate their bouncing behaviors and resources effectively together.

Utilizing Unique Superpowers Jointly. Starting from Level Two, StarRescue assigns freezing and burning superpowers to each child, so they need to jointly apply these two superpowers to accomplish the game goal. In Level Three, all children have both superpowers, and the pair needs to coordinate and strategize the allocation of powers to accomplish the task.

3.2 Level Design and the Matching Social and Collaborative Skills

The game prototype contains four levels: one single-player tutorial level and three collaborative levels. The two-player levels incorporated sharing and mutual planning collaboration aspects, which are two key dimensions in Giusti et al.'s [22] collaboration model. We employ a four-level approach to scaffold the development of collaborative relationships between pairs with gradually increased task complexity, following Silva et al.'s collaboration model [42]. As a result, from the tutorial level to the third level, the game becomes more difficult and demanding for collaboration.

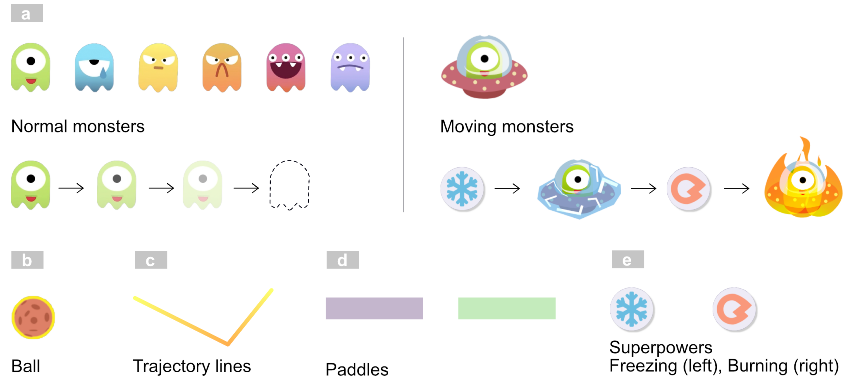


Figure 1: Key elements in the game: (a) static monsters and moving monsters; (b) ball; (c) trajectory lines; (d) paddles; (e) superpowers.

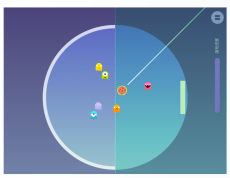
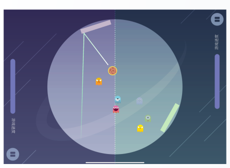
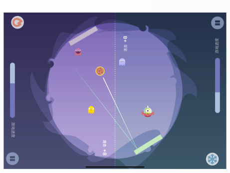
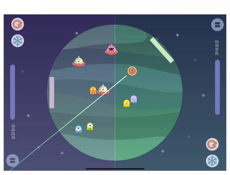
Level #	Game Interface	Level Elements	Learning Obejctives
Tutorial level (single player)		Ball Paddle ⨉ 1 Static monster ⨉ 6	**Sharing:** Learning when and how to perform one's own turn.
Level 1		Ball Paddle ⨉ 2 Static monster ⨉ 6	**Sharing:** (1) Each player plays an indispensable role (2) Joint-control and joint-attention is required **Mutual Planning:** How to bounce the ball to hit all monsters efficiently?
Level 2		Ball Paddle ⨉ 2 Static monster ⨉ 6 Moving monster ⨉ 3 Superpower (freezing) ⨉ 1 Superpower (burning) ⨉ 1	**Sharing:** (1) Bring one's unique skill to the collaboration (2) Further realize each player's unique role **Mutual Planning:** (1) When and how should each player apply their unique skill? (2) How to pass the ball so that the burning power can be applied in time?
Level 3		Ball Paddle ⨉ 2 Static monster ⨉ 6 Moving monster ⨉ 3 Superpower (freezing) ⨉ 2 Superpower (burning) ⨉ 2	**Sharing:** Develop the team's own collaboration strategy to divide the work and allocate the resources **Mutual Planning:** How to divide the work between the two players when outside restrictions no longer exist?

Figure 2: StarRescue's level design, including screenshots of game interface design, unique elements included in each level, and the objectives of each level design: 1st row: the tutorial level; 2nd row: level one; 3rd row: level two; and 4th row: level three.

3.2.1 The Tutorial Level. The tutorial level (Fig. 2-a) is designed to help children familiarize themselves with the gameplay individually before joining pairs. In this single-player level, children practice catching the ball as it rebounds off a protective white "wall" on the opposite side. This practice allows them to grasp how to respond to the reflection from the other side. Additionally, children learn to adjust the paddle's angle to align the trajectory line with the monsters. They also realize that paddle movement is confined to a semi-circle, which comprises half of the game interface. This process aids children in understanding when and how to perform their tasks, even without a full awareness of the collaborative aspect. It introduces the concept of "sharing resources" [42], which pertains to game control rights in our context.

3.2.2 Level One. Level One (Fig. 2-b) pairs two players together to facilitate children in recognizing their roles and initiating plans for eliminating the monsters. In this level, each child controls half of the screen and takes turns navigating the ball. When child A passes the ball to child B, B needs to catch the ball immediately (respond to A's information) and then pass the ball back to A (send information to A through actions). This continuous ball-passing process fosters the exchange of information between children and encourages them to respond to each other through actions [42]. Furthermore, this level marks the beginning of their mutual-planning action [22] and their partnership [10] as they share the same goal of eliminating static monsters.

3.2.3 Level Two. As the pair grows more comfortable collaborating together, Level Two (Fig. 2-c) raises the collaboration's difficulty by introducing moving monsters and assigning unique superpowers to each child (*e.g.*, child A can only freeze monsters while child B can only burn monsters). The pair's relationship becomes more interdependent because eliminating moving monsters requires applying their unique superpowers in a specific sequence (burning after freezing) within a time constraint. For example, after child B skillfully directs the ball toward a monster, they might coordinate with child A, prompting them to apply the freezing power at the right moment to facilitate the sequence. In turn, child A may ask B to burn the monster in a timely manner after they have frozen it. Throughout this process, both children contribute their distinct roles to the gameplay, and their active involvement is essential to helping each other hit the goal [42]. From the mutual-planning [22] perspective, the pair are encouraged to pay closer attention to each other and the gameplay so that they will know how to collaboratively bounce the ball to the moving monster twice within the time restriction and when to apply their unique skills.

3.2.4 Level Three. In Level Three (Fig. 2-d), children enter a more open environment where pairs are not bound by constraints or assigned superpowers. Both players have access to the freezing and burning superpowers. With more flexibility, the pairs gain the freedom to formulate their unique collaboration strategy [42]. They can engage in more discussions regarding task division and the allocation of shared resources, considering both the sharing and mutual planning aspects of the collaboration [22].

3.2.5 The Reward System. StarRescue incorporates a rewarding system to encourage and engage children. When a pair successfully completes a level, they receive game diamonds in their shared account. The reward quantity is determined by the maximum number of consecutive ball passes achieved by the pair during the level, motivating children to repeat this desired collaboration behavior [18]. These diamonds can be exchanged for items to adorn their shared spaceship. To unlock all decorations, the team must replay any of the last three levels multiple times while maintaining effective collaborative performance.

4 METHOD

We conducted a between-subject study to evaluate StarRescue's effectiveness and usability over three consecutive days, with each session lasting one hour. The study involved a total of 32 autistic children, with 20 participants in the experimental group using StarRescue and 12 in the control group who did not engage with any intervention. The independent variable is whether participants participated in the game intervention. The dependent variable was their performance and social and motor skill improvements in the post-test compared to the pre-test. The study was conducted according to the principles of the Declaration of Helsinki [24] and was approved by the School of Psychological and Cognitive Sciences at Peking University's Institutional Review Board. We obtained written consent from the primary guardians and caregivers of the children and verbal consent from the children themselves. All children received toys as gifts for their participation.

4.1 Participants

We initially recruited a total of 36 autistic children to evaluate StarRescue via convenient and snowball sampling approaches at the beginning. All participants were recruited from the researchers' personal network, prior mailing lists of autistic participants, and recommendations from participants. All children participants were enrolled in special education programs and/or actively participated in behavioral intervention sessions during the study period. Therefore, we decided to set up a do-nothing control group and compared progress between the StarRescue experimental group and the control group to minimize the potential learning effects and impacts gained from their education programs or intervention sessions.

Twenty-two autistic children without cognitive impairment (AC-NCI) were assigned to the experiment group (one girl, age Mean ± SD = 5.61 ± 0.62, full-scale IQ (FSIQ)[3] Mean ± SD = 119.95 ± 14.98). Another fourteen age- and IQ-matched AC-NCI were assigned to the do-nothing control group. In the end, two children from the experimental group and two from the control group dropped out of the study because of illness and other reasons. Thus, the final total number of participants was 32, including 20 children in the experiment group (one girl, age Mean ± SD = 5.58 ± 0.54, FSIQ Mean ± SD = 120.25 ± 15.31) and 12 children in the control group (two girls, age Mean ± SD = 5.46 ± 0.64; FSIQ Mean ± SD = 113.12 ± 18.27). The participants' IQs in two groups could be matched with each other, $t(30) = 1.179$, $p = .248$. Besides, 16 out of the 22 autistic

[3]Full-Scale Intelligence Quotient is a composite score derived from the Wechsler Intelligence Scale for Children (WISC) [62], a widely used standardized test for assessing the cognitive abilities and intelligence of children. FSIQ represents an individual's overall cognitive functioning and general intelligence, combining scores from various sub-tests that measure different cognitive domains such as verbal comprehension, perceptual reasoning, working memory, and processing speed.

children's parents answered our post-test open-ended questions and provided feedback. Please see Appendix A.1 Table 1 for the demographics of the children participants in the experiment and control groups.

