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Children's Spatial Play With a Block Building Touchscreen Application

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Spatial play contributes to children's early development of spatial skills, which are foundational for STEM achievement. A growing genre of spatial play for young children is digital block play. We asked how 3- to 6-year-old children (N = 117) engaged in digital block play and whether children's age, gender, and spatial skills were correlated with this play. Children completed a spatial skills assessment and played a popular digital block play app, *Toca Blocks*. We developed a coding scheme that measured children's play behaviors in the app, and reliably detected individual differences in this play. Children actively manipulated the digital blocks, and there were differences in their block play by age and gender. However, children's spatial skills were not associated with their play in the app. The present work shows that digital block play supports play behaviors similar to those supported by physical blocks, but whether and how digital block play facilitates spatial learning is still unknown. The results are discussed in terms of potential ways to implement digital spatial play apps that might engage children's spatial skills and support their spatial and STEM learning.

Keywords: apps, spatial play, touchscreen media, spatial skills, digital games

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INTRODUCTION

Spatial skills are important for STEM learning, even from a young age. For example, there is a strong association between spatial skills and mathematics performance, a critical foundation of many STEM topics (e.g., Lubinski and Benbow, 1992; Casey et al., 2008; Mix and Cheng, 2012; Verdine et al., 2014a,c). The connection between spatial skills and mathematics potentially begins as early as infancy (Gallistel and Gelman, 1992), perhaps due to a shared common neural code between space and number within the intraparietal sulcus (McCrink and Opfer, 2014; Hawes and Ansari, 2020). Spatial skills also play a specific role in intellectual creativity in STEM (Kell et al., 2013) and if and how STEM learners use external spatial representations, such as maps, models, diagrams, graphs, and sketches, during problem solving (Uttal et al., 2013; Mix, 2019). Finally, there is emerging evidence (although still preliminary), including well-controlled experiments, that training spatial skills may lead to gains in STEM interest, achievement, and retention (e.g., Sorby et al., 2013; Cheng and Mix, 2014).

One experience that contributes to children's spatial skill development is their *spatial play,* such as play with blocks, puzzles, and board games (Caldera et al., 1999; Siegler and Ramani, 2008; Levine et al., 2012; Verdine et al., 2014c; Jirout and Newcombe, 2015). Spatial play facilitates children's spatial thinking and creates opportunities for them to practice their spatial skills. When children engage in spatial play, they often must rotate and rearrange toys, which results in visual changes to object orientations. The opportunity for children to notice the spatial changes that they physically create promotes spatial thinking (Wakefield et al., 2019). Moreover, the frequency of children's spatial play is predictive of their spatial skills (Levine et al., 2012; Verdine et al., 2014a; Jirout and Newcombe, 2015). There is now substantial evidence that spatial play can contribute both to spatial development and to the development of relevant STEM skills (e.g., Gunderson et al., 2012).

In recent years the opportunities for children's spatial play have been transformed through the tremendous growth in digital apps. Ten years ago, touchscreens and tablets were novelties; now they are nearly ubiquitous and are available for very young children (Rideout, 2017). Consequently, spatial games that were once reserved for children's play with physical materials, such as blocks and puzzles, now occur on touchscreen devices in the form of *digital spatial play*. Early evidence suggests a positive association between children's spatial skills and their digital spatial play (Polinsky et al., 2021) and that these skills can be strengthened through children's play on touchscreen devices (Bower et al., 2021). Additionally, digital spatial play is also a culturally relevant part of young children's everyday lives and is a growing context for children's play (Gee, 2003; Flynn et al., 2019). Therefore, we must also examine *how* children play with these apps.

In this paper, we focus on how children engage in one form of digital spatial play, digital block play. There is increasing excitement for and growth of digital block building games, and some are designed for young children, including 3-year-olds. One example of a digital block play touchscreen game, or app, is Minecraft by Microsoft, which has sold over 100 million copies (Sarkar, 2017) and is most often played by children who are five and older. Another example is Toca Blocks by Toca Boca, which is currently ranked 40th in paid education apps in the Apple App Store and is designed for children ages four plus. Most block play apps are completely open-ended and unstructured; children can build whatever they choose without the constraints of defined levels or time limits.

We focus on digital block play because physical block play has been studied extensively (Reifel and Greenfield, 1982; Brosnan, 1998; Caldera et al., 1999; Stiles and Stern, 2001; Casey et al., 2008; Bower et al., 2020). Blocks are appropriate for children across the preschool years (Casey et al., 2008) and facilitate several different types of play that include both structured and unstructured building activities (Bower et al., 2020). When children play with physical blocks, they can stack, rotate, and arrange them in a variety of different ways. Some children use similarly shaped blocks to create the same relation exclusively and consecutively, for example, by only stacking blocks vertically on top of each other to create a tall tower (Stiles and Stern, 2001). Other children may use a wide range of blocks and produce several different types of spatial relations by building tall towers upward and using blocks of different dimensions to create bridges and structures with more depth (Stiles and Stern, 2001). These different ways of building with blocks allow children to notice and experience the outcomes of different types of spatial manipulations that they physically create. Because research on physical block play shows an association between children's block building behaviors and their characteristics (Goodson, 1982; Reifel, 1984; Caldera et al., 1999; Casey et al., 2008; Verdine et al., 2017), in this study we consider how children engage in digital block play and the role of children's age, gender, and spatial skills in this play.

First, children's age is associated with their block play behaviors. In general, the complexity and sophistication of the structures that children build during block play develops during early childhood. Children begin their block building by using a single block that represents one object and then transition toward building horizontal, floor-like, two-dimensional structures. By 3 and 4 years of age, children build three-dimensional structures, which primarily include vertical towers, and between four and seven, begin to incorporate complex structures, such as bridges and arches, into their building (Goodson, 1982; Reifel, 1984; Casey et al., 2008). This development is associated with children's evolving motor abilities, their emergent understanding of part-whole relationships, and their growing spatial abilities (Reifel and Greenfield, 1982, 1983; Gura, 1992; Caldera et al., 1999; Casey and Bobb, 2003).

Additionally, boys and girls may build with blocks in different ways, with boys tending to build more complex structures than girls (Goodfader, 1982; Sluss, 2002). This difference may be due to early socialized gendered toy preferences (Caldera et al., 1989; Campbell et al., 2002; Cherney, 2018; Coyle and Liben, 2020), and the fact that construction toys are often marketed toward and considered made for boys (Cherney et al., 2003; Cherney and Voyer, 2010; LoBue and DeLoache, 2011; Coyle and Liben, 2020). Consequently, male children may have more block play experiences than their female peers, which supports them in building complex structures (Doyle et al., 2012; Nazareth et al., 2013; Pruden et al., 2019). Beyond complexity, gender differences sometimes emerge in the types of structures children build. For example, Ramani et al. (2014) found that girls included more symbolic features of buildings, such as windows and doors, in their constructions than boys did. However, it is important to note that not all studies of children's block play consistently show gender differences (e.g., Verdine et al., 2014c).

