ABSTRACT
Restricted and repetitive behaviors (RRBs) are a core symptom and an early marker of autism. RRBs often impede children’s play skills and become a barrier to learning and social adaptation. Despite technologies for detecting certain forms of RRB, assessment and intervention for RRB still heavily relies on professional experience and effort. Guided Play is a technology that uses instrumented games or toys as a platform to understand children’s play behavior and facilitate behavioral intervention during play. This paper presents the design and implementation of the technology, as well as an evaluation on 6 children with autism. The results show that children with RRBs in real-life activities also exhibit similar patterns in a similar digital activity, and that digital coaching can reduce RRBs by expanding children’s play skill repertoire and promoting symbolic play.

ACM Classification Keywords
K.4.2 Social Issues: Assistive technologies for persons with disabilities

Author Keywords
Children; ASD; Autism; Health; Behavior sensing; Intervention; Play; Pretend play; Symbolic play; Object play; Evaluation; Assistive technology.

INTRODUCTION
Human behavior is complicated and dynamic. It is shaped by genetics and environment, triggered by emotions, thoughts, and desires. Some physical and mental disorders may also manifest themselves in behavior. One example is autism spectrum disorder (ASD), or autism, a neurodevelopmental disorder that affects an individual’s social communication, sensory processing, and behavior. Children with autism often behave in ways that are unusual and baffling to others. Some of them move their body repetitively (Stereotypical Motor Motions, SMMs), some have narrowed interests (e.g., in wheels), and some insist on ritualistic routines (insistence on sameness). These are called Restricted and Repetitive Behaviors (RRBs), also known as stereotypical behaviors, one of the core symptoms and diagnostic criteria of autism [1]. Although RRBs may serve some functional purposes such as coping with anxiety, they often impede children’s play skills and become a barrier to their learning and social adaptation [24].

Many parents start to worry about their children’s development when they see behaviors like hand-flapping; after all, RRBs are one of the earliest signs that can predict later diagnosis of autism [29]. Unfortunately, rigorous professional testing is required to diagnose autism, mainly by the examination of behavior. Partially because of the lack of awareness and medical resources, in spite of the fact that autism can be reliably diagnosed as early as 18 months of age, on average the actual diagnosis in the US happens at approximately 4 years of age [5].

To treat autism including RRB, a young child is recommended to receive at least 20 hours per week of intervention using methods such as Applied Behavior Analysis (ABA) [39]. Such intensive treatments have increased the costs of autism by several-fold over the last decade [3]. Hence, there has been a great interest in technology that can complement assessment and treatment by a human provider.

The current generation of children is growing up in an unprecedentedly digitally dense world. Children’s medical records are digital, they talk to Siri, and learn STEM (science, technology, engineering, and mathematics) subjects using smart toys. We envision a future where machines will provide us with even more insights into our children’s development and become a valuable assistant in their lives. We have witnessed this trend in the recent decade in numerous iPad apps for autism [18], smart toys [20], wearables [14], and therapeutic robots [6].

Smart sensing technologies are now available to recognize certain types of RRB. For example, accelerometers [27, 14, 40, 17] and video cameras [9, 13] have been used to recognize and measure SMMs and provide data for identifying markers of autism and for assessing treatment progress. Despite existing sensing technologies, more subtle forms of RRB such as narrowed interests and insistence on sameness are underinvestigated. In addition, few technologies can facilitate or even implement behavioral interventions.

We attempt to push forward the state of technology to not only recognizing and assessing RRBs, but also to delivering behavioral interventions within the context of play. This pa-
per introduces Guided Play\(^1\), one of the first digital solutions that can collect data about children’s play behavior and provide behavioral interventions using principles of ABA [4]. Guided Play utilizes everyday objects such as digital games and smart toys as a platform to analyze a child’s play behavior, and coaches the child to play in a more functional and symbolic way, a fundamental step towards improvements in other developmental areas such as social skills.

In this paper, we first describe the design of Guided Play and the features of the Guided Play Blocks app, a digital building block game in the Guided Play family. We then present the results from a clinical trial at an autism treatment organization on 6 children with autism. Finally, we discuss the implications and limitations of the current technology, and outlines directions for future work.

BACKGROUND AND RELATED WORK

Our work is related to children’s play skills development and computerized behavior assessment and intervention.