All participants in our study have been previously diagnosed as autistic children by experienced hospital pediatricians based on the DSM-IV-TR diagnostic criteria [51]. Additionally, the diagnoses of these children were further confirmed by the Childhood Autism Rating Scales (CARS) based on observation and Social Responsive Scale (SRS) [60] and Autism Spectrum Quotient: Children's Version (AQ-Child) [3] based on parental reports. We measured participants' IQ using the Wechsler Intelligence Scale for Children - Fourth Edition [62]. All participants' scores were above 90 on the IQ tests, so they were children without cognitive impairment who had similar intelligence to age-matched typical development children. As reported by their parents, all children participants were familiar with touchscreen devices, such as tablets and touchscreen phones. Also, most have used at least one touchscreen device several times per week in their school classrooms or intervention programs and for their leisure time at home.

4.2 Procedures

Upon the arrival of pairs of children with their parents or guardians, we first explained the study's purposes and obtained their consent. For participants in the experimental group, the same pair were invited to join the study for three sessions on three consecutive days, for one hour per day. In the pre-test, we measured their demographic information, the Theory of Mind (ToM) scale, fine motor skills, and hand-eye coordination skills. After collecting pre-test measurements, we showed the children StarRescue and briefly introduced the gameplay. We gave each child an iPad to let them practice the Tutorial Level and become familiar with the game. Then, we asked the pair to sit across from each other and play the other game levels together. The children can play one or more levels per day according to their collaboration outcomes and progress. Specifically, upon successfully navigating through the Tutorial Level, Level One, Level Two, and Level Three in sequence for the first time, the pair can freely select and play any levels of their choice. During the play sessions, we measured their in-game performances. After the entire three sessions, we collected the same set of measurements as in the pre-test. Additionally, we invited the parents to answer a short survey with open-ended questions to collect their feedback after the entire study. For participants in the control group, we only collected data regarding their fine motor skills, Theory of Mind (ToM) scale, and hand-eye coordination test before and after the study period, without offering any games. See Fig. 3 for the study procedure. The one-hour time slots in Fig. 3 refer to the length of the entire study session we scheduled with the participants, and the actual average playtime for each pair was around 40 minutes. Also, short 3- to 5-minute breaks (e.g., drinking water or going to the bathroom) were encouraged during the play sessions. We decided on this playtime based on observation from an informal pilot test with two children. We found that the pair needed some time to build rapport before entering into an optimal collaborative relationship.

4.3 Measurements

Theory of Mind (ToM) Test. One of the main determinants of competence in social interactions is the ability to take another person's perspective [55]. Theory of Mind (ToM) is the awareness of the thoughts, beliefs, and desires of other people, which is often used to measure autistic children's perspective-taking ability [64]. Components of ToM typically emerge in the following order: (a) diverse desires (DD); (b) diverse beliefs (DB); (c) knowledge access (KA); (d) false belief (FB); and (e) hidden emotion (HE) [64].

Fine Motor Skills. Since participants used their index fingers to control a small paddle extensively with precision in our game, we assumed that such exercises would promote their fine motor skills. Therefore, we tested their fine motor skills before and after the intervention using an adapted version of the classical test for dexterity in the neurodiversity population (e.g., stroke, multiple sclerosis, and Charcot-Marie-Tooth disease), which also showed good reliability and validity among children [58]. In our study, children were instructed to insert twelve pegs one by one using one hand as quickly as they could. We measured the total time to obtain information on the fine motor skills and repeated the test three times to obtain stable performance.

Hand-eye Coordination Skills. StarRescue incorporates a lot of exercises designed to enhance hand-eye coordination skills, such as tracking the moving trajectories of the ball and monsters and interacting with the screen interface. Given this, we are curious if such skills could be transferred to real-world contexts. We utilized the ball-catching task from the Movement Assessment Battery for Children: Second Edition to measure the ability of eye-hand coordination and anticipation (MABC-2) [27]. In our study, the researcher stood 2.5m away from the child and threw a ball to one of three locations: in front of the child, to the left of the child, and to the right of the child. All balls fell into the half-circle in front of the child within 0.5m. Each location was repeated three times in a random sequence. We coded the children's performance following prior work that did similar tasks before [38]. See Appendix A.2 Table 2 for coding details.

In-Game Data. In the experimental group, participants' in-game data were automatically logged into the backend of Unity during their play sessions. The in-game data tracked how long it took each child to become comfortable with the gameplay, the levels each pair chose to play and how much time they spent on those levels, as well as the frequency and the superpower(s) used by each participant on each level.

Open-ended Survey Questions and Observations (From Parents). During the experiment, 16 out of 20 children's parents stayed in the testing room and observed their children playing the game. To learn from parents' perspectives and observations during the study, we asked them open-ended questions in a semi-structured, one-on-one way in the post-test. The survey questions center on StarRescue's efficiency and usability as well as parents' general comments and expectations towards this game. See Appendix B for the survey questions.

Researchers' Observations. Two researchers played integral roles in hosting study sessions with the experiment group. While one of them was primarily responsible for facilitating the study sessions, the other served as a note-taker and took comprehensive

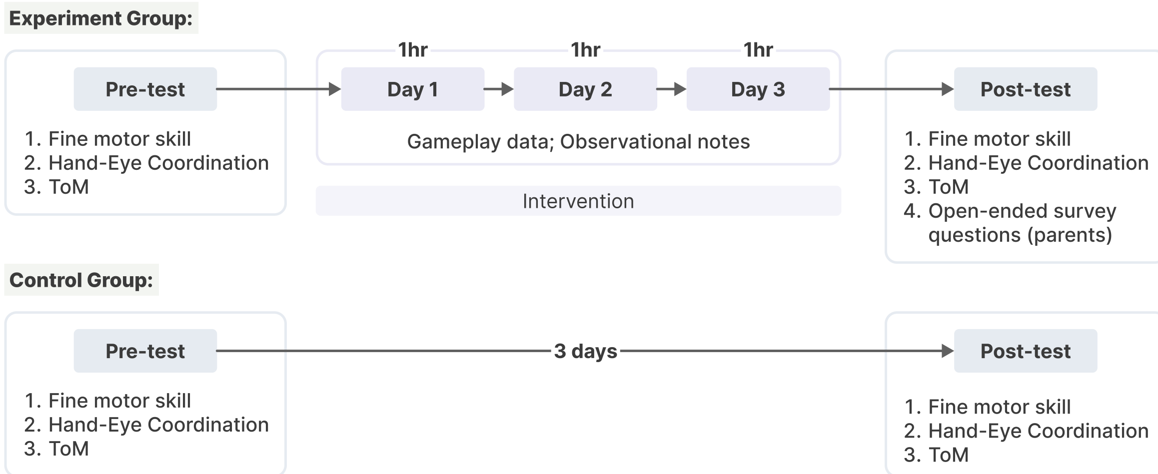


Figure 3: The study procedures and measurements.

observational notes covering a wide range of aspects. Specifically, the notes include autistic children's actions, emotions, verbal and non-verbal communication, and any interactions that happened between them and their pairs. Also, considering that some children's parents stayed in the testing room, the observation notes also covered interactions that occurred between autistic children as players and their parents as game spectators.

4.4 Data Analysis

Quantitative Data Analysis. We conducted inferential analysis of the quantitative data collected from both study groups (*i.e.*, ToM scores, fine motor skills, and hand-eye coordination test performances) using SPSS[4] to (1) compare the experimental group participants' performance changes before and after the game sessions, and (2) to compare the social and motor skill changes between the experimental group and the control group. We adopted a Shapiro-Wilk test and a Levene's test to assess the normality and homogeneity of the collected data. A one-way and mixed ANOVA test and pairwise Tucky's test were used to analyze data that were normally distributed and maintained a homogeneous variance, while a Kruskal-Wallis test and pairwise Dunn's test were used to analyze those that violate normality or homogeneity. All the statistical conclusions were evaluated with a significance level of p = .050.

Qualitative Data Analysis. The qualitative analysis covered both parents' responses to the open-ended survey questions and researchers' observation notes. We transcribed answers to open-ended survey questions and analyzed the transcripts using an open-coding approach to further understand parents' attitudes and feedback toward the game based on their observations during the study. We also followed the same procedure to analyze the observation notes, seeking insights into autistic children's social skills and the interaction dynamics between pairs during the three-day study sessions. Two researchers first independently coded all transcripts and then discussed their codes. After discussion, they reached a consensus, consolidated the list of codes, and then discussed and categorized codes into final themes. The main themes from parents' open-ended responses were about parents' attitudes toward the game's efficiency, game usability, and their future expectations of the game. The main themes from researchers' notes are autistic children's evolving collaboration and communication skills and parents' role as spectators in the gameplay.

[4]Statistical Package for the Social Sciences (SPSS): www.ibm.com/products/spss-statistics

5 RESULTS

In this section, we report findings of the children's in-game social interactions and social skill changes from researchers and parents' observations and ToM scores; their motor skills changes from the fine-motor tests and the hand-eye coordination tests; and usability evaluations based on children's in-game performances and parents' feedback.

5.1 Potentials in Autistic Children's Social Skill Improvements

We analyzed changes from multiple measurements to evaluate Star-Rescue's impact on AC-NCI participants' social interaction and collaboration skills, including parents' and researchers' observations, ToM score improvements, and children's performances in the unrestricted interaction stage in Level Three.

5.1.1 *Social Interactions among Autistic Children in the Experimental Group.*

Based on both researchers' observations and parents' feedback, conversations among children are gradually initiated during the gameplay. Such conversations are mainly about reminding their partners to perform game tasks (N = 9), imagining and creating extended stories for the monsters (N = 5), and celebrating their achievements with their partners (N = 11). Besides, eight of the ten pairs would also have fives, one of the body languages learned at the special education programs, after they successfully finished the game.