Finally, children's spatial skills are associated with what and how they build with physical blocks. By the time children are in preschool there is variability in the strength of children's spatial skills (Newcombe and Frick, 2010; Levine et al., 2012). Moreover, those children with stronger spatial skills tend to build more complex structures than their peers (Brosnan, 1998; Verdine et al., 2014c). For example, Caldera et al. (1999) observed children's free play with blocks, and measured the complexity of their building process, such as the types of block placements, the adjustments children made to their constructions, and how frequently they rotated their blocks. The results revealed a significant association between the complexity of children's building approach and their spatial visualization skills. Additionally, in a more recent study, in which children were asked to replicate a model of a block construction, Bower et al. (2020) demonstrated an association between 3-year-olds block building behaviors and strategies and their spatial skills.

As age, gender, and spatial skills play a role in what and how children build with physical blocks, they may also play an important role in children's digital block play. However, a question remains about the unique features of the digital technology and whether children have different experiences when they engage with digital blocks in comparison to those they have when playing with physical blocks (Lee et al., 2018; Worsley and Bar-El, 2020).

In some ways, digital features may augment children's block play. For example, digital block play apps provide children with an endless number of blocks, allowing children to build without the limitation of quantity. Additionally, during digital block play children have more options for the types of block structures, arrangements, and patterns they can create (Lee et al., 2018) because their built structures do not have to comply with the rules of physics. For example, when playing with digital blocks children can defy gravity and build structures that lack solid foundations but will not crumble. Finally, in digital block play games, children can easily navigate through their environment and change their perspectives on the screen. Sometimes this navigation is carried out with the use of avatars, digital characters, who can stand on top of blocks, explore the digital world, and easily spin around. Other apps simply make it possible for children to use their fingers on the screen to rotate the digital environment and even to take on a birds-eye point of view (Worsley and Bar-El, 2020).

However, some of the unique features of digital technology may also hinder children's block play. Specifically, children may be limited in the ways they can manipulate the blocks as the blocks are within a two-dimensional medium. The design of some apps simulates a three-dimensional depth, which allows children to change their perspectives to see all sides of the blocks or environment. However, even with that simulation of depth the blocks are being manipulated on a two-dimensional screen. Without the physical three-dimensionality, digital blocks may not create realistic depth cues when stacked and may not give children the same tactical cues needed to develop spatial relations.

These differences across the physical and digital mediums lead to the two aims of this paper. The first aim was to examine how children engaged in digital block play and to investigate the different patterns of this play. The second aim was to explore whether and how children's age, gender, and spatial skills were associated with their digital block play. In addition, we explored the influence of the potential covariate of prior media experience on children's digital block play because it has been shown to impact children's touchscreen play in past research (Aladé and Nathanson, 2016). Children between the ages of three and six, were asked to play with a commercially available block building touchscreen application called Toca Blocks, by Toca Boca (Toca Blocks, 2017). This app was chosen due to its popularity (it is the first block building app, on the Top Paid iPad Kids Apps list created by Apple), making it a prototypical example of a block building app for children of this age group. Therefore, we believe a focus on how children play with this app could provide insight into the spatial skills children practice during block play.

MATERIALS AND METHODS

Participants

The participants were 117, 3- to 6-year-old children (M = 4.88 years, SD = 1.19, 50.4% females)[1]. Children were recruited from a large laboratory database of families from the greater Chicago area who had expressed interest in participating in research in response to emails, phone calls, and other advertisements. Parents indicated their children's race and ethnic background: 71% Caucasian, non-Hispanic, 6% Asian, 4% Black or African American, and 13% indicated multiracial. Additionally, parents recorded their highest level of education: 2.7% completed some college, 33% held a college degree, 3% had completed some of their post graduate education, 45% held a master's degree, and 12% held a Ph.D. or a professional degree. Children received a book and a tee-shirt as a thank you gift. Additionally, data from 14 children (M_{age} = 4.4, 43% females) was discarded due to refusal to complete the task, and data from 2 children (6.9 and 6.2 years, both male) was discarded due to a screen recording failure.

Spatial Skills Measures

To our knowledge, there is currently not a spatial skills assessment that spans the 3- to 6-year-old age range; therefore, the assessments we used to measure children's spatial skills differed for younger and older children. The 3- and 4-year-old participants completed the 2D and 3D Test of Spatial Assembly (TOSA) (Verdine et al., 2014c), whereas the 5- and 6-year-old participants completed the Children's Mental Transformation Task (CMTT) (Ehrlich et al., 2006).

Test of Spatial Assembly

The TOSA is a match-to-sample spatial assembly task (Verdine et al., 2014c). Children completed 14 trials, including two practice trials, in which they created a copy of a sample arrangement of geometric shapes for the 2D trials and a copy of interlocking blocks for the 3D trials (**Figure 1**). The stimuli for this assessment were created based on the Test of Spatial Assembly (TOSA) Instruction Manual (Verdine and Golinkoff, 2017). For each 2D trial, children are provided an 8.5-inch by 10.5-inch magnetic white board, on which there is a 2.25-inch by 2.25-inch laminated picture of the sample geometric arrangement placed on the left side of the board, and the corresponding cut out magnetic foam shapes, randomly dispersed behind a black line drawn down the right side of the board. Children used these magnetic foam pieces to create a copy of the sample arrangement displayed in the picture on the white board. Similarly, for each 3D TOSA trial, children are provided a glued together sample arrangement of interlocking LEGO Duplo Blocks, and the corresponding free LEGO Duplo Blocks that they could use to recreate the sample arrangement. The order of both the 2D and 3D TOSA trials are fixed beginning with a training trial and become progressively more difficult with each trial.

[1]The spatial abilities data of the 3- and 4-year-old children (n = 51), was previously published in Polinsky et al. (2021) paper. However, this publication did not include data on the 5- and 6-year-old children or on any children's play with Toca Blocks.

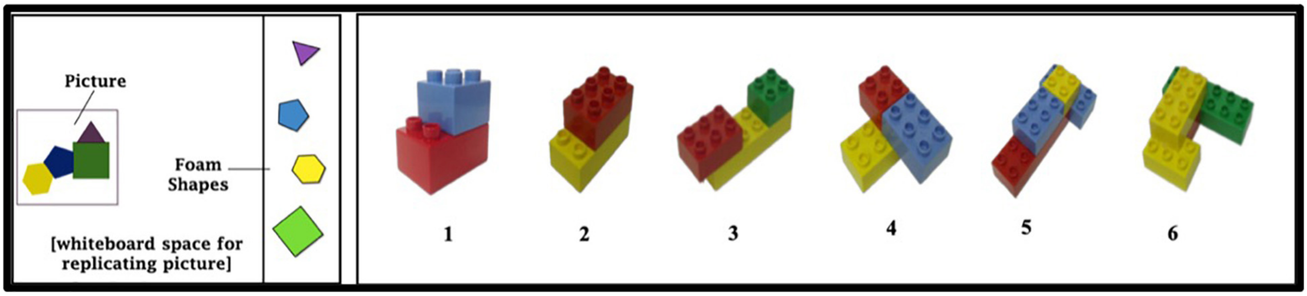

FIGURE 1 | The left side of the figure is a schematic of one trial of the 2D TOSA. The right side of the figure includes the block constructions used for each 3D TOSA trial. The number below the construction indicates on which trial each construction was used (Verdine and Golinkoff, 2017).