Developmental Stages of Object Play

Object play is an early-emerging skill that correlates with a child’s development. It is generally developed in several stages. Sensory-motor or exploratory play refers to manipulation of objects in order to gain information about the physical world (e.g., mouthing a block). Functional play is the use of an object in ways that are socially and functionally intended (e.g., stacking blocks) [38]. Symbolic or pretend play involves treating an object or situation as if it is something else (e.g., making a block rocket and launching it) [25].

Symbolic play also happens at several stages. At lower stages, children may use one object to represent another (representational play) and take simple actions of pretend play, e.g., talking on a toy phone. At higher stages, they engage in pretend play that involves multiple objects, assigned roles, plot, and planning. They may also combine several objects to create a new object using sophisticated mechanisms [10].

Children play with objects such as building blocks in many ways, including throwing, stacking, connecting, and creating patterns with them. By the age of four, children start to use blocks representationally [19], namely they use blocks to make familiar objects, such as cars, houses, etc.

Object Play in Children with Autism

Since autism was first defined as a disorder, Restricted and Repetitive Behaviors (RRBs) have been included as a core symptom. Restrictedness refers to narrowed and inflexible interests, as well as insistence on same environment. Repetitiveness often manifests itself in rhythmic motor movements, repetitive speech, routines, and rituals [24].

RRB also shows up in children’s play. In the absence of intervention, children with autism often play in inappropriate ways. Particularly, most of them struggle with symbolic play and are preoccupied with sensory stimulating activities [25]. They may play only with a limited selection of objects, in a limited number of ways, and have less functional and symbolic play behavior [1]. Expanding behavior repertoire and increasing diversity and variability are believed to be beneficial for improving symbolic play skills [41].

Automatic RRB Assessment

A large body of existing studies of RRB detection and measurement focuses on Stereotypical Motor Movements (SMMs), given that body motions often emit significant acceleration and visual signals recognizable by sensors.

One such line of research uses wearable accelerometers to measure body movements, and machine learning algorithms to identify SMM [14, 27, 13, 33]. Another approach is to track body motion in videos and use computer vision to detect motion patterns [12, 31, 9] as well as other behavioral elements such as facial expression, eye gaze, engagement, etc [32, 16].

In addition to SMMs, children with ASD often exhibit unusual and prolonged object exploratory behaviors during play [7, 29]. Several smart toys with embedded wireless sensors have been created [40, 17] to track and identify stereotypical body movements in play such as shaking, spinning, banging, etc.

Our work is different in that it addresses a subtle form of RRB not fully supported by existing technology – insistence on sameness and provides a platform for integrating data from multiple sources.

RRB Interventions

In autism treatment practice, Applied Behavior Analysis (ABA) is the most frequently used method. Several studies have examined the effectiveness of ABA procedures for reducing RRBs. Wolfe et al. [41] suggested that building response repertoires, prompting variability, and reinforcing variability are effective for reducing RRBs in individuals with autism. Miller and Neuringer [26] found that percentile schedule is able to significantly increase response variability in a computer game. Similar to using digital building blocks, Napolitano et al. [28] successfully increased response diversity of children with autism in playing with physical building blocks using a lag reinforcement schedule.

There are also many studies attempting to complement human interventions using digital technology. For example, the introduction of the iPad has greatly increased the accessibility of digital applications and has ignited an excitement in the autism community. Hourcade [18] is among the earliest that studied the effectiveness of tablet apps for improving social interaction in children with autism. Many apps and systems have been created to address various aspects of autism, such as social skills [8], speech [15], sensory processing [30], play skills [20], etc.

Guided Play can be considered as a digital therapeutic system that aims to reduce RRBs and improve play skills using principles of ABA.

DESIGN PRINCIPLES

The goal of Guided Play is to create a platform that can understand children’s play behavior and improve play skills, such

\(^1\)The Guided Play app is available at [URL removed for double-blind review]
As representational and symbolic play, Guided Play embodies the following design principles.

**Ubiquitous.** RRB manifests itself in many areas, such as body motion, special interests, language, and object manipulation. One of the challenges of understanding behavior is to capture its context, e.g., antecedent and consequence. It is therefore necessary to collect behavioral data about a child’s life continuously and ubiquitously. Unlike previous studies that used different approaches separately, Guided Play aims to create a platform that can integrate data from multiple sources and using multiple interaction models (e.g., digital and tangible).