Most children demonstrated a progressive evolution in their ability to provide constructive reminders to their partners for improved team performance over the three game sessions. In the initial session, many children did not pay close attention to their partners' performances. When one of the pairs lost focus, the other partner would often take over both roles to fulfill the turn-taking tasks. In some instances, children improperly assumed control of their partners' roles and managed the entire game, as they were unwilling to share the screen. For instance, when P14 was not paying attention to the game, P13 controlled two paddles at the same time. When such circumstances arose, parents and researchers would inform children that they were not handling issues in an appropriate way and would remind them of more acceptable behaviors. As children gradually got more practice and became more familiar with the gameplay, they became aware that they should take turns and follow the game rules. They also learned to help their partners with verbal cues instead of directly interfering with their partners' game objects or taking control of both sides' roles. As a result, most children gained confidence in managing their unique roles on their part of the screen. They also became comfortable sharing screen control when it was not their turn, using simple verbal reminders or instructions to enhance the overall team performance. For instance, when P18 was aimlessly moving the paddle without paying attention to the ball, his partner P17 reminded him, *"Catch the ball!"*, which was intended to communicate the idea that *"you should not overlook your responsibility. Please catch the ball!"*. Besides reminding their partners to catch the ball in all levels, such reminding behaviors appeared more frequently, especially in levels Two and Three, where one usually tried to remind the other to use their unique superpowers. For example, when P5 had the opportunity to freeze the moving monster but forgot to activate the superpower as the ball approached, we observed P6 calling out his name and reminding him to tap on the superpower button twice during a short period of time. This was P6's progress, considering that she remained silent while facing similar circumstances at the beginning of the study. Across the three sessions, most children learned to share their control over the game and share the screen with their partners following the turn-taking game rules, implicitly achieving the sharing and joint-performance collaborative goals.

Most children exhibited an increasing ability to mutually plan and negotiate certain game decisions with their partners over the course of the three game sessions. Specifically, children negotiated which superpower each person should use at the beginning of Level Three. They also gradually learned how to mutually plan for their spaceship's decoration within the reward system. Initially, although pairs of children were expected to collaboratively decide on spending their earned diamonds for spaceship decoration, none of the pairs discussed or negotiated with each other. Out of the ten pairs, most (N = 8) disregarded their partners' preferences and traded diamonds for rewards until their diamonds were gone, while two pairs showed no interest in the rewards. However, later, with researchers' and/or parents' suggestions, some pairs began taking turns making the purchase decisions, and other pairs shared their thoughts and mutually decided on their decoration selection. By the last game session, about half the pairs were aware that they should plan or negotiate with their partners. They learned to ask (e.g., "Can we buy this telescope?"), persuade (e.g., "I think this is good"), and compromise (e.g., "Alright").

5.1.2 Changes in Theory of Mind (ToM) Scores in the Experimental Group. We first confirmed that the experimental group (Mean ± SD = 3.55 ± 1.23) and the control group (Mean ± SD = 3.33 ± 1.30) performed similarly in the pre-test (t-test, $t(30) = 0.471$, $p = .641$. We conducted a 2 × 2 Group (experimental vs. control) × Condition (pre vs. post) mixed ANOVA of the ToM scores. We identified a significant Group × Condition interaction effect, $F(1, 30) = 4.327$, $p = .046$, and a significant main effect of Condition, $F(1, 30) = 4.327$, $p = .046$, but no significant main effect of Group, $F(1, 30) = 1.311$, $p = .261$. A simple effect test found that the experimental group performed significantly better in the post-test (Mean ± SD = 4.05 ± 0.887) than in the pre-test (Mean ± SD = 3.55 ± 1.234), $F(1, 30) = 11.54$, $p = .002$, while the control group performed similar in the pre-test (Mean ± SD = 3.33 ± 1.303) and the post-test (Mean ± SD = 3.33 ± 1.303), $F(1, 30) = 0.00$, $p > .05$. The result (Fig. 4-a) indicated that repetition of the ToM tests did not improve participants' performance, but StarRescue game interventions facilitated children's ToM test scores.

5.2 Experimental Group's In-Game Collaborative Task Performances

5.2.1 Practice Time in the Tutorial Level. Children joined the study and began by practicing the Tutorial Level and familiarizing themselves with ball navigation and monster elimination tasks. On average, children spend 549.5 seconds (N = 20, SD = 344.27s) for 2.25 times (SE = 0.25) in getting familiar with the game navigation and turn-based tasks (Fig. 5). The practice time follows the Gaussian normal distribution, which shows that the game has a good entry difficulty level.

5.2.2 Play Times of Each Level Played per Session. After successfully completing the Tutorial Level, Level One, Level Two, and Level Three in sequential order for the first time, each pair gained the freedom to play any levels they chose. Figure 6-a shows the detailed percentage composition of each level's play times across three experiment days, which implied the children's selection and preferences of game levels.

Kruskal-Wallis tests showed that the number of times that Level Two was played did not have any significant differences. However, the play times of both Level One and Level Three had significant differences: for Level One, there was a significant difference between the first day and the second day (p = .002) and between the first and the third sessions (p = .002) from Dunn's tests. For Level Three, there was a significant difference between the first and second sessions (p = .004) and also between the first and third sessions (p = .000). Such significant differences indicated that children preferred an easier level at the beginning and became more willing to challenge themselves with harder levels in the second and third sessions.

5.2.3 Level Completion Duration. Figure 6-b reported the average time it took pairs of children to complete each level across the three study sessions. The ANOVA test and the Kruskal-Wallis test, respectively, show that there is a significant difference in the time spent completing Level One and Level Two during the three sessions. However, there is no significant difference in the time required to complete Level Three. Further, Tukey pairwise testing and Dunn's

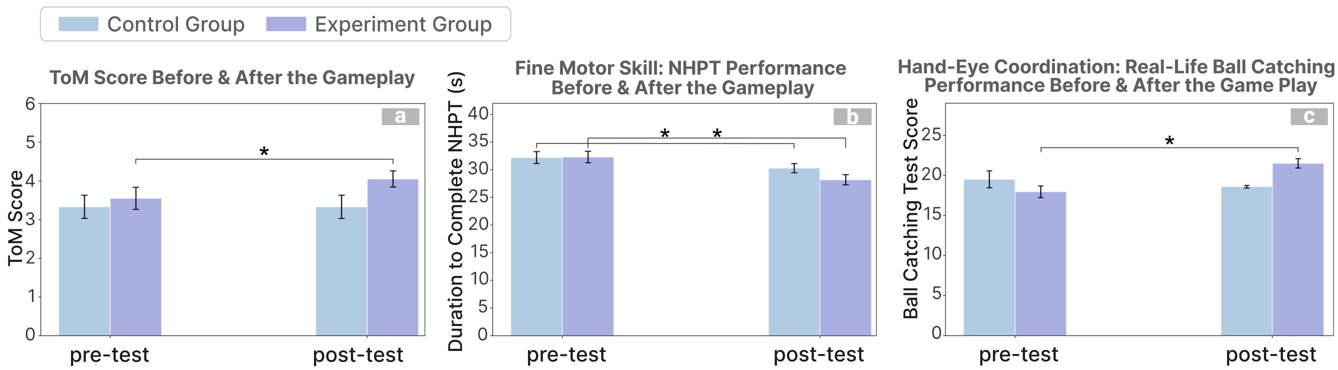


Figure 4: Comparison between pre-test and post-test performance for both control and experiment groups (a: TOM score, b: fine motor skill, c: hand-eye coordination).

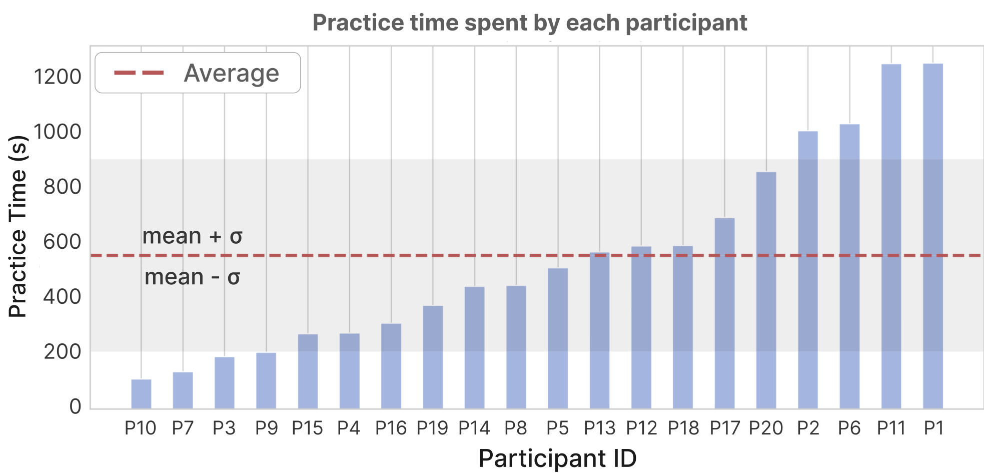


Figure 5: Children's Practice Time Length Distribution in the Tutorial Level.