Both the 2D and 3D TOSAs begin with a practice trial, in which the experimenter showed the child a target arrangement and said, "See my model/picture and see my blocks/pieces. I am going to make my blocks/pieces look just like my model/picture." Then the experimenter moved their blocks or pieces into an incorrect arrangement, and asked the child, "Does this look like my model/picture?" When the child declared that the arrangement was incorrect, the experimenter repeated this routine a second time, again placing the blocks/pieces into the incorrect arrangement. After the child declared for a second time that the arrangement was incorrect, the experimenter finally created an accurate arrangement. Then, the experimenter asked the child, "Can you make your blocks/pieces look just like the model/picture?" and passed them the practice blocks or pieces and the practice model or picture. Once the child correctly completed the practice trial, the experimenter moved on to the latter trials. At the beginning of each trial the experimenter said, "Can you make these blocks/pieces look just like this model/picture," and then passed the model and blocks or whiteboard to the child. The target designs remained visible throughout each respective trial, and feedback was not provided. Trials were not timed; they ended when children indicated to the researcher that they had completed their geometric arrangement or block construction. Children's answers were recorded by the experimenter, who took a photograph of each arrangement created by the child at the end of the experimental session. Each photograph was taken with a digital camera from the same height and angle for each trial. These photographs were used for later coding by trained researchers.

Scoring

The 2D and 3D TOSA were scored using the coding scheme used by Verdine et al. (2014b,c). The 2D TOSA trials received a score based on how closely the child's geometric arrangement matched the model. For every trial, each shape was compared to the model and was coded based on its accuracy (0 or 1) of three spatial relations: *horizontal and vertical direction*, the placement of the shape on the whiteboard, *adjacent pieces*, next to which other shapes the shape being scored was placed, and *relative position*, the placement of the shape being scored in relation to the central shape of the arrangement. The points for each shape across all 2D trials were summed for a maximum of 73 points, which was then transformed into a *z*-score. One researcher independently coded all the 2D TOSAs. To check reliability, a second researcher coded 20% of the 2D TOSAs, resulting in a Cohen's kappa of 0.97. In the current study, the 2D TOSA was reliable, $a = 0.79$.

The 3D TOSA trials were scored in a similar manner to the 2D trials using the Verdine et al. (2014b,c) coding scheme. Each block of every trial was compared to the model and received an accuracy score (0 or 1) for its placement regarding three spatial relations: *vertical location*, a block's placement above or below other blocks, *rotation*, the orientation of each block, and *translation*, the placement of the block in the correct location within the model. The points for each block across all 3D trials were summed for a maximum of 46 points, which was then transformed into a *z*-score. One researcher independently coded all the 3D TOSAs. To check reliability, a second researcher coded 20% of the 2D TOSAs, resulting in a Cohen's kappa of 0.90. In the current study, the 3D TOSA did not have high reliability, $a = 0.552$[2]. Younger children's spatial abilities scores were created by averaging each child's z-score for the 2D and 3D trials.

Children's Mental Transformation Task

Five- and six-year-old participants completed the CMTT, a multiple-choice spatial skills assessment that has been used to assess spatial skills in young children in past research (Ehrlich et al., 2006). Children are shown a target picture of a 2-dimensional shape that is divided and separated into two halves on the vertical line of symmetry (Ehrlich et al., 2006). These halves are rotated and translated apart and placed on their own full piece of paper in a flip book. While the target is still visible, children are shown four whole shape choices that the two target pieces could make if put together (**Figure 2**). The four shape choices are all on the same piece of paper and contain three foils and one correct answer. Children are then asked to choose which shape would be created by putting together the two target pieces. The CMTT has 32 trials, and each trial is one of four different types: horizontal translation, diagonal translation, horizontal rotation, and diagonal rotation. On the first trial of the CMTT the experimenter tells the child, "Look at these pieces. Look at these pictures. If you put the pieces together, they will make one of the

[2]Despite the low reliability of the 3D TOSA, the findings do not change when we remove it from the analysis. Therefore, we maintain children's 3D TOSA score as an element of our measure of younger children's spatial abilities.

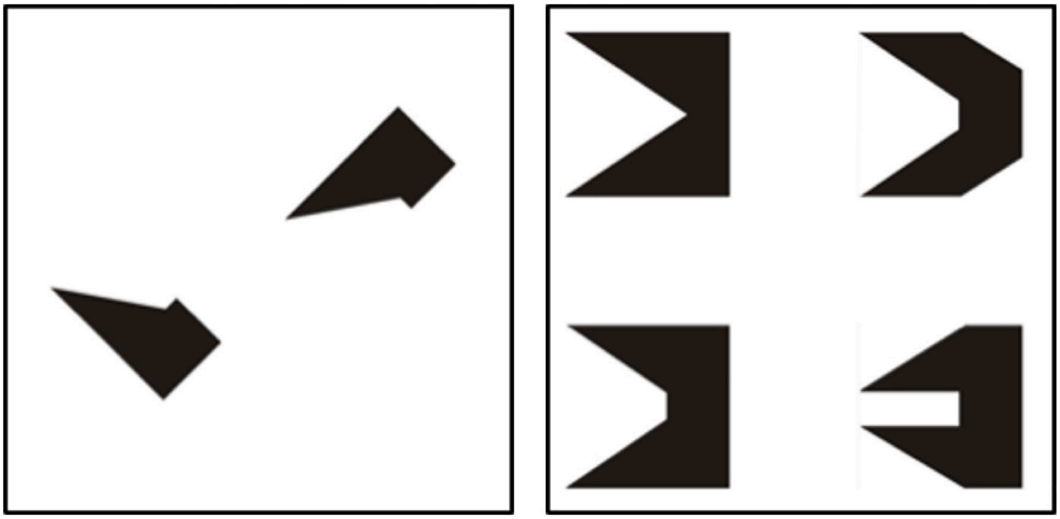

FIGURE 2 | A sample item of the Children's Mental Transformation Task (Ehrlich et al., 2006).

pictures. Point to the picture the pieces make." For all subsequent trials, the experimenter asks the child to, "Point to the picture the pieces make." Children's choices for each trial were recorded by the experimenter. The number of trials in which children chose the correct shape were summed and divided by the total number of trials to create a proportion correct score for each child. In the current study the CMTT was reliable, $a = 0.74$.

Prior Media Experience Survey

Parents completed a survey on their children's prior media experience on an iPad. The media usage and attitudes questions were based on a survey used by Sheehan et al. (2018). This survey yielded two measures of media use: (1) amount of time the child spent using media yesterday and (2) children's age of first exposure to media. First, parents reported the amount of time that their child spent using the computer, internet, video game devices, smartphones, tablets, eReaders, and voice control systems the previous day. Second, parents indicated children's earliest age of exposure to smartphones/tablets, video calling, videos, and smartphone and tablet applications. Parents chose the age range, below 9 months to between 5- and 6-years of age, in which their child's earliest exposure to each media occurred, resulting in an age of first exposure to tablets variable.