**Extensible.** Guided Play is an open platform. It provides a data integration and analysis service via an open API. Third-party components can connect to the service, upload data in designated formats, and receive synthesized results. The data is time synchronized to facilitate data integration from multiple sources. The platform also provides an SDK (Software Development Kit) that can be integrated into existing systems (e.g., digital games) for data retrieval.

**Intervention.** Guided Play follows the principles of many proven behavioral intervention techniques, such as building response repertoire, prompting, and differential reinforcement [41]. It attempts to implement them in a child-friendly and sensory-rich fashion. With its automatic data collection and intervention, parents can have deeper insights into their child’s play skills and interests so that they can update their strategies for interacting with their child. Behavioral therapists can use this technology to maintain a digital portfolio of their patients’ behavior and complement their behavioral intervention.

**ARCHITECTURE**

Guided Play is an intelligent agent behind a game or smart toy that transforms it into a platform for behavioral assessment and intervention. We call such a game or toy **apparatus.** As illustrated by Figure 1, Guided Play inserts an **instrument** into the apparatus as a sensing and communication plug-in. An instrument can be a wireless sensor embedded in a smart toy similar to those used in Westeyn et al. [40] or a software component running inside a computer game.

Inspired by the principles of ABA, Guided Play embodies the following steps in shaping players’ behavior:

- **Observing.** The instrument continuously reads and sends behavioral data to **Guided Play Coach**, the decision making component of the system, which then measures various aspects of the behavior, including complexity, diversity, and size of repertoire.

- **Detecting.** When a RRB is detected based on pre-defined cutoff criteria, Guided Play Coach via the instrument gives instructions to the apparatus to start behavior coaching.

- **Joining.** The apparatus will then play **with** the child (prompting next move, taking turns, etc.) instead of being played by the child (without any intervention of the child’s behavior).

- **Guiding.** Following the best practices of RRB intervention [41], Guided Play Coach instructs the apparatus to expand the player’s behavior repertoire by modeling new responses and to vary his/her responses by giving prompts.

- **Reinforcing.** When desired behavior is observed, the apparatus will deliver individualized reinforcements to promote and maintain the behavior.

**GUIDED PLAY BLOCKS**

As the first activity in the Guided Play family, we created Guided Play Blocks, a digital building block game on the iPad. The main goal of Guided Play Blocks is to improve children’s representational and symbolic play skills in building blocks.

We chose a block game for several reasons. First, the level of block play is highly related to the stages of child development, including spatial cognition, fine-motor skills, classification, math, and social skills [37]. Second, blocks have been successfully used in previous studies of RRB interventions [28]. From a technical point of view, block play is structured, and computers can capture and analyze the dynamics of block play behavior.

Figure 2 gives a screenshot of the Guided Play Blocks running on an iPad. On the left-hand side, there is a **block panel** supplying blocks in various colors. All blocks are of the same size and shape at the initial level. Higher levels provide blocks of different sizes and shapes. A player can move the blocks one at a time from the block panel to the center **canvas** using...
a drag-and-drop gesture. The supply of blocks is unlimited. When a block is placed on the canvas, it is aligned with an assistive grid automatically to accommodate young children’s inaccurate gestures, and a new one is be created to fill the empty spot left on the block panel. Sound and animation effects accompany the game actions to make the block play more engaging.

**Behavior Modeling and Analysis**

We use a graph-based formalism to model dynamic building operations and static block structures. Each block movement will generate an operation graph representing the operation and a structure graph as a snapshot of the block structure updated by the operation. A (node-edge) graph is a set of nodes connected by edges. As an example, Figure 3a shows a block structure and its corresponding structure graph after the ith operation. Figure 3b represents the i+1-th operation that transforms structure i into structure i+1 shown in Figure 3c.

In the graphs, a node always represents a block. In an operation graph, e.g., the one shown in Figure 3b, the edge indicates the operation, annotated by its action (“*”: new block, “+”: connect to, “-”: disconnect from, etc.) and orientation (e.g., block 4 is connected to block 1 on the right). In a structure graph, an edge represents the connection between two blocks. The orientation of an edge is denoted as a degree in the polar coordinate system. For example, in Figure 3a, the edge from node 3 to node 2 indicates that node 3 is connected to node 2 from the top (270 degrees).