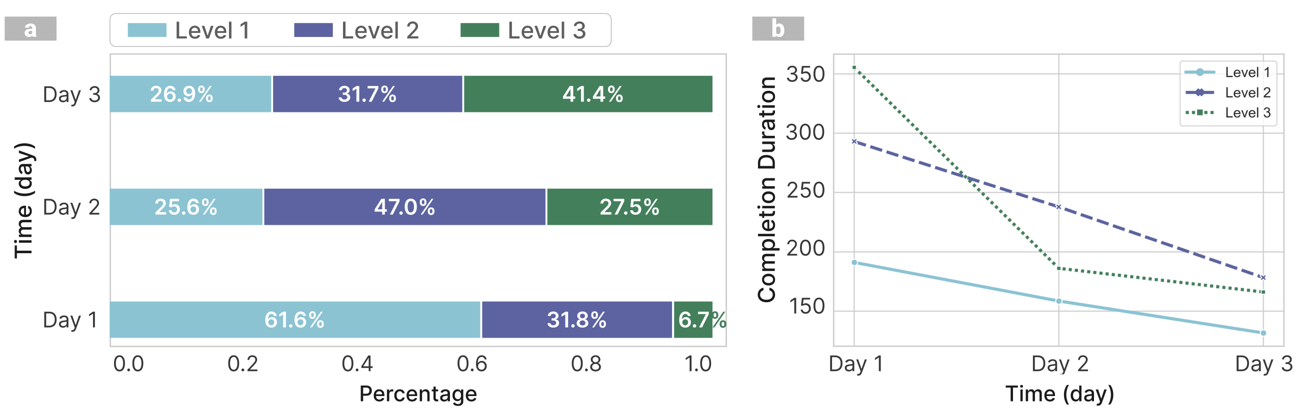


Figure 6: (a) Proportion of Level Completion by Pairs of Children Across Three Study Days. The stacked bar chart illustrates the percentage of each level played (Level 1, Level 2, and Level 3) on Day 1, Day 2, and Day 3. (b) Average Level Completion Times by Pairs of Children Across Three Study Days (Level One, Level Two, and Level Three).

test show that children can finish both Level One and Two significantly faster in the last session compared with the first session, which potentially indicates that the children performed better and might have a smoother collaboration with each other in turn-taking and navigating paddles, while Level Three was a more free level that took children longer time to discuss and negotiate.

5.2.4 Superpower Usage in Level Three. Since the children were offered both burning and freezing superpowers in Level Three, the pairs could jointly decide their roles through mutual planning in a flexible way. Thus, the children's superpower usage could represent their engagement with the game tasks and also indicate whether the two children collaborated with each other in an equal way. We repeatedly performed the ANOVA test (if assumptions were satisfied) and the Kruskal-Wallis test (otherwise) on each pair's gameplay data to evaluate if there were differences between their superpower usage. Results demonstrated that five pairs did not show any significant differences in the number of times applying superpowers, indicating both children were equally engaged (Fig. 7) in their Level Three collaboration during the last game session.

5.3 Autistic Children's Positive Changes in Fine Motor Skill & Hand-Eye Coordination

Here, we report findings from both the experimental group and the control group's motor skills and compare their changes. For the fine motor skill test, we did not observe any significant differences between the experimental group (Mean ± SD = 32.29 ± 4.47) and the control group (Mean ± SD = 32.19 ± 4.60) in the pre-study, t-test, $t(30) = 0.062$, $p = .950$. Then we conducted a 2 × 2 Group (experimental vs. control) × Condition (pre vs. post) mixed ANOVA test. We found a significant Group × Condition interaction effect, $F(1, 30) = 5.31$, $p = .028$, and a significant main effect of Condition, $F(1, 30) = 39.92$, $p < .001$. We did not identify a significant main effect of group $F(1, 30) = 0.48$, $p = .494$. Simple effect tests found that both the experimental and control groups spent less time in the post-test (expt, Mean ± SD = 28.18 ± 3.87; control, Mean ± SD = 30.28 ± 3.48) than in the pre-test (expt, Mean ± SD = 32.29 ± 4.47; control, Mean ± SD = 32.19 ± 4.60); expt, $F(1, 30) = 49.56$, $p < .001$, control, $F(1, 30) = 6.44$, $p = .017$. The results (Fig. 4-b) indicated that repetition of the fine motor task could facilitate performance, but the game intervention facilitated skill development more than simple repetitions.

For the hand-eye coordination tests, no significant difference was identified between the experimental group (Mean ± SD = 17.95 ± 3.03) and the control group (Mean ± SD = 19.67 ± 5.00) in the pre-test, t-test, $t(30) = -1.214$, $p = .234$. Based on a 2 × 2 Group (experimental vs. control) × Condition (pre vs. post) mixed ANOVA test of the total scores, we found a significant Group×Condition interaction effect, $F(1, 30) = 11.74$, $p = .002$, and a significant main effect of Condition, $F(1, 30) = 9.733$, $p = .004$. We did not observe any significant main effect of Group, $F(1, 30)$, $p = .908$. A simple effect test found that the experimental group performed better in the post-test (Mean ± SD = 21.50 ± 2.48) than in the pre-test (Mean ± SD = 17.95 ± 3.03), $F(1, 30) = 28.58$, $p < .001$, while the control group performed similar in the pre-test (Mean ± SD = 19.50 ± 4.54) and the post-test (Mean ± SD = 18.59 ± 5.00), $F(1, 30) = 0.04$, $p = .847$. The results (Fig. 4-c) indicated that repetition of the catching task did not improve hand-eye coordination performance, but the game intervention facilitated hand-eye coordination skills in the real world.

5.4 Usability Evaluation: Findings from Parents' Feedback

5.4.1 Overall Enjoyment and Engagement. According to parents' responses, most of the children enjoyed playing StarRescue and they could not wait to start the game. Many parents (N = 11/16) mentioned that their children would be excited when they heard that they could play the game again on the second and third experiment days. Parents responded that some children also asked their parents when they could play StarRescue again during the study period. P6 and P14 even actively shared their playing experience with their family when they went back home. Most of the parents responded that they looked forward to the launch of the game so that they could download it from the app store and let their kids play it outside of study. Many parents also said that they would play it together with their children and let their children lead the collaboration process. Some parents also mentioned that they would like to have typical developing (TD) children to play StarRescue with their children.

5.4.2 Difficulty Progression. As for the game's difficulty progression, most parents (N = 13/16) thought StarRescue's level progression and difficulty settings were acceptable and great for their children. Depending on children's skill levels, some parents mentioned that they expected future levels to be progressively more challenging, whereas others thought the current levels were good enough for their children. For instance, parents of P1, P2, and P5 found Level Two and Level Three were already complicated for their children to handle, and the parents observed that their children rarely chose higher levels on their own. In fact, a few mentioned that their children would feel reluctant to join higher game levels when their partners chose difficult ones. The children would have resistant behaviors like pressing the return button or expressions like "No! I don't want to." For example, P5's parent reported that P5 preferred to play Level One because it is the easiest level, so he had confidence in playing it well. Several parents (P1, P2, P5, and P18) suggested that children could overcome their fear of higher levels through better understanding of the game, more frequent practice, and receiving timely rewards. These approaches, they believed, would build their confidence.

5.4.3 Collaborative Tasks' Potentials in Enhancing Social Skills. Most parents believed that collaboration and teamwork were very crucial skills for their children to work on, and they all agreed that StarRescue's turn-taking and superpower game features could improve their children's collaboration skills. Some parents who closely observed the game (P7, P11, P12, P20) also believed that children's collaboration skills were enhanced even when they were just taking turns to pass the ball and were not skilled enough to hit the monster by adjusting their own paddles. These parents also commented that the turn-taking mechanics could be an unconscious process that the children themselves might not even be aware of. Ten parents mentioned that their children learned to pay attention

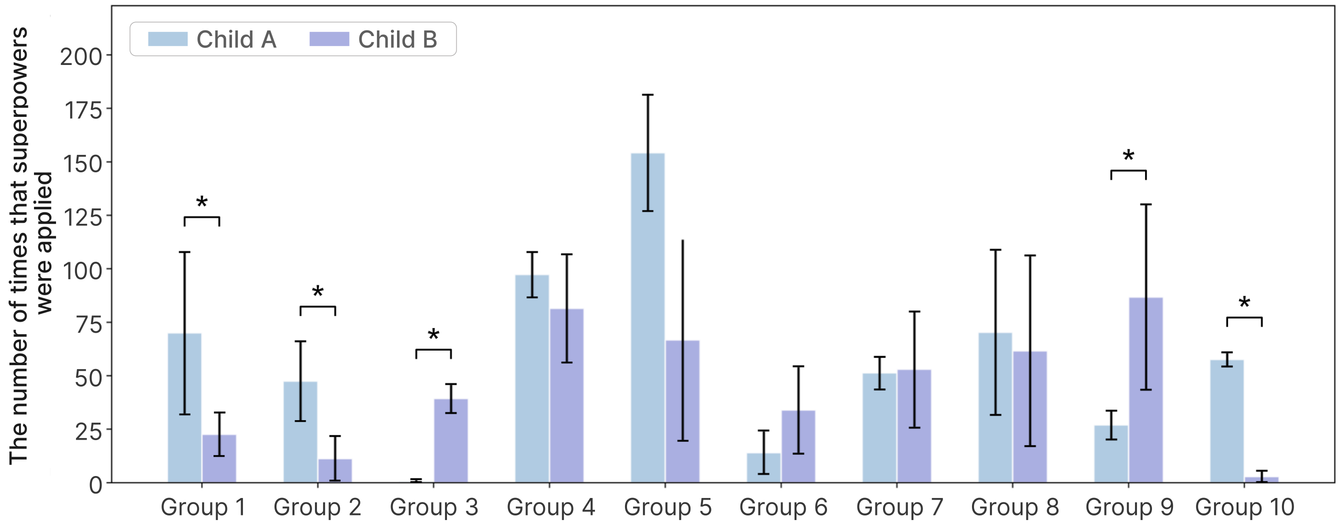


Figure 7: The number of times each child in each group applied superpowers in level three on experiment Day 3.

to their partners' actions during turn-taking based on their observations. Moreover, some parents pointed out that the superpower assignment mechanics in Level Two and Level Three were effective. For instance, P20's parent highlighted that the children were trained to use these two superpowers together, and she liked the idea that the superpowers needed to be used in a specified sequence: burning after freezing. Meanwhile, some parents responded that StarRescue can be used as a platform to help kids initiate conversations, even though the effectiveness of such communication might depend on the children's language ability. These parents thought that their children were provided with a strong motivation to speak up, which is a more natural and better way to improve communication skills easily. P7's parent pointed out that P7 talked a lot more when playing StarRescue with P8, compared with playing other things with P8 (the same partner). She said, "When playing with LEGO bricks with P8, he can only express his own ideas and talk with himself. But when playing this game, StarRescue, he can keep talking throughout the gameplay with P8 because he has to do so on some levels." Besides in-game communications, parents reported that new expressions emerged even outside the gameplay. Surprisingly, two parents (from two different pairs) reported that new conversations emerged even outside the gameplay. Parents of P7 and P20 told us that they surprisingly heard their children were trying to allocate different tasks and roles to other children when they were playing outdoors, which implies the potential of transferring autistic children's skills gained from games to real-life practices. Many parents suggested that more communication could be facilitated if the parents intentionally taught their kids how to express certain ideas before the game started and let them practice during the gameplay.