Touchscreen Game

Toca Blocks (2017) is a touchscreen game for children 4-years-old and older. The game can be downloaded from the Apple App Store or from Google Play. Toca Blocks does not include any levels or stated goals and instead allows children to build and explore freely using a variety of blocks. Toca Blocks is set in a landscape that includes green grass and an endless sky, which sometimes displays features resembling daytime and sometimes displays features resembling nighttime. The virtual environment includes a wide range of different colored blocks, which children can place throughout the landscape. Children can use the blocks in several ways. First, they can place blocks throughout the landscapes to create patterns and/or build two dimensional structures. Second, they can change the colors of the blocks by layering them on top of one another. Third, children can remove blocks from structures that were pre-designed to create pathways or rooms. In addition, the game had a variety of other props that children could use with the blocks, such as furniture, balloons, and fruits and vegetables. Children could use three avatars to engage with the structures they created and the objects in the environment. These avatars could run, jump, and dance, and could also destroy and remove blocks that were on their path. Beyond avatars, the game provided children with a variety of tools they could use to explore and manipulate the world. These tools included a digital scroll wheel that children could use to change their view of the landscape, a pencil that could color large spaces with blocks, and a chomping avatar that destroyed unwanted blocks. See **Figure 3** for a visual of the game's features. Finally, there are no rules in Toca Blocks, so children are free to engage with the game as they choose.

Procedure

The experiment was video recorded with consent from the children's parents and assent from the child. Children participated in the study in a quiet testing room in a lab space on a Midwestern campus with a trained researcher. First, children completed their age group's respective spatial skills assessment. Next, all children played Toca Blocks on an iPad for 7 min, as this time period was long enough to capture variation in game play while maintaining children's attention within the longer study session and was similar to the time allotted for game play in other studies (Polinsky et al., 2021). A timer was set at the beginning of the game. Before beginning the game, every child was provided the same instructions developed for the study.

> "Let's play the game Toca Blocks. Have you ever played Toca Blocks before? Ok great! I can show you how. In this game you can

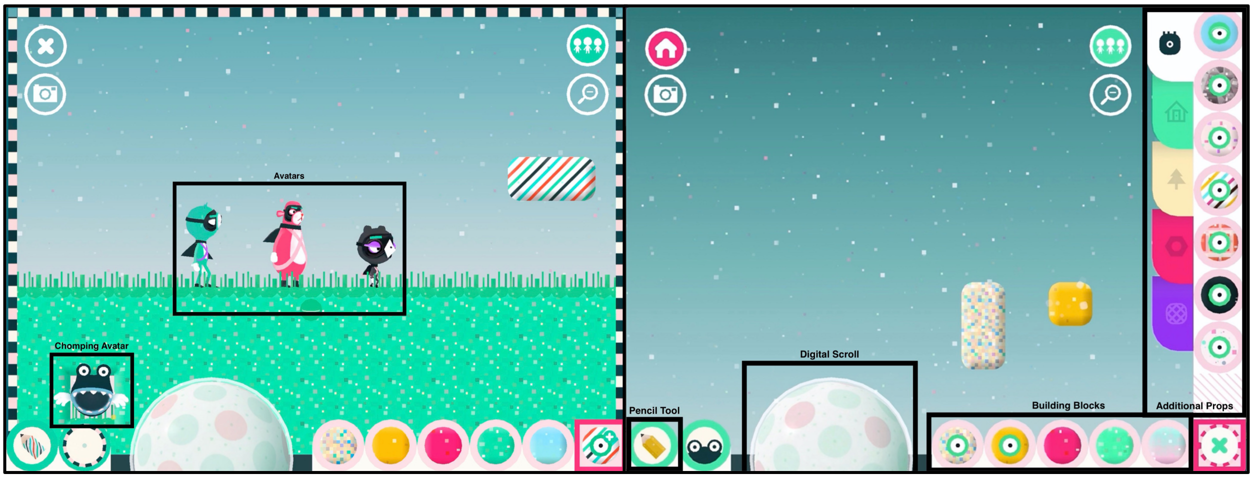

FIGURE 3 | The left side of the figure showcases the avatars with which children can play. The right side of the figure showcases the tools available for children to use to build structures and explore the environment.

build and explore, there are no right or wrong answers. See down here (point to blocks on bottom right of screen), there are blocks. You can drag the blocks up to the grass and build with them. To make the blocks change you can put one on top of the other. You can build anything you want, sort of like regular blocks. Then you see down here (point to avatars), there are all of these characters. You can drag them up here so they explore the world you build. If you press this button (point to circle triangle button) the character will move. Do you want to give it a try?"

During the game children's performance was recorded using the Softin Technology Co., Ltd. Screen Recorder application on the iPad.

Touchscreen Game Coding

We created a coding scheme to capture children's Toca Blocks play behaviors from screen recordings of them playing the game (see **Table 1** for more description). This coding scheme was based on research that coded children's block play behaviors (Ramani et al., 2014) and play during digital games (Marsh et al., 2016).

To adapt these coding schemes for our purposes we held a series of consensus meetings between the first three authors to establish codes that captured the observed behaviors. At the first meeting the researchers reviewed the screen recordings together and discussed and identified global play behaviors. Through these discussions the group came to a consensus on three main categories of game play behaviors: (1) object play, (2) avatar play, and (3) perspective changes. These behaviors are described in detail below. Next, we coded a set of videos using those codes. In a second coding meeting we analyzed differences in the three main types of behaviors and created a coding scheme to better capture observations. This analysis resulted in classifying the three main types of behaviors into subcategories: *strategic*, appearing direct and systematic, or *exploratory*, appearing unstructured. These behaviors were notable because they appeared to parallel pre-existing hierarchies of the types of children's play ranging from entirely goal-directed and systematic to completely unstructured and open-ended (Zosh et al., 2018). In the third step, we coded a subset using the more detailed coding reaching consensus that all observed behaviors were captured by our coding scheme. In the final phase we conducted moment-by-moment coding of the screen recordings using Datavyu (Datavyu Team, 2014).

To establish inter-rater reliability, two researchers coded 20% of the touchscreen play recordings, which resulted in an ICC > 0.82, indicating good reliability. Intraclass correlations are the most appropriate reliability measure for coding continuous data because they account for similarity and proximity (Shrout and Fleiss, 1979; Syed and Nelson, 2015). ICCs greater than or equal to 0.70 are considered acceptable reliability levels (Ostrov and Hart, 2012). The same two trained researchers split the remaining screen recordings and coded every child's behavior, resulting in a set of continuous codes for each child. From this coding, we created a variable that represents proporion of time that each type of behavior occurred. This variable was calculated by dividing the total amount of time in seconds for each behavior by the total amount of time children played. See **Figure 4** for proportion of time children spent in each play behavior.