The system maintains a history of all the operations and structure snapshots. Based on the graph model, the system can independently compute the following metrics.

**Variability** consists of operational variability and structural variability. Operational variability measures the variability of block operations (e.g., stacking on top, connecting to left, disconnecting, etc.). Similar to Napolitano et al. [28], it is measured as the average difference between the operation graphs within a given time window. Structural variability is the variability of completed block constructions. It is calculated as the average difference between the structure graphs within a given time window.

**Complexity** measures the complicatedness of the blocks and their relationships. It is based on the following block complexity metrics that are indicative of developmental stages [34, 36]: dimensions (height and width), size (number of blocks and connections), symmetry (reflectional and rotational), dimensionality (0D, 1D, 2D, and 3D), and stage complexity (line, cross, enclosure, and bridge).

**Compliance with guidance** captures how well a child follows the guidance of the system. It is calculated as the structural similarity between an instructed construction and the actual construction the child has made.

**Structural categories.** We are interested in the categories of the constructions a child has made. The system groups similar block structures into clusters using a hierarchical clustering algorithm [21] and allows adult users to validate and modify the clusters. Each cluster then represents a structural category of the constructions.

The automatically generated structural categories also help with manual analysis.

**Symbolic categories.** Based on the structural categories, adult users can identify the symbolic meanings of the constructions and form symbolic categories (e.g., cars, animals, etc), which give an overview of behavior repertoire and symbolic play skills of a child.

**Diversity** measures the range of different block constructions. It can be calculated by the number of distinct construction instances (e.g., five different cars) as well as the number of symbolic categories of the constructions (e.g., cars and planes).

**Behavior Shaping**

Guided Play works in two modes. The free play mode allows a player to build anything using the blocks without interventions from the system. The system quietly tracks a player’s interactions with the game, while only providing sound and visual feedback to block movements in order to keep the player engaged. The feedback is not differential, i.e., not contingent on how the block is moved, what is built, or the selection of size, color, and shape.

The system may decide to switch to the guided play mode based on pre-defined criteria, such as when the player’s percentage of symbolic play falls below a certain threshold. Caregivers and professionals may manually override the system’s decision. In the guided play mode, the system uses the following proven methods [41] to influence a player’s behavior.

- **Building repertoire.** Limited response repertoires is one of the reasons for RRB [41]. Guided Play attempts to expand a player’s construction diversity by modeling similar but different responses (new objects to build). It maintains a library of constructions collected from all the players and grouped by age. Based on a child’s current repertoire of block constructions, it finds a construction in the library that is closest to yet different from the child’s constructions as a suggested object to build next.

- **Prompting.** In addition to the prompts from caregivers and therapists, the system can independently prompt the player to build a new structure using background and shape outlines, as shown in Figure 4. The background is relevant to the theme of the target object or object category. The outline prompts the player to complete the construction by...
“filling in the blanks”. When the system detects that the player is not following the prompt, it may generate a next move for the player by adding a missing block to the outline until the player comes back to the game or the construction is completed.

- **Reinforcing.** In ABA, differential reinforcement refers to reinforcing (rewarding) desired behavior and not reinforcing undesired behavior. Studies have shown that differential reinforcement reliably promotes desired behaviors in children with autism, including those in block play [41]. The system issues rewards at different levels according to users’ compliance with the guidance using sound and visual effects. The rewards can be personalized using preference testing [28]. Timing of the rewards can be controlled by reinforcement schedules, such as percentile schedule [11].

**EVALUATION**
We evaluated Guided Play Blocks on 6 children with autism at an autism treatment organization. This section presents the study and its results.

**Research Questions**
We want to know whether digital sensing and coaching by Guided Play can capture and influence stereotypical play behavior in children with autism. Our hypotheses are: (H1) a child with RRBs in a real-life activity may also exhibit similar patterns in a digital replica of the activity, and (H2) interventions performed in the digital activity may have impact on his/her behavior in real-life. We decided to test these hypotheses by answering the following research questions.

RQ1: For a child with RRBs in real-life, does his/her behavior in Guided Play show similar patterns (for H1)?

RQ2: Do digital behavioral interventions provided by Guided Play significantly change children’s behavior in the app (for H2)?

RQ3: If the answer to RQ2 is true, do those effects generalize back to the real-world (for H2)?