5.4.4 Effectiveness in Improving Hand-Eye Coordination and Fine Motor Skills. Nearly all the parents pointed out that the game demanded lots of hand-eye coordination and fine motor skills overall. Parents commented from their perspective that their children needed to be extremely focused on observing the game scene and their partners and making reactions in time to catch the ball and eliminate monsters. Also, the children need to use their fingers' fine motor movement to trace a circular route and navigate the paddle. Four parents actively reported that they could observe improvements in their kids' game performances when observing how they navigate the paddle and interact with the iPad.

5.4.5 Concerns and Risks. However, besides positive attitudes towards this game and observed potential for improvements in collaboration and motor skills, three parents also expressed their concerns about digital game addiction. They (P2, P9, and P16) thought iPad games were extremely attractive to kids and that the playing should be strictly controlled. Also, although more than half of the parents reported that their children favored the outer space game theme, P8's and P11's parents both mentioned that their children had limited and narrow interests, so the game theme was less attractive to them at first glance. The parents suggested including more theme choices that closely relate to their daily lives and interests, e.g., football, food, or shopping, to attract children with diverse preferences.

5.5 Observations of Parents' Impacts on Children's Game Performances as Spectators

We observed that parents, as spectators, had a unique impact on their children's game performance. During the three-day period, 16 out of 20 children's parents accompanied their children to participate in the one-hour StarRescue experimental session, thereby unconsciously becoming spectators in their children's gameplay. Notably, we observed and identified two types of parent spectators. The first type (parent A in Fig. 8), comprising less than one-fourth of the parents, actively monitored their children's game performances. Parents of this type provided timely feedback on their children's performance, such as encouragement. For instance, P6 and P11's parents cheered them on as they were learning to control the paddle and apply the superpower, alleviating their fear of difficulty and growing their confidence.

Conversely, the second type of parents (parent B in Fig. 8) waited on the other side of the lab room silently, not actively observing their children's game sessions. Yet, interestingly, their presence still influenced their children's behaviors. Many children proactively initiated interactions with their parents during gameplay, offering updates on their progress. For instance, each time P13 and his partner triumphed over a monster, he enthusiastically reported to his parent, *"We knocked off another monster, Daddy!"* In return, his parent recognized the pair's achievement, serving as an additional layer of reward. In summary, we observed that most parents in this study, whether actively engaged or silently observing, played positive spectator roles in their autistic children's game experiences, potentially influencing and enhancing their performance and confidence.

6 DISCUSSIONS

We aim to explore a collaboration model for implementing social games for autistic children without cognitive impairment (AC-NCI) in a two-player collaborative game context. After a pilot study with teachers and parents, we designed a turn-taking-based game adopting a progressive, collaborative flow with consistent narratives to facilitate autistic children's social skills and collaborations. Results from a three-day user evaluation with 32 autistic children (20 in the game group) demonstrated positive improvement in their social and motor skills. Here, according to our findings and observations, we further discuss several implications and inspirations for future social games and research focused on autistic children.

6.1 An Integrated Collaboration Model with Scaffolding Levels and Collaborative Tasks

In StarRescue, we adopted an in-game collaboration strategy based on Silva et al. and Giusti et al.'s collaboration models [22, 42] and integrated them to achieve more progressive yet engaging collaboration experiences for autistic children (without cognitive impairment). Giusti et al. [22] identified four collaboration patterns (ways of collaboration, i.e., choosing together, constraints on objects, different roles, and ownership) falling under three collaboration aspects (i.e., joint-performances, sharing for common goals, and mutual planning). However, these rich components were designed specifically for AC-NCI. These social games were implemented in several separate mini-games without narrative connections and continuity, which could be challenging to motivate children for sustainable play. In contrast, Silva et al.'s proposed framework has four collaborative stages dedicated to autistic children with cognitive impairment (AC-CI) [42]. Therefore, StarRescue explored a new collaboration approach by integrating the sharing and mutual-planning collaborative dimensions proposed in Giusti et al.'s work [22] and following the four-stage progressive flow in Silva et al.'s [42].

Findings from StarRescue showed the integrated collaboration model and progressive, collaborative approach worked for AC-NCI as well, allowing children to start with a simple action that gradually fosters their engagement in working with their partners. Notably, this progressive feature ensures an inclusive playing environment where children with varying skill levels can find the game levels that they enjoy. The pair of children can practice the target skills at easier levels at their own pace before they feel comfortable advancing to more challenging levels. We believe this is crucial for autistic children to engage in the game and build confidence, thinking of their sensitivity to setbacks and failures. We suggest future collaboration games adopt a progressive flow, customized for unique social interaction skills (e.g., turn-taking) and especially complicated social collaborations.

6.2 Respecting (and Evaluating) Autistic Children's Freestyle Verbal and Nonverbal Social Interactions

Prior work considered integrating autistic children's unique preferences and personal impairment levels when designing social games. For instance, Giusti et al. [22] suggested respecting children's game culture when designing social games to meet their expectations and facilitate their intrinsic motivation for playing social games with other people. Several studies also customized their games based on autistic children's cognitive impairment levels. For instance, many research prototypes [5, 7, 22, 50] explored collaboration strategies in social games that were customized for "high-functioning autism" children (here in this paper, referred to as autistic children without cognitive impairment). Meanwhile, a few [42, 68] were also designed and tested with "low-functioning autism" children (here in this paper, referred to as autistic children with cognitive impairment). We found that successful social games usually respect autistic children's unique personal traits and preferences without forcing collaboration during play sessions.

The goal of StarRescue was to initiate collaboration progressively and promote communication acceptance rather than forcing verbal communication and collaboration. As shown in StarRescue (Section 3.2), autistic children did not join their partners in the collaborative tasks right away. They were given sufficient opportunities to practice their own skills and then took part in their collaborative roles after they felt comfortable doing so. After they were familiar with Level One and Two tasks, children were again given the freedom to decide their own roles (in using superpowers) in Level Three. When it's not preferred by the children or when they are not in a comfortable mode of expression, forcing verbal communication can lead to stress, anxiety, and frustration for autistic individuals [65].

Therefore, we propose future work to respect autistic children's intentions and choices of play/collaboration by providing a flexible game setup and enough individual preparation and exploration opportunities for social collaboration tasks. Furthermore, future collaborative game tasks should be either achieved through verbal or non-verbal approaches for autistic children, considering their varying personal skill levels and preferences. The idea is to promote communication acceptance in an inclusive and supportive environment rather than imposing one specific mode of communication and causing uncomfortable, pressured, and frustrating feelings or moments. Such flexible social interactions are one of the distinct advances social games could create, fostering a sense of membership, partnership, and friendship that leads to further improved social experiences.

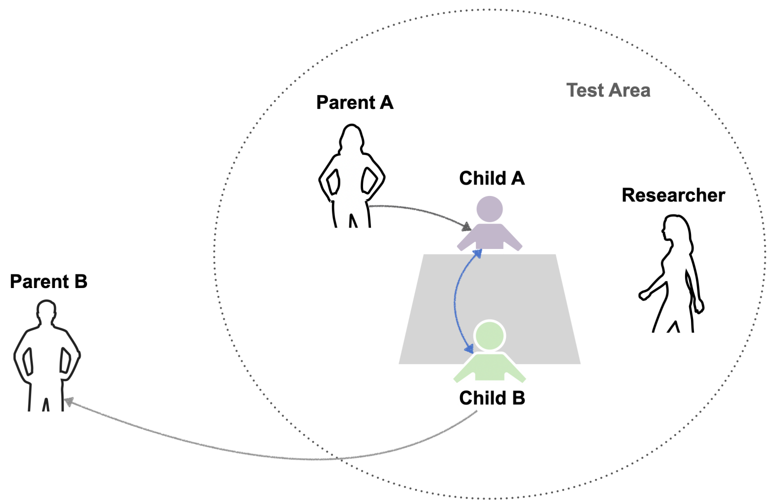


Figure 8: Interaction dynamics among parents and children in a study environment.

6.3 Parents' Critical Roles as Invisible Partners in Social Games

We discovered that autistic children's parents could play a critical yet "invisible" role in social games, whose presence implicitly affected their children's engagement and in-game behaviors. In our observations (Section 5.5), some parents actively engaged in the game and research process as game spectators and, meanwhile, their children's implicit partners. Parents' involvement encouraged the children timely and reminded them to express and behave appropriately, creating positive gaming experiences for the children participants. Parents with such *assistant* roles in StarRescue have been previously identified as one of the nine spectator persona types by Cheung and Huang [11].

Considering the guardianship between these parents and their autistic children, parents' motivations to play the helper role extend beyond their social needs as spectators, as outlined by Seering et al. [54]. Their involvement was further motivated by the profound parent-child bond that led to unconditional support for their children. Previously, Kappen et al. [32] examined spectators' impact on typically developing (TD) college players in co-located games, and their findings revealed that silent audiences could decrease players' performances. In contrast, our findings showed that both parent type A's active engagement and parent type B's mere presence all functioned as motivating factors for their children to strive for better performance (Fig. 8). This discrepancy of spectators' impacts on players' performances may be attributed to the distinctive parent-child relationship, in which children strive to gain attention and recognition from their parents.