Object Play

Object play was coded when children engaged with the on-screen building blocks or other available props, such as miniature furniture or balloons. We coded two subcategories of object play, a strategic subcategory and an exploratory subcategory. The strategic subcategory was *Object Play Construction* and was coded when children used the building blocks to create structures. These structures needed to include at least two blocks to be coded as construction because one block can be randomly placed without revealing intention to build. This category of play is the most like play with tangible building blocks, even though the virtual blocks can be used in ways that defy physical properties (e.g., floating in space or removing blocks from foundations without consequence). On average, children engaged in Object Play Construction for 21% of their play time. The exploratory

TABLE 1 | The coding scheme used to code children's Toca Blocks play.

	Code	Code subcategory	Description
	No move	Not applicable	No changes are made to the screen for a period of 6 s or longer.
Object play	Object play exploration	Exploratory	The child tests out different block and object functions by layering several blocks on top of each other, exploring how the side panel objects interact with the blocks or avatar, and sporadically placing individual blocks.
	Object play construction	Strategic	The child builds a tower or creates a pattern by placing two or more blocks on, next to, on top of, or under each other.
Avatar play	Avatar exploration	Exploratory	The child moves their avatar through the environment. This includes the avatar hopping, walking, sliding, skipping, or dancing on any material without creating change to the space.
	Avatar manipulation	Strategic	The child uses an avatar to move or destroy any object.
Perspective changes	Exploratory perspective changes	Exploratory	The child changes the view of the environment by scrolling in a non-linear or circular direction.
	Strategic perspective changes	Strategic	The child changes the view of the environment and immediately engages with the available materials in that new location.

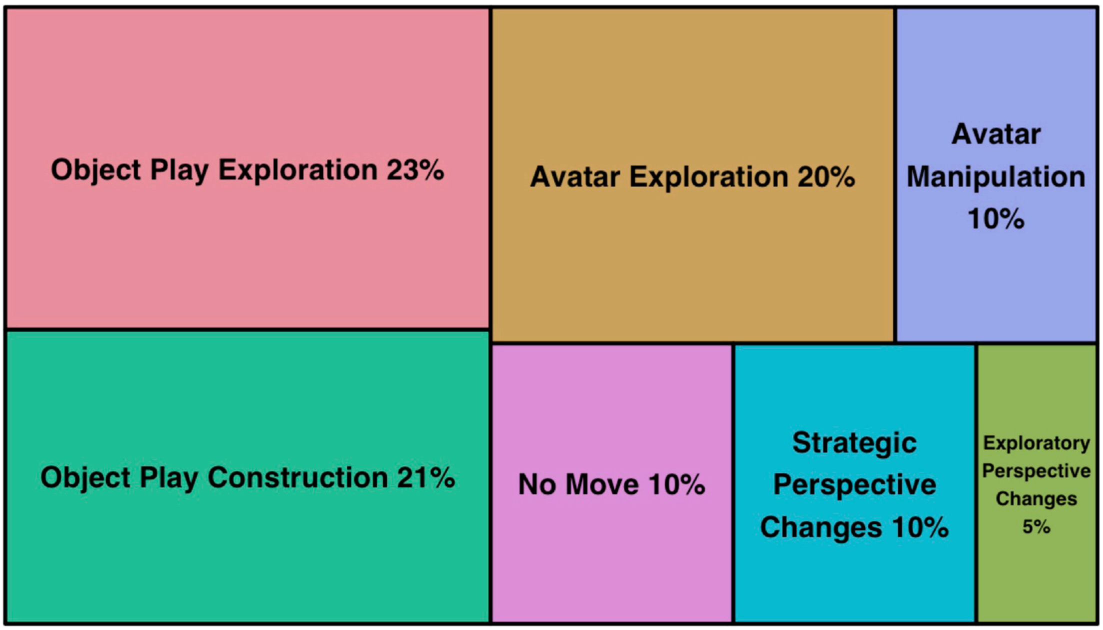

FIGURE 4 | Treemap illustrating the percentage of Toca Blocks play time children on average spent engaging in each play behavior.

subcategory was *Object Play Exploration* and was coded when children engaged with the blocks in ways that weren't building. For example, children could change block colors and features by layering the blocks on top of one another without creating a visible structure or pattern. Object Play Exploration could also include singular blocks being placed on the screen not in relation to a structure or block pieces, for example, blocks placed in mid-air not near other blocks. This category of play was unique to the digital medium as children cannot easily change the color or features of tangible blocks. On average, children spent 23% of their play time engaging in Object Play Exploration.

Avatar Play

Avatar play was coded when children engaged with any of the on-screen characters. This code included when children moved the avatar through the game or used the avatar for deleting objects from the space. A strategic subcategory of avatar play was coded as well as an exploratory subcategory of avatar play. The strategic subcategory was *Avatar Manipulation* and was coded when the child used the avatars to remove, destroy, or erase objects in the environment. For example, the game includes an avatar who removes blocks by chomping them with their mouth and a child might manipulate this avatar to "erase" an existing building or even part of the ground in order to create an underground room. This code was subcategorized as strategic as the child manipulated the avatar to do something purposeful in the environment, often related to building or destroying structures. On average, children spent 10% of their play time engaging in Avatar Manipulation. The exploratory subcategory was *Avatar Exploration* and was coded when the child used the avatar to move through the game space seemingly without purpose besides exploring. For example, when we observed this behavior, a child might have their avatar walk around the environment, jumping over encountered objects, but not interacting with them in any way. On average, children engaged in Avatar Exploration for 20% of their play time.

Perspective Changes

Perspective changes were play behaviors in which children adjusted their view on the screen. For example, this behavior would occur when a child zoomed in or out, scrolled up or down, and navigated horizontally. We coded a strategic subcategory and an exploratory subcategory of perspective changes. The strategic subcategory was *Strategic Perspective Changes*, which were coded when a child manipulated the screen to have a new point of view and then moved or placed a block or an avatar within this new perspective. For a behavior to be coded this way it must have been immediately followed by either an object play or avatar play behavior. This code also included behaviors where children adjusted their view momentarily and returned immediately to a landmark on the screen, or a previously seen location or structure. For example, a child might have a view of the on-screen environment that includes a tower that they just built. Then they might manipulate their view of the screen by scrolling toward the right, such that the tower is out of view, and then immediately scroll back to the tower. This code was strategic because the changes to the on-screen environment appeared precise and predictable. On average, children made Strategic Perspective Changes for 10% of their play time. The exploratory subcategory was *Exploratory Perspective Changes*, which were behaviors that manipulated the screen to have a new point of view, but then did not result in an immediate object play or avatar play behavior. For example, having the block or avatar spinning around in a circle or continuously scrolling through the screen. On average, children spent 5% of their play time making Exploratory Perspective Changes.

No Move

We also included a No Move code, with which we marked all time periods greater than 6 seconds in which children were not engaging with the on-screen environment. This lapse in engagement with the game may have been a result of the child considering their next move, speaking with the researcher, or focusing their attention elsewhere. Coding this category allowed us to determine the time children spent actively engaged with the game. On average children's play behaviors were coded as No Move for 10% of play time.