**Participants**
We recruited 6 children (ages 4 to 5, 5 male) from the patients receiving ABA service at an autism treatment organization. They all met the following inclusion criteria: ages between 2 and 5, having a diagnosis of autism, being able to use the iPad properly, and having RRBs at least in playing with physical building blocks and similar toys. Their names are anonymized in this paper. A research assistant (referred to as experimenter thereafter) with a background in ABA from this organization interacted with the participants.

**Materials**
We conducted all experimental sessions in a room with minimal distractions at a site of the organization. The physical materials used in the sessions was an Apple iPad Air 2 (with a 9.7 inch screen and 2048 x 1536 resolution). Guided Play Blocks version 1.1 was installed on those devices. We only used the app at the first level at which the blocks are all square, of the same size, and comes in 7 colors. Considering our young participants’ short attention spans, the experimenter also brought some favorable activities into the room. They were put aside during the sessions and were used only when the participants were taking breaks.

**Pilot Study**
We conducted a pilot study with 2 children (3 and 4 years old, both male) at a different site of the same organization before the formal study in order to test the usability of the system and to refine study design. The data from the pilot study are not included in this paper.

**Procedure**
Similar to previous studies of RRB interventions [23, 22], our experiment utilizes a multiple baseline across subject design, in which the participants transitioned from a baseline phase (free play mode) to a treatment phase (guided play mode) in staggered temporal order. Because of the design, instead of letting the system decide when guided play kicks in, we moved a participant to the treatment phase once we confirmed that the data in the baseline phase had stabilized, i.e., no new patterns were emerging. Such a design enables us to conclude that changes in data are due to the treatment rather than to random factors.

The experimenter conducted one session per week for each participant over consecutive weeks (except in a few times instances when the participants were not available). Each session lasted for up to one hour with intermittent breaks between the trials. Four participants had 6 sessions and two had 5 sessions.

**Baseline**
In the baseline phase, the experimenter gave a participant an iPad with the Guided Play Blocks app running in the free play mode, in which the feedback from the system is not differential. The experimenter first demonstrated the app by moving some blocks to the canvas randomly and then prompted the participant to “build something”. The experimenter praised the participant constantly when he/she stayed within the app but did not give specific instructions on what to build. When a construction was completed or the canvas became full, the experimenter cleared the canvas by long-pressing the “Next” button and prompted the participant to continue with a new construction. We considered a construction completed when
the participant expressed so verbally or physically (e.g., pushing the iPad away) or when the participant was no longer engaged with the app.

The participants were allowed to take breaks upon request or when disengaged. During the breaks, the participant could play with their favorite activities and were brought back to the study after approximately 5 minutes.

**Treatment**

The treatment phase used the Guided Play app in the guided play mode. The experimenter first demonstrated the use of the app to the participant by selecting a category, selecting an target object under the category, constructing the object by filling out the outline, and receiving a completion reward. The experimenter then asked the participant to follow the same procedure based on his/her own choice of target object. We did not let the system decide target objects because we wanted the participants to have the same choices and to be able to choose their most favored target objects. The system used in the study provides 6 categories of constructions (animal, transportation, toy, etc.), each having 6 objects. Using the same protocol as used in the baseline phase, once a construction was completed, the experimenter prompted the participant to continue this process until a break was needed.

Unlike the baseline phase in which the system did not provide differential reinforcements, in the treatment phase, the system reinforced behaviors that were compliant with the outline using a 3-level reinforcement schedule.

Level 1: sound for connecting blocks.

Level 2: sound and visual effects for placing blocks into the outline.

Level 3: animation relevant to the target object for completing the construction (e.g., a flying plane in the case shown by Figure 4).

**Return to baseline**

In order to test generalizability of the learned skills, the two most compliant participants were placed back to the baseline condition after the treatment. Both of them refused to play in the free play mode and demanded the guided play mode, presumably because of the stronger reinforcements in the guided play mode. We did not continue the sessions due to their resistance. For the same reason, we did not have a chance to test generalizability to physical building blocks.

**Treatment Target and Measurement**

We collect both quantitative and qualitative data to answer our research questions. RQ1 will be answered by the data in the baseline, and RQ2 can be answered by the changes in data between the two phases.