In prior work, Musick et al. investigated family gaming experiences and parent-child relationships; they found that TD children enjoyed parents' spectator roles for their encouragement and help, and the families appreciated shared experiences and family moments [43]. Similarly, as shown in our findings, parents' spectator roles also positively impacted autistic children's in-game performances, parent-child relationships and communication, and facilitated shared moments. For instance, autistic children shared their in-game achievements with their parents (Section 5.5), and StarRescue gaming experiences became a discussion topic among parents and their autistic children (Section 5.4.1). Despite parents' unique spectator roles in shaping autistic children's experience playing collaborative social games, few existing studies (including StarRescue) considered parents' engagement in autistic children's play sessions explicitly or investigated parents' behaviors and influences on children's motivation and engagement.

Therefore, we propose future work to involve parents of autistic children and consider their unique assistive and accompanying spectator roles in both the game design stage and evaluation stage. For instance, additional game features or narratives could be designed to purposefully involve parents and enhance their participation as audiences, thereby transforming the act of spectating into a more engaging experience [36]. Future work could also conduct controlled experiments with a focus on evaluating the influence of parents' spectator roles on autistic children's performances, understanding optimal parental behaviors, and maximizing the benefits of their involvement.

6.4 Insights into Game Design Features and Potential Future Improvements

Results from Section 5.1.1 and Section 5.4.3 indicated that the turn-taking mechanism facilitated our design objectives of (a) promoting autistic children's sharing and mutual planning collaboration behaviors and skill development and (b) creating engaging game experiences. Next, we discuss three major insights into game design features and potential improvements for future collaborative social games designed for autistic children.

Cultivating Interdependent Relationships in Collaborative Play. StarRescue's reciprocal ball-passing dynamic (i.e., catching the ball before bouncing it) and the unique ordering of applying the superpower feature required the children to closely attend to their pairs' actions and maintain connections with their pairs, cultivating interdependent relationships between the pairs. As evidenced in sections 5.1.1 and 5.4.3, interdependent relationships successfully fostered children's joint attention and motivated them to assist their pairs for better joint performances. Prior collaborative game research has likewise incorporated varied approaches to strengthen interdependent relationships. For instance, Chin and Bernard-Opitz's game [12] aimed to train autistic children's conversational skills through turn-taking, consisting of tasks of paying attention, waiting, and providing responses. Other research games either allowed one player's action after the other player's in co-located scenarios [22, 42] or provided unique information to players so they could complement their partner's part before proceeding with the gameplay in remote scenarios [48]. Therefore, we suggest future social games consider implementing collaborative mechanics that can facilitate interdependent relationships, which can increase their awareness of collaborative tasks and support the children in maintaining close connections in the collaboration process.

Raising Children's Awareness for Shared Ownership through Territory Boundary Design. StarRescue divided the interface into two halves visually, representing each player's territory and restricted paddle movements within their respective half-spaces. From our observational results (Section 5.1.1), such clear territory borders were confirmed to be necessary because some autistic children tended to control their partners' half space in the early stages of the study. Thus, StarRescue's center boundaries clearly indicated each player's territory and visualized the corresponding ownership of the shared control. Interestingly, prior work identified that players' on-screen territory can be shaped by their off-screen physical proximity [4]. Further, Wehbe et al. [63] found that players would negotiate through verbal communication to prevent others' bodies from presenting in their physical, personal gameplay space. Envisioning that this communication opportunity would further support autistic children's social skills development, we would like to foster such conversation by gradually blurring or even eliminating the on-screen space boundaries in later levels, after they have grown familiar with the shared control. Inspired by Wehbe et al.'s idea of "variable boundary enforcement" [63, p. 192], future StarRescue work could rethink the need for visualizing explicit borders at different levels and further explore autistic children's collaborative performance at advanced game levels without clear boundaries. This idea aligns with the fourth stage proposed in Silva et al.'s [42] collaboration model, aiming to achieve free and flexible play experiences.

Incorporating Game Elements to Guide Mutual Planning. Our findings suggest that autistic children engaged in mutual planning behaviors, which is a collaboration dimension proposed by Giusti et al. [22]. For example, most children started to negotiate superpower allocation and coordinate and reward purchases (Section 5.1.1). Since parents noted that their children were more motivated to talk during the StarRescue compared with other collaborative activities (Section 5.4.3), we plan to create more opportunities for mutual planning conversations in future game iterations - For instance, by adding extra collaborative tasks that prompt the pairs to discuss and reach agreements about superpower allocations, reward purchases, level selection, and spaceship decorations before making final decisions. Such a conversation touch-point feature may further improve children's motivation to freely discuss their thoughts with others and understand each other's roles in collaborative game tasks.

6.5 Limitations and Future Work

In general, our study has several limitations that could be considered and improved in future research. Our study primarily engaged autistic children without cognitive impairment (AC-NCI) as study participants. While we initially attempted to also design and test with autistic children with cognitive impairment (AC-CI), our preliminary investigations with teachers and parents revealed that most AC-CI participants had varying cognitive abilities. Also, AC-CI need more support when navigating the iPad and engaging in basic conversations with researchers during pilot tests. Future work could further explore the application of the progressive collaboration model and involve children on the autism spectrum with diverse cognitive abilities.

Further, our study duration was limited to three days for each pair of participants, conducted within a controlled lab setting. Future research could consider conducting the study in the field, utilizing participants' own mobile devices at their homes, to investigate potential social behaviors mediated by the game in more naturalistic settings.

Moreover, we mainly collected psychological assessments and tests, parental reports, in-game performances, and observations to evaluate changes in participants' social behaviors and skills. While these methods provided valuable insights, they may not comprehensively capture all changes. Future research could explore alternative evaluations, such as analyzing video recordings during play sessions via the manual or AI-based automatic behavioral coding approach to recognize the children's facial expressions, body gestures, and other indicators of active social collaboration.

Finally, due to various constraints, we were unable to follow up with the participants after the study to measure long-term changes or potential impacts in real-world contexts. Future work could further investigate the potential transferability of such collaborative game strategies and their sustained effect over time.

7 CONCLUSION

In this research, we introduce the design of StarRescue, a turn-taking-based collaborative tablet game for autistic children without cognitive impairment (AC-NCI), which integrates a progressive, collaborative model. We conducted a three-day user study with 32 AC-NCI to further evaluate the impacts of StarRescue on autistic children's social skills. The game facilitates collaborative engagement through sharing and mutual planning activities, organized into an adjusted four-stage collaboration model for AC-NCI. Results indicated that AC-NCI demonstrated potential improvements in social skills based on observations, parental feedback, and Theory of Mind (ToM) scales. Our findings underscored the positive influence of turn-based mechanics on the social behaviors (e.g., communication, joint attention) of AC-NCI progressively. In summary, our research contributes valuable insights into autistic children's play processes and social behaviors and provides critical implications for future HCI research through the implementation and three-day evaluation of the StarRescue prototype.

ACKNOWLEDGMENTS

We thank Duke Kunshan Synear-Wang Cai Grant and Science and Technology Program of Guangzhou City (202007030011) for funding this research. The contributions of Rongqi Bei, Yihe Wang, and Yuxuan Huang were made during their roles as Research Assistants at Duke Kunshan University.