RESULTS

Data were analyzed using the Psych Package in R (Revelle, 2019). In line with our first aim, to examine how children engaged in digital block play, we present descriptive statistics of behaviors and results from a One-Way ANOVA that examined differences in the proportion of time children spent engaging in each play behavior. Then, we report findings from a cluster analysis that grouped children based on their play behaviors. Finally, to examine our second aim, to explore whether and how children's age, gender, and spatial abilities were associated with their digital block play, we tested our potential covariates of prior media experience and used correlational analyses and t-tests to test the relationships between children's characteristics and their game play.

TABLE 2 | Means and standard deviations of the proportion of Toca Blocks play time children spent engaging in each play behavior.

Play behavior	*M*	*SD*	Minimum	Maximum
Object play construction	0.21	0.17	0	0.77
Object play exploration	0.23	0.17	0.02	0.83
Avatar exploration	0.20	0.17	0	0.67
Avatar manipulation	0.10	0.14	0	0.80
Strategic perspective changes	0.10	0.06	0	0.28
Exploratory perspective changes	0.05	0.07	0	0.28
No move	0.10	0.11	0	0.53

TABLE 3 | Means and standard deviations of the proportion of time children spent in each play behavior by cluster.

Play behavior	Object play group		Avatar play group	
	M	*SD*	*M*	*SD*
Object play construction	0.27	0.19	0.13	0.09
Object play exploration	0.33	0.17	0.11	0.06
Avatar exploration	0.11	0.10	0.31	0.18
Avatar manipulation	0.06	0.10	0.15	0.17
Strategic perspective changes	0.09	0.06	0.11	0.05
Exploratory perspective changes	0.05	0.07	0.06	0.07
No move	0.08	0.08	0.14	0.13

Children's Play With Toca Blocks

To address our first aim of investigating how children engaged in digital block play, we examined the proportion of play time children spent in each play behavior (see **Table 2** for means and standard deviations). We used a one-way ANOVA to examine differences between the proportion of play time children spent engaging in each play behavior. The independent variable was play behavior, such as Avatar Exploration or Object Play Construction, and the dependent variable was proportion of play time spent engaging in each behavior. There were significant differences in the overall proportion of time children spent engaging in each play behavior, $F(700) = 26.65$, $p < 0001$. Exploratory *post hoc* analysis with Tukey adjustments revealed that children spent a greater proportion of their time engaging in Object Play Construction, Object Play Exploration, and Avatar Play Exploration than they spent engaging in any other type of play (all p's < 0.001). However, there were no significant differences between the proportion of time children spent engaging in these three behaviors (Object Play Construction, Object Play Exploration, and Avatar Play Exploration) (all p's > 0.5).

To further understand the patterns of children's Toca Blocks play, we investigated if different children tended to use a combination of certain play behaviors. For example, did some

TABLE 4 | Means (and standard deviations) of and age differences in proportion of Toca Blocks play time children spent engaging in each type of play behavior.

	Younger children		Older children		Age	Cohen's
	M	*SD*	*M*	*SD*	Differences	*d*
1. Object play construction	0.23	(0.18)	0.19	(0.15)	*t*(97) = 1.39	0.28
2. Object play exploration	0.23	(0.17)	0.24	(0.17)	*t*(97) = 0.14	0.03
3. Avatar exploration	0.13	(0.12)	0.26	(0.19)	*t*(97) = 4.09**	0.82
4. Avatar manipulation	0.09	(0.12)	0.11	(0.19)	*t*(97) = 0.30	0.82
5. Strategic perspective changes	0.09	(0.05)	0.11	(0.06)	*t*(97) = 1.54	0.31
6. Exploratory perspective changes	0.08	0.08	0.03	0.05	*t*(97) = 3.24*	0.64
7. No move	0.14	(0.12)	0.07	(0.08)	*t*(97) = 3.43**	0.68

*$p < 0.05$, **$p < 0.001$.

TABLE 5 | Means (and standard deviations) of and gender differences in proportion of Toca Blocks play time children spent engaging in each type of play behavior.

	Girls		Boys		Gender	Cohen's
	M	*SD*	*M*	*SD*	Differences	*d*
1. Object play construction	0.24	(0.18)	0.16	(0.15)	*t*(97) = 2.55*	0.52
2. Object play exploration	0.25	(0.17)	0.22	(0.17)	*t*(97) = 0.14	0.74
3. Avatar exploration	0.17	(0.15)	0.23	(0.18)	*t*(97) = 1.95	0.39
4. Avatar manipulation	0.09	(0.12)	0.12	(0.16)	*t*(97) = 1.31	0.26
5. Strategic perspective changes	0.10	(0.05)	0.10	(0.06)	*t*(97) = 0.50	0.10
6. Exploratory perspective changes	0.05	0.06	0.06	0.08	*t*(97) = 0.91	0.08
7. No move	0.11	(0.10)	0.10	(0.11)	*t*(97) = 0.47	0.09

*$p < 0.05$.

children spend most of their time exploring without strategic play? Therefore, we conducted an exploratory cluster analysis using Ward's method to examine the process of children's Toca Blocks play more deeply. Ward's method is most appropriate for quantitative variables, and using a cluster analysis could reveal different styles of children's Toca Blocks play behaviors (Morey et al., 1983; Milligan and Cooper, 1987; Breckenridge, 2000; Phillips and Lonigan, 2009). We entered the proportion of time children spent engaging in each play behavior into our cluster analysis. The gap statistic method (Tibshirani et al., 2001), a technique used for estimating the number of clusters in a data set, yielded three distinct groups. To understand these groups, we first examined the descriptive statistics by cluster of the proportion of time children spent engaging in each play behavior. We found that children in Cluster 1 spent the greatest proportion of play time engaging in Object Play Exploratory, children in Cluster 2 spent the greatest proportion of play time engaging in Object Play Construction, and children in Cluster 3 spent the greatest proportion of their play time engaging in Avatar Play Exploratory. Next, we examined the number of children in each group (Cluster 1: n = 34; Cluster 2: n = 22; Cluster 3: n = 45). Given the large size discrepancy between Cluster 2 and Cluster 3, and that children in both Cluster 1 and Cluster 2 spent the greatest proportion of their play time engaging in a form of object play, we combined Cluster 1 and Cluster 2 into one group of children. Therefore, our cluster analysis led to the creation of two groups of children, an Object Play group (n = 56) and an Avatar Play group (n = 45). **Table 3** shows the proportion of time children spent engaging in each play behavior as a function of these two groups.

Although these clusters provide a picture of how different children played Toca Blocks, t-tests and chi-squared analyses did not reveal any differences in age, gender, and spatial skills between these two groups (all p's > 0.09). Thus, we do not use the clusters in the remaining analyses, which examined our second research aim.