The independent variable is the presence of guided play in the conditions, i.e., free play v.s. guided play. The treatment target is to promote representational and symbolic play skills. The improvements can be reflected by the following dependent variables: (1) Percentage of representational constructions shows the stages of the play, i.e., how much of play is representational and symbolic. (2) Number of representational constructions and (3) total number of symbolic categories including non-representational indicate the diversity of the block play behavior. (4) Finally, compliance with guidance tells us how effectively this system influenced behavior.

Although the system collects other types of behavior data such as color, size, and shape of blocks, we only consider the structures of completed constructions in this study.

**Results**

In this section, we present the results of our qualitative and quantitative analysis of the data.

**Baseline**

We first analyze the symbolic meanings of the constructions in the baseline using the following steps. By running a clustering of the constructions and manually validating and modifying the clusters, we obtain structural categories of each participant’s constructions. Then, we identify the symbolic meanings of the clusters and label them. Finally, we identify the stage of object play based on the following criteria:

- **Representational**: the construction resembles in shape a real-life object.
- **Functional**: the blocks are used to form patterns not resembling real-life objects.
- **Sensory-motor**: the construction does not form a recognizable pattern or object. We assume that such behaviors are motivated by the sensory simulations offered by the system, confirmed by the observations of the experimenter.

Figure 5 summarizes the stages of the participants’ constructions in the baseline. In general, only 28% constructions are representational, 9% are functional, and 63% are sensory-motor. Representational constructions are mostly letters, numbers, and geometric shapes. Some participants seemed to treat the canvas as a puzzle board and attempted to fill up the entire space. These behaviors are labeled as functional play. The majority of sensory-motor constructions are random placement of blocks.
Based on the distribution of the stages, we can identify 3 behavior profiles. David, Daniel, and John were able to make many recognizable and meaningful objects. Kimberley mainly enjoyed filling up the entire canvas. Jason and Mike mostly placed the blocks randomly.

Figures 6, 7 and 8 illustrate the constructions of 3 representatives, one for each of the 3 profiles. Daniel’s constructions are divided into 4 clusters, of which three clusters are representational objects (i.e., labeled “letter”, “tree”, and “rectangle”) and one is all random placement. It is apparent that he has a strong interest in letters (and numbers, as shown by the data in the treatment phase), which are almost 70% of all the 48 constructions he has made in this phase. His preoccupied action with the alphabet, as captured by this digital world matches his interest in real-life. Kimberley’s constructions are dominated by space filling, while Jason seemed to have no idea of what to build without external assistance.

Figures 9 and 10 compare the number of representational constructions and the number of symbolic categories in both phases. The participants made far fewer recognizable objects in the baseline, and the objects all fall into narrowed categories, such as letters and simple geometric shapes.

To summarize, the play behaviors in the baseline contain more sensory-motor play than functional and symbolic play behaviors, and the diversity of the constructions in terms of symbolic meaning and structural category is low. These findings corroborate previous observations of play behavior in the autism
population [25]. It is apparent that all the participants showed behavior patterns typical in this population and consistent with their real-life behaviors. We therefore conclude that RQ1 is true and hypothesis H1 is confirmed.

Treatment
We perform the same analysis of symbolic meanings of the constructions in the treatment phase. As shown by Figure 11, among all the constructions, 87% are representational, 1% are functional, and 13% are sensory-motor.

We then look at the changes in percentage of symbolic play at the individual level. As depicted by Figure 12, all participants started to make significantly more symbolic constructions right after transitioning to the treatment phase. This indicates that the changes are caused by the introduction of guided play. Figure 13 illustrates a sample of John’s constructions to demonstrate this effect.

We also notice a drop of percentage of symbolic play after the second treatment session for some participants. According to the experimenter, the participants usually tried most of their favorite target objects in the first treatment session and started to feel bored when we asked them to repeat the trials.

As shown by figures 9 and 10, the participants made significantly more representational constructions in the treatment phase, and the symbolic meanings of the constructions cover a wide range.

Finally, we calculate compliance with guidance of the participants. Table 1 shows the result. Most of them were able to understand the intention of the guidance and follow the instructions well. One exception is Daniel, who still made a majority of constructions based on his own narrowed interest in letters and numbers. It seems that the reinforcements were not motivating enough to compete with his interests.

We conclude that Guided Play significantly increased the amount of representational play as well as the size and diversity of the response repertoire. The evidence confirms that RQ2 is true.