REFERENCES

[1] American Psychiatric Association. 1995. Diagnostic and Statistical Manual of Mental Disorders, 4th ed. (DSM-IV). *AJP* 152, 8 (Aug. 1995), 1228–1228.
[2] American Psychological Association. 2023. *Inclusive language guide* (2 ed.). https://www.apa.org/about/apa/equity-diversity-inclusion/language-guidelines.pdf Accessed: February 18, 2024.
[3] Bonnie Auyeung, Simon Baron-Cohen, Sally Wheelwright, and Carrie Allison. 2008. The Autism Spectrum Quotient: Children's Version (AQ-Child). *J. Autism Dev. Disord.* 38, 7 (Aug. 2008), 1230–1240.
[4] Alec Azad, Jaime Ruiz, Daniel Vogel, Mark Hancock, and Edward Lank. 2012. Territoriality and behaviour on and around large vertical publicly-shared displays. In *Proceedings of the Designing Interactive Systems Conference* (Newcastle Upon Tyne, United Kingdom) *(DIS '12)*. Association for Computing Machinery, New York, NY, USA, 468–477.
[5] A Battocchi, F Pianesi, D Tomasini, M Zancanaro, G Esposito, P Venuti, A Ben Sasson, E Gal, and P L Weiss. 2009. Collaborative Puzzle Game: a tabletop interactive game for fostering collaboration in children with Autism Spectrum Disorders (ASD). In *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces* (Banff, Alberta, Canada) *(ITS '09)*. Association for Computing Machinery, New York, NY, USA, 197–204.
[6] Nirit Bauminger. 2007. Brief report: group social-multimodal intervention for HFASD. *J. Autism Dev. Disord.* 37, 8 (Sept. 2007), 1605–1615.
[7] Sara Bernardini, Kaśka Porayska-Pomsta, and Tim J Smith. 2014. ECHOES: An intelligent serious game for fostering social communication in children with autism. *Inf. Sci.* 264 (April 2014), 41–60.
[8] Allison M Birnschein, Courtney A Paisley, and Theodore S Tomeny. 2021. Enhancing social interactions for youth with autism spectrum disorder through training programs for typically developing peers: A systematic review. *Res. Autism Spectr. Disord.* 84 (June 2021), 101784.
[9] 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 Adulthood* 3, 1 (March 2021), 18–29.
[10] Louanne E Boyd, Kathryn E Ringland, Oliver L Haimson, Helen Fernandez, Maria Bistarkey, and Gillian R Hayes. 2015. Evaluating a Collaborative iPad Game's Impact on Social Relationships for Children with Autism Spectrum Disorder. *ACM Trans. Access. Comput.* 7, 1 (June 2015), 1–18.
[11] Gifford Cheung and Jeff Huang. 2011. Starcraft from the stands: understanding the game spectator. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Vancouver, BC, Canada) *(CHI '11)*. Association for Computing Machinery, New York, NY, USA, 763–772.
[12] H Y Chin and V Bernard-Opitz. 2000. Teaching conversational skills to children with autism: effect on the development of a theory of mind. *J. Autism Dev. Disord.* 30, 6 (Dec. 2000), 569–583.
[13] Dasom Choi, Sung-In Kim, Sunok Lee, Hyunseung Lim, Hee Jeong Yoo, and Hwajung Hong. 2023. Love on the Spectrum: Toward Inclusive Online Dating Experience of Autistic Individuals. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23)*. Association for Computing Machinery, New York, NY, USA, 1–15. https://doi.org/10.1145/3544548.3581341
[14] Daniel O David, Cristina A Costescu, Silviu Matu, Aurora Szentagotai, and Anca Dobrean. 2020. Effects of a Robot-Enhanced Intervention for Children With ASD on Teaching Turn-Taking Skills. *Journal of Educational Computing Research* 58, 1 (March 2020), 29–62.
[15] Geraldine Dawson, Karen Toth, Robert Abbott, Julie Osterling, Jeff Munson, Annette Estes, and Jane Liaw. 2004. Early social attention impairments in autism: social orienting, joint attention, and attention to distress. *Dev. Psychol.* 40, 2 (March 2004), 271–283.
[16] Florence D DiGennaro Reed, Sarah R Hyman, and Jason M Hirst. 2011. Applications of technology to teach social skills to children with autism. *Res. Autism Spectr. Disord.* 5, 3 (July 2011), 1003–1010.
[17] Demetria Loryn Ennis-Cole. 2015. *Technology for Learners with Autism Spectrum Disorders*. Springer International Publishing.
[18] Charles B Ferster. 1964. Positive Reinforcement and Behavioral Deficits of Autistic Children. In *Conditioning Techniques in Clinical Practice and Research*, Cyril M Franks (Ed.). Springer Berlin Heidelberg, Berlin, Heidelberg, 255–274.
[19] S Fletcher-Watson, H Pain, S Hammond, A Humphry, and H McConachie. 2016. Designing for young children with autism spectrum disorder: A case study of an iPad app. *International Journal of Child-Computer Interaction* 7 (Jan. 2016), 1–14.
[20] Sue Fletcher-Watson, Alexandra Petrou, Juliet Scott-Barrett, Pamela Dicks, Catherine Graham, Anne O'Hare, Helen Pain, and Helen McConachie. 2016. A trial of an iPad™ intervention targeting social communication skills in children with autism. *Autism* 20, 7 (Oct. 2016), 771–782.
[21] Deborah G Garfin and Catherine Lord. 1986. Communication as a Social Problem in Autism. In *Social Behavior in Autism*, Eric Schopler and Gary B Mesibov (Eds.). Springer US, Boston, MA, 133–151.
[22] Leonardo Giusti, Massimo Zancanaro, Eynat Gal, and Patrice L (tamar) Weiss. 2011. Dimensions of collaboration on a tabletop interface for children with autism spectrum disorder. In *Proceedings of the 2011 annual conference on Human factors in computing systems - CHI '11* (Vancouver, BC, Canada). ACM Press, New York, New York, USA.
[23] Howard Goldstein, Louise A Kaczmarek, and Kristina M English. 2002. *Promoting Social Communication: Children with Developmental Disabilities from Birth to Adolescence.* Paul H. Brookes Publishing Company.
[24] Michael D E Goodyear, Karmela Krleza-Jeric, and Trudo Lemmens. 2007. The Declaration of Helsinki. *BMJ* 335, 7621 (Sept. 2007), 624–625.
[25] Charline Grossard, Ouriel Grynspan, Sylvie Serret, Anne-Lise Jouen, Kevin Bailly, and David Cohen. 2017. Serious games to teach social interactions and emotions to individuals with autism spectrum disorders (ASD). *Comput. Educ.* 113 (Oct. 2017), 195–211.
[26] İpek Gürbüzsel, Tilbe Göksun, and Aykut Coşkun. 2022. Eliciting parents' insights into products for supporting and tracking children's fine motor development. In *Proceedings of the 21st Annual ACM Interaction Design and Children Conference* (Braga, Portugal) *(IDC '22)*. Association for Computing Machinery, New York, NY, USA, 544–550.
[27] Lyn Henderson. 2007. Theorizing a Multiple Cultures Instructional Design Model for E-Learning and E-Teaching. In *Globalized E-Learning Cultural Challenges*. IGI Global, 130–154.
[28] Jorge Fernández Herrero and Gonzalo Lorenzo. 2020. An immersive virtual reality educational intervention on people with autism spectrum disorders (ASD) for the development of communication skills and problem solving. *Education and Information Technologies* 25, 3 (May 2020), 1689–1722.
[29] Kat Houghton, Julia Schuchard, Charlie Lewis, and Cynthia K Thompson. 2013. Promoting child-initiated social-communication in children with autism: Son-Rise Program intervention effects. *J. Commun. Disord.* 46, 5-6 (Oct. 2013), 495–506.
[30] Juan Pablo Hourcade, Stacy R Williams, Ellen A Miller, Kelsey E Huebner, and Lucas J Liang. 2013. Evaluation of tablet apps to encourage social interaction in children with autism spectrum disorders. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Paris, France) *(CHI '13)*. Association for Computing Machinery, New York, NY, USA, 3197–3206.
[31] Yuxuan Huang, Yihe Wang, Tongxin Xiao, Rongqi Bei, Yuhang Zhao, Zhicong Lu, and Xin Tong. 2022. StarRescue: Transforming A Pong Game to Visually Convey the Concept of Turn-taking to Children with Autism. In *Extended Abstracts of the 2022 Annual Symposium on Computer-Human Interaction in Play* (Bremen, Germany) *(CHI PLAY '22)*. Association for Computing Machinery, New York, NY, USA, 246–252.
[32] Dennis L Kappen, Pejman Mirza-Babaei, Jens Johannsmeier, Daniel Buckstein, James Robb, and Lennart E Nacke. 2014. Engaged by boos and cheers: the effect of co-located game audiences on social player experience. In *Proceedings of the first ACM SIGCHI annual symposium on Computer-human interaction in play* (Toronto, Ontario, Canada) *(CHI PLAY '14)*. Association for Computing Machinery, New York, NY, USA, 151–160.
[33] 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 (May 2016), 442–462.
[34] Steven L Kent. 2001. *The Ultimate History of Video Games, Volume 1: From Pong to Pokemon and Beyond . . . the Story Behind the Craze That Touched Our Lives and Changed the World.* Crown.
[35] Sojung Kim and Elizabeth Clarke. 2015. Case study: An iPad-based intervention on turn-taking behaviors in preschoolers with autism. *Behavioral Development Bulletin* 20, 2 (Oct. 2015), 253–264.
[36] Simone Kriglstein, Günter Wallner, Sven Charleer, Kathrin Gerling, Pejman Mirza-Babaei, Steven Schirra, and Manfred Tscheligi. 2020. Be Part Of It: Spectator Experience in Gaming and Esports. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI EA '20)*. Association for Computing Machinery, New York, NY, USA, 1–7.
[37] Rebecca Landa. 2007. Early communication development and intervention for children with autism. *Ment. Retard. Dev. Disabil. Res. Rev.* 13, 1 (2007), 16–25.
[38] Rebecca J Landa, Joshua L Haworth, and Mary Beth Nebel. 2016. Ready, Set, Go! Low Anticipatory Response during a Dyadic Task in Infants at High Familial Risk for Autism. *Front. Psychol.* 7 (May 2016), 721.

[39] Kwangwon Lee and Hannah H Schertz. 2020. Brief Report: Analysis of the Relationship Between Turn Taking and Joint Attention for Toddlers with Autism. *J. Autism Dev. Disord.* 50, 7 (July 2020), 2633–2640.

[40] Meghann Lloyd, Megan MacDonald, and Catherine Lord. 2013. Motor skills of toddlers with autism spectrum disorders. *Autism* 17, 2 (March 2013), 133–146.

[41] 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, Christine M Ladd-Acosta, Dedria McArthur, Elise T Pas, Angelica Salinas, Alison Vehorn, Susan Williams, Amy Esler, Andrea Grzybowski, Jennifer Hall-Lande, Ruby H N Nguyen, Karen Pierce, Walter Zahorodny, Allison Hudson, Libby Hallas, Kristen Clancy Mancilla, Mary Patrick, Josephine Shenouda, Kate Sidwell, Monica DiRienzo, Johanna Gutierrez, Margaret H Spivey, Maya Lopez, Sydney Pettygrove, Yvette D Schwenk, Anita Washington, and Kelly A Shaw. 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 Surveill. Summ.* 72, 2 (March 2023), 1–14.

[42] Greis F Mireya Silva, Alberto Raposo, and Maryse Suplino. 2015. Exploring Collaboration Patterns in a Multitouch Game to Encourage Social Interaction and Collaboration Among Users with Autism Spectrum Disorder. *Comput. Support. Coop. Work* 24, 2 (June 2015), 149–175.

[43] Geoff Musick, Guo Freeman, and Nathan J McNeese. 2021. Gaming as Family Time: Digital Game Co-play in Modern Parent-Child Relationships. *Proc. ACM Hum.-Comput. Interact.* 5, CHI PLAY (Oct. 2021), 1–25.

[44] Jean-Paul Noel, Matthew A De Niear, Nicholas S Lazzara, and Mark T Wallace. 2018. Uncoupling Between Multisensory Temporal Function and Nonverbal Turn-Taking in Autism Spectrum Disorder. *IEEE Transactions on Cognitive and Developmental Systems* 10, 4 (Dec. 2018), 973–982.