Children's Characteristics and Toca Blocks Play

To address our second aim, we conducted a second set of analyses examining differences in children's play behaviors depending on several different characteristics including age, gender, and spatial skills. We begin this section with preliminary analyses focused on children's prior media experiences as a potential covariate. On average children used digital media for 123.28 min (SD = 153.8) the day prior to the study, and had their first exposure to tablets between 2- and 3-years-old (SD = 1.52). The amount of time children spent engaging with digital media the day prior to the study was not associated with the proportion of play time children spent engaging in each Toca Blocks play behavior (p's > 0.16). Similarly, there were no differences in the proportion of time children spent engaging in any play behaviors based on the age range of their first exposure to tablet devices (p's > 0.10). Therefore, we did not include either measure of prior experience in our analyses.

Developmental Differences in Toca Blocks Play

In our first analysis, we focused on developmental change in children's play behaviors. We used a series of Pearson's correlations to examine the association between the proportion of time children spent in each play behavior and their age in months (see **Table 4** for *r*-values). We found that on average, as age increased, the proportion of time children spent engaging in Exploratory Perspective changes decreased, $r(94) = -0.25$, $p = 0.02$. Additionally, on average, as age increased the proportion of time children spent engaging in Avatar Exploration increased as well, $r(94) = 0.35$, $p < 0.001$. Finally, as age increased the proportion of Toca Blocks play time in which children did not interact with the screen decreased, $t(94) = -0.32$, $p = 0.002$. There were no other significant associations between children's age and their Toca Blocks play behaviors.

Gender Differences in Toca Blocks Play

For our second analysis, we examined if there were gender differences in children's Toca Blocks play. For each play behavior, we ran a *t*-test with gender as the between group variable and the proportion of time spent engaging in that behavior as the dependent variable (see **Table 5** for means by gender and for *t*-tests and respective effect sizes). Results revealed that girls ($M = 0.25$, $SD = 0.17$) spent a greater proportion of their time engaging in Object Play Construction than boys did ($M = 0.16$, $SD = 0.14$), $t(97) = 2.55$, $p = 0.01$.

Spatial Skills Differences in Toca Blocks Play

In our final analysis, we examined the connection between children's spatial skills and their Toca Blocks play. Since younger and older children completed different spatial skills assessments (because of the lack of an appropriate test that spanned the entire age range), we conducted these analyses by age group. For both groups of children, we ran a series of correlations between scores on the spatial skills assessments and the proportion of time children spent engaging in each play behavior (see **Table 6** for all correlations). Our analyses revealed that there was not an association between younger children's spatial skills as measured by the TOSA and the proportion of time they spent engaging in any of the play behaviors, all r's < 0.18, all p's > 0.1. Similarly, we did not find a significant correlation between older children's spatial skills as measured by the CMTT and the proportion of time they spent engaging in any of the play behaviors, all r's < 0.12, all p's > 0.2.

TABLE 6 | Correlations between spatial skill assessment scores and the proportion of play time younger (TOSA scores) and older (CMTT scores) children spent engaging in each type of play behavior.

	TOSA scores	CMTT scores
	r-values	*r*-values
1. Object play construction	0.10	−0.09
2. Object play exploration	0.06	0.16
3. Avatar exploration	0.02	−0.08
4. Avatar manipulation	0.09	−0.08
5. Strategic perspective changes	−0.13	0.26
6. Exploratory perspective changes	−0.08	−0.11
7. No move	−0.25	0.05

DISCUSSION

This study aimed to examine how young children played with a digital block play app, Toca Blocks, and to explore the role of children's characteristics in this play. In pursuit of these aims, we developed a coding scheme that could reliably measure how children played with Toca Blocks. Using this coding scheme, we discovered differences in the proportion of time children engaged in various play behaviors. Additionally, we found that age and gender were associated with some play behaviors, but that spatial skills were not. These findings provide insight into the potential role of digital block play apps in children's spatial skill development, which could have implications for STEM learning.

Measuring Digital Block Play

As digital block play is a growing component of children's early spatial experiences, an important contribution of this study was the development of a coding scheme that provided insight into how children play with these apps. This coding scheme built on well-established methodologies for measuring children's play with physical blocks (e.g., Caldera et al., 1999; Kamii et al., 2004; Casey et al., 2008; Ramani et al., 2014; Bower et al., 2020) and simultaneously accounted for the unique elements of digital technology. For example, in addition to block play behaviors our coding scheme captured children's engagement with the Toca Blocks avatars and with the tools provided for changing perspectives on the screen. Moreover, our coding scheme measured two types of play for each main play behavior category. These subcategories of play behaviors were broadly associated with actions that appeared more exploratory, they did not end with a change to the objects in the environment, or more strategic, the behavior ended with a change to objects in the environment. This breakdown reflects that digital block play apps present children with opportunities to explore the game environment and experiment with objects, in addition to building definitive structures. Therefore, with our coding scheme we could examine how children engaged in an environment designed for block play in ways that may only be supported by the unique digital elements of digital block play apps.

Digital Block Play Behaviors

We found that in comparison to all other play behaviors children spent a greater proportion of their time engaging in Object Play Construction, Object Play Exploration, and Avatar Exploration. Although Toca Blocks is designed for these play behaviors, when children play with the app they are not instructed to play with the blocks or the avatars. Thus, these findings indicate that children interact with blocks in a digital environment, even without instructions.

Children's natural engagement with the blocks and avatars may reflect the strength of the cultural forms of tangible blocks and figurines in engaging children in play regardless of the medium. Cultural forms are elements of a design that tap into a user's pre-existing conventions of how to interact with objects or others in a given situation (Horn, 2018). As the avatars resemble the physical figurines and characters children play with outside of apps, avatars may act as a cultural form that engage children in playing with their character. Additionally, children's engagement in Object Play could be a result of the strength of the cultural form of blocks, even those on a digital device, to involve children in object manipulation. Our finding that digital blocks engage children in block play behaviors without explicit instructions indicates that at a minimum digital block play apps can immerse children in the types of spatial activities, such as block play, that support spatial learning (e.g., Casey et al., 2008).

Additionally, our cluster analysis, intended to understand patterns in children's digital block play, revealed that children tended to spend most of their play time engaging in either Object Play or Avatar Play, as opposed to a combination of them both. Those children who primarily engaged in Object Play tended to stack blocks into towers, place blocks in midair, and layer blocks on top of each other to change their colors. Those children who primarily engaged in Avatar Play tended to use the avatars to move around the world and navigate through the created block structures. However, children did not seem to build structures for the avatars to play in, suggesting that children's play with either objects or avatars does not necessarily lead to play with the other. These findings parallel research on children's block play in the classroom, which demonstrates that when replica play toys, such as cars, trucks, and figurines, are placed in the block building center, children engage in less block building. Trawick-Smith et al. (2017) suggest that replica toys in block building centers simply provide an alternative activity to the block play. Consequently, when children choose to play with replica toys in building centers they are limited in the quantity and quality of building they can simultaneously complete. The current study furthers this past research on physical block play by demonstrating that in the digital medium children do not integrate construction play with their play with figurines.