Table 1: Compliance with guidance.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>David</td>
<td>0.76</td>
</tr>
<tr>
<td>Daniel</td>
<td>0.33</td>
</tr>
<tr>
<td>John</td>
<td>0.91</td>
</tr>
<tr>
<td>Jason</td>
<td>0.99</td>
</tr>
<tr>
<td>Kimberly</td>
<td>0.68</td>
</tr>
<tr>
<td>Mike</td>
<td>0.76</td>
</tr>
</tbody>
</table>

Mean 0.74
SD 0.23

Discussion
This section discusses the implications of our work, particularly focusing on digital technology for behavior assessment and intervention. We also review the limitations of current technology and threats to the validity of the study results.

Implications
There have been many digital systems addressing the challenges faced by individuals with autism. In particular, smart sensing technology is now able to detect and assess certain types of stereotypical behavior in real-world. Our work shows that children’s stereotypical behavior in the digital world resembles that in real-life. This may inspire research into other types of behavior assessment using digital technology, which could lead to a more comprehensive understanding of children’s behavior.

Another important finding is that Guided Play replicates the effects of behaviors intervention traditionally provided by human professionals. This opens the doors to many application scenarios, including clinical behavior therapy, school education, and educational toys. Other related populations, such as those with dementia, may also benefit from such a technology for cognitive assessment and training [2, 35].

Limitations and Threats to Validity
Human behavior is so complex and diverse, even in playing with toys as simple as building blocks. There are many information channels that are not collected by our system, such as verbal response, emotion, and body movement. The system still requires adult observation and supervision to fully understand and scaffold play. In the experiment, for example, the experimenter often needed to take notes on what happened outside the system and give additional prompts to the participants. We do not consider this as a major limitation because individuals with autism often need life-long support, and digital systems can still be a valuable complement. This limitation also calls for an integrated approach that can combine multiple types of data, which is exactly why Guided Play is a open platform. We also hope that future systems will include...
more activities like Guided Play Blocks, especially tangible smart objects such as SPRING [20], to support the various play needs of children.

Unfortunately we were not able to test whether the effects seen in the digital activity generalize to other activities. Considering that skill generalization in the autism population is difficult even with human professionals, we believe that our work still contributes to the area of technical innovations for behavior coaching, as it replicates the effects of interventions provided by human therapists. Given the short duration of the study, we also do not know whether the effects will continue to exist over a longer timeframe. Future work should attempt to answer these questions.

A threat to the validity of our study results is manual coding of symbolic meaning based on static block structures. Although we follow a common definition of object play stages, our coding may not truly represent the intentions of the play, because aspects of meaning might be present beyond the visual characteristics of the constructions. For example, we can not claim that placing a single block on the canvas is always meaningless. We have seen one participant performing a movie theme using two blocks to be the characters. The play was still stereotypical (he did this many times, and his language was scripted) but was dramatic and full of pretend play. This threat is mitigated by the observations of the experimenter that most participants did not perform any observable pretend play during their sensory-motor play. In addition, we are confident that our claims of the effectiveness of the system are valid regarding increasing behavior diversity and repertoire, which are fundamental steps towards improving symbolic play skills.

Another related threat to validity lies in our assumption that when we use shape outlines to teach block construction, the participants understand the symbolic meanings behind filling out an outline. There is a possibility that they followed the guidance only to seek sensory stimulation. As researchers in child development still debate over what pretend play is, it is difficult to conclude how much of their seemingly symbolic play is truly symbolic. This threat can be alleviated by the observation that when the participants chose their favorite target
We have presented a study of the effectiveness of Guided Play for increasing behavior repertoire and diversity, and consequently reducing stereotypical behavior and improving symbolic play skills in children with autism. The design and features of the system are inspired by the principles of behavioral interventions, and Guided Play utilizes children’s interests in digital systems to motivate learning and behavior change. Guided Play successfully replicates the effects of RRB intervention conducted by professionals, confirming its potential for other types of behavioral intervention. The technology also creates a platform for long-term and large-scale data collection about children’s behavior and development, which may lead to autism prediction and diagnosis based on big data and machine intelligence, as well as data-driven parenting and education.

Directions of future work include creating more activities, especially tangible smart objects, for the Guided Play family. For further evaluation of the technology, we would test the generalizability of the effects to physical activities as well as its long-term effectiveness. A comparative study between the autistic and neurotypical populations is also in our interest.

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