[45] Behnaz Nojavanasghari, Charles E Hughes, and Louis-Philippe Morency. 2017. Exceptionally Social: Design of an Avatar-Mediated Interactive System for Promoting Social Skills in Children with Autism. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI EA '17)*. Association for Computing Machinery, New York, NY, USA, 1932–1939.

[46] Reiko Ohara, Yuji Kanejima, Masahiro Kitamura, and Kazuhiro P Izawa. 2019. Association between Social Skills and Motor Skills in Individuals with Autism Spectrum Disorder: A Systematic Review. *Eur J Investig Health Psychol Educ* 10, 1 (Dec. 2019), 276–296.

[47] Yanhui Pang. 2010. Lego games help young children with autism develop social skills. *Int. J. Educ.* 2, 2 (Dec. 2010).

[48] Sarah Parsons. 2015. Learning to work together: Designing a multi-user virtual reality game for social collaboration and perspective-taking for children with autism. *International Journal of Child-Computer Interaction* 6 (Dec. 2015), 28–38.

[49] Sam Perochon, J Matias Di Martino, Kimberly L H Carpenter, Scott Compton, Naomi Davis, Steven Espinosa, Lauren Franz, Amber D Rieder, Connor Sullivan, Guillermo Sapiro, and Geraldine Dawson. 2023. A tablet-based game for the assessment of visual motor skills in autistic children. *NPJ Digit Med* 6, 1 (Feb. 2023), 17.

[50] Anne Marie Piper, Eileen O'Brien, Meredith Ringel Morris, and Terry Winograd. 2006. SIDES: a cooperative tabletop computer game for social skills development. In *Proceedings of the 2006 20th anniversary conference on Computer supported cooperative work* (Banff, Alberta, Canada) *(CSCW '06)*. Association for Computing Machinery, New York, NY, USA, 1–10.

[51] American Psychiatric Association. 2000. Quick Reference To The Diagnostic Criteria From DSM-IV-TR American Psychiatric Association -pdf download free book. https://mlodyobywatel.ceo.org.pl/sites/mlodyobywatel.ceo.org.pl/files/webform/pdf-quick-reference-to-the-diagnostic-criteria-from-dsm-iv-tr-american-psychiatric-association-pdf-download-free-book-50e1a06.pdf. Accessed: 2023-9-15.

[52] Aurora Ruiz-Rodriguez, Ana I Martinez-Garcia, and Karina Caro. 2019. Gesture-based Video Games to Support Fine-Motor Coordination Skills of Children with Autism. In *Proceedings of the 18th ACM International Conference on Interaction Design and Children* (Boise, ID, USA) *(IDC '19)*. Association for Computing Machinery, New York, NY, USA, 610–615.

[53] Hannah H Schertz, Samuel L Odom, Kathleen M Baggett, and John H Sideris. 2018. Mediating Parent Learning to Promote Social Communication for Toddlers with Autism: Effects from a Randomized Controlled Trial. *J. Autism Dev. Disord.* 48, 3 (March 2018), 853–867.

[54] Joseph Seering, Saiph Savage, Michael Eagle, Joshua Churchin, Rachel Moeller, Jeffrey P Bigham, and Jessica Hammer. 2017. Audience Participation Games: Blurring the Line Between Player and Spectator. In *Proceedings of the 2017 Conference on Designing Interactive Systems* (Edinburgh, United Kingdom) *(DIS '17)*. Association for Computing Machinery, New York, NY, USA, 429–440.

[55] Margaret Semrud-Clikeman. 2007. Assessment of Social Competence in Children. In *Social Competence in Children*, Margaret Semrud-Clikeman (Ed.). Springer US, Boston, MA, 39–49.

[56] Barbara Sher. 2009. *Early Intervention Games: Fun, Joyful Ways to Develop Social and Motor Skills in Children with Autism Spectrum or Sensory Processing Disorders.* John Wiley & Sons.

[57] Tracey Silveira-Zaldivara, Guil Özerk, and Kamil Özerk. 2021. Developing social skills and social competence in children with autism. *Lnternational Electron. J. Elem. Educ.* 13, 3 (March 2021), 341–363.

[58] Y A Smith, E Hong, and C Presson. 2000. Normative and validation studies of the Nine-hole Peg Test with children. *Percept. Mot. Skills* 90, 3 Pt 1 (June 2000), 823–843.

[59] Tina L Stanton-Chapman and Martha E Snell. 2011. Promoting turn-taking skills in preschool children with disabilities: The effects of a peer-based social communication intervention. *Early Child. Res. Q.* 26, 3 (July 2011), 303–319.

[60] Algemene Gegevens Vragenlijst. 2012. Social Responsiveness Scale (SRS-). https://www.kenniscentrum-kjp.nl/wp-content/uploads/2020/03/Social-Responsiveness-Scale-SRS-2.pdf. Accessed: 2023-9-15.

[61] Lisa Walsh, Sinéad Lydon, and Olive Healy. 2014. Employment and Vocational Skills Among Individuals with Autism Spectrum Disorder: Predictors, Impact, and Interventions. *Review Journal of Autism and Developmental Disorders* 1, 4 (Dec. 2014), 266–275.

[62] David Wechsler. [n. d.]. Wechsler Intelligence Scale for Children, Fourth Edition. *https://psycnet.apa.org › doiLandinghttps://psycnet.apa.org › doiLanding* ([n. d.]).

[63] Rina R Wehbe, Terence Dickson, Anastasia Kuzminykh, Lennart E Nacke, and Edward Lank. 2020. Personal Space in Play: Physical and Digital Boundaries in Large-Display Cooperative and Competitive Games. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–14.

[64] Henry M Wellman and David Liu. 2004. Scaling of theory-of-mind tasks. *Child Dev.* 75, 2 (March 2004), 523–541.

[65] Cara Wilson, Margot Brereton, Bernd Ploderer, and Laurianne Sitbon. 2019. Co-Design Beyond Words: 'Moments of Interaction' with Minimally-Verbal Children on the Autism Spectrum. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19, Paper 21)*. Association for Computing Machinery, New York, NY, USA, 1–15.

[66] Robert H Wozniak, Nina B Leezenbaum, Jessie B Northrup, Kelsey L West, and Jana M Iverson. 2017. The development of autism spectrum disorders: variability and causal complexity. *Wiley Interdiscip. Rev. Cogn. Sci.* 8, 1-2 (Jan. 2017).

[67] Qin Wu, Rao Xu, Yuantong Liu, Danielle Lottridge, and Suranga Nanayakkara. 2022. Players and Performance: Opportunities for Social Interaction with Augmented Tabletop Games at Centres for Children with Autism. *Proc. ACM Hum.-Comput. Interact.* 6, ISS (Nov. 2022), 161–184.

[68] Qin Wu, Chenmei Yu, Yanjun Chen, Jiayu Yao, Xi Wu, Xiaolan Peng, and Teng Han. 2020. Squeeze the Ball: Designing an Interactive Playground towards Aiding Social Activities of Children with Low-Function Autism. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–14.

[69] Lian Zhang, Qiang Fu, Amy Swanson, Amy Weitlauf, Zachary Warren, and Nilanjan Sarkar. 2018. Design and Evaluation of a Collaborative Virtual Environment (CoMove) for Autism Spectrum Disorder Intervention. *ACM Trans. Access. Comput.* 11, 2 (June 2018), 1–22.

[70] Gaoxia Zhu, Su Cai, Yuying Ma, and Enrui Liu. 2015. A Series of Leap Motion-Based Matching Games for Enhancing the Fine Motor Skills of Children with Autism. In *2015 IEEE 15th International Conference on Advanced Learning Technologies*. 430–431.

A APPENDIX A

A.1 Participants' Demographics

	Experiment	Control	Group Differences
N	20	12	N/A
Boy (Girl)	19 (1)	10 (2)	N/A
Age in years (SD)	5.58 (0.54)	5.46 (0.64)	t(30) = .559, p = .580
Full scale IQ (FSIQ)	120.25 (15.31)	113.12 (18.27)	t(30) = 1.179,p = .248
Verbal IQ (VIQ)	118.00 (13.17)	112.75 (20.39)	t(30) = 0.887,p = .382

Table 1: Demographics of the participants in the experiment and control groups.

A.2 Hand-Eye Coordination and Anticipation Coding Table and References

Score	Description of the behavior
0	There was no hand or body movement toward the ball in anticipation
1	The child moved hand in anticipation but no contact with the ball
2	The child moved hand in anticipation and touched the ball, but did not catch it
3	The child caught the ball successfully

Table 2: Coding schema for the maturity of children's Eye-hand coordination and anticipation ability.

B APPENDIX B

Open-ended oral survey questions for parents. Please note that: (1) various follow-up questions were asked based on each parents' responses and (2) the sequences of asking these questions were vary from parents to parents based on the conversation flow.

(1) Do you agree that StarRescue can enhance children's collaborative abilities, that is, their capacity to achieve shared goals through cooperation? In comparison to other games or traditional intervention methods, what advantages do you think StarRescue offers (or cannot offer) for fostering collaboration?
(2) Do you agree that StarRescue can facilitate communication and interaction among children and others? In comparison to other games or traditional intervention methods, what advantages do you think StarRescue offers (or cannot offer) for facilitate communication?
(3) How would you rate the level of difficulty of StarRescue compared to other games or traditional intervention methods? What are some other games or traditional intervention methods that you are referring to?
(4) How would you assess the level of enjoyment provided by StarRescue compared to other games or traditional intervention methods? What are some other games or traditional intervention methods that you are referring to?
(5) Would you be willing to play StarRescue with children or recommend it to other kids?
(6) Apart from the intervention experiment, do children tend to bring up or discuss this game?
(7) Would you like to share any additional comments or suggestions regarding this game?