Although children may spend more time engaging in either Object or Avatar Play, both types of play may individually provide children unique spatial opportunities. Object Play and Avatar Play emphasize one or the other of two kinds of engagement by children that parallel the main categories of spatial skills – those that support object manipulation and those that support representing and navigating environments (Chatterjee, 2008; Newcombe et al., 2013). Object Play more closely resembles object manipulation, as during this play children can manipulate and arrange the blocks and visualize the outcomes of these spatial transformations. Avatar Play more closely resembles navigation, as children use their avatars to explore the world. An important element of children's early spatial skill development is having play experiences that involve object manipulation and having play experiences that involve navigation (Pritulsky et al., 2020). The current study shows that digital block play may be a platform that can engage children in object manipulation and navigation, even if those activities do not occur simultaneously.

Children's Play Behaviors and Their Age, Gender, and Spatial Skills

The second aim of this study was to examine linkages between children's individual characteristics and how they played with digital blocks. First, we found age differences in children's play. Younger children tended to spend a greater proportion of their time engaging in Perspective Change Exploratory behaviors than older children, and older children spent a greater proportion of their play time engaging in Avatar Exploration behaviors than younger children. This increased engagement in avatar play with age reflects the developmental trajectory of children's symbolic understanding of dolls, especially when being used as representations of themselves (DeLoache et al., 1995; Uttal et al., 1998). Children's ability to use dolls as representations of themselves, for example to demonstrate where a sticker was placed on their own body, develops between the ages of two and five (Lytle et al., 2015). This symbolic representation of dolls is challenging for children younger than 5, particularly when the doll is in the two-dimensional form, such as a paper doll. During digital block play, avatars act as two-dimensional dolls that represent the child in the game. Given the developmental trajectory of children's symbolic understanding of dolls, it could be that younger children do not fully comprehend what avatars represent, preventing the young children in our study from engaging in Avatar Exploration as much as the older children.

Moreover, these developmental differences could also be attributed to the types of apps different aged children play with at home, and subsequently the digital play experiences most familiar to them. Research shows that between 4 and 5 years of age there is a sharp increase in the number of children who begin playing the extremely popular game, Minecraft (Mavoa et al., 2018). During Minecraft children explore the game world and build with blocks using an avatar. Accordingly, the older children in our study may have had more experiences using avatars in their play at home, and consequently may have been more drawn to engage with them for exploration during Toca Blocks. However, we did not measure the types of apps with which children play at home.

Additionally, we found gender differences in children's Object Play. Overall, girls tended to engage in Object Play Construction, meaning they built structures, more than boys. This finding parallels past research on gender differences in the types of structures children build during block play. As an example, Ramani et al. (2014) found that while boys and girls spent the same amount of time engaging in block play and built equivalently complex structures, girls included more symbolic features (e.g., a window) of the house structure they were building. Similarly, in the digital medium, girls tend to play Minecraft in Creative mode, where the focus is on creating structures using freely available resources, more than boys, who often play in Survival mode, where they must avoid hostile creatures and spend time collecting resources for building (Mavoa et al., 2018). Together, these findings suggest that during either physical or digital block play girls may focus more on what they are building than boys, but more research is still needed.

Finally, there were no associations between the proportion of time children spent engaging in any Toca Blocks play behaviors and their spatial skills. This null result contrasts with recent research demonstrating a positive connection between children's spatial skills and their performance on other digital spatial play activities (Bower et al., 2021; Polinsky et al., 2021). For example, using a portion of this same sample of children, Polinsky et al. (2021) found a positive correlation between children's performance on the TOSA and their play with two digital puzzle play apps. However, the digital spatial play activities used in prior research differ from Toca Blocks in that they provide children with very specific goals to complete. As play goals can be important for promoting children's spatial thinking (Ferrara et al., 2011), the open-ended and creative nature of Toca Blocks may contribute to our finding that children's spatial skills are not associated with their play behaviors in this app. Additionally, this null finding could also be due to the spatial assessments used in this study. Given the unique affordances of digital block play, such as the ability to defy gravity, it is possible that the TOSA and CMTT, physical spatial skill assessments, could not capture the types of spatial skills children used when engaging in play with Toca Blocks. While this game is unrelated to spatial skills (in this sample) there is still more research needed to understand the role of digital block building apps for young children.

Limitations

A few limitations of this study should be noted. First, children's play was measured by the time spent engaging in certain types of play behaviors as opposed to a more in-depth coding of how children were manipulating objects on the screen. Attention toward how children specifically manipulated the on-screen environment will help reveal children's spatial practices during digital block play. Second, we faced a challenge in finding a pre-existing spatial skill assessment that could reliably measure the spatial skills of children across all age groups in our study. This challenge prevented us from comparing the role of spatial skills in children's Toca Blocks play across all age groups. Moreover, this challenge highlights a need for the development of spatial skills assessments that can be more readily conducted with children of a wide age range. Third, although we accounted for some of children's prior media experiences in our analyses, we did not specifically measure the types of apps with which children play at home. In turn, we cannot make claims about the potential role of the types of children's prior media experiences in their digital block play. Fourth, the study's correlational design prevents us from assessing the directionality and causality between children's individual characteristics and their Toca Blocks play. Fifth, children only played with one digital block play app in this study, even though this is a growing genre of apps for young children. To understand the generalizability of our findings to other apps from the same genre future research must examine children's play with other digital block play apps. Finally, our findings are constrained by the diversity of our sample. Most of the participating children were Caucasian and from relatively high socioeconomic backgrounds. This sample of children may have greater access to touchscreens and apps than other children (Rideout, 2017). These potential differences in experiences could impact how children played Toca Blocks. Therefore, to understand children's digital block building sandbox games, future research must include a broad sample.

Implications for STEM Education and Future Directions

Despite these limitations, our work highlights the potential role of digital block play apps in children's spatial skill development and STEM learning. This study demonstrates a promising finding that apps can successfully engage children in playing with blocks. However, how children engage in this play varies by individual characteristics and a short amount of open-ended play time may not engage children's spatial skills. Nonetheless, playing with digital blocks in an educational setting could capitalize on the opportunities for object manipulation these apps provide and might engage children in using their spatial skills in ways that may lead to spatial learning. We would suggest that when using digital block play apps in classrooms, educators may need to provide students with a clear goal that requires students to build structures that could facilitate their noticing of and considering spatial relations. Second, educators may need to provide play instructions that vary by student, such that boys may need more encouragement to build structures with these blocks, and slightly older children may need support to build with blocks in addition to exploring with their avatars. Finally, it could be that repeated and prolonged Toca Blocks play may be necessary to engage children in using their spatial skills while using this digital block play app. Future research should examine whether Toca Blocks can successfully engage children in using their spatial skills when these suggested conditions are met. This continued research can provide insight into whether digital block play apps can support children's spatial skill development and ultimately their STEM learning.

Conclusion

In conclusion, this study provides a starting point for continued research on digital block play. These digital block play apps are important because they extend the spatial play opportunities available to young children. Spatial play opportunities are one main contributor to children's early spatial skill development. As we found that these digital block play apps can engage children in object manipulation with digital blocks and objects, our research demonstrates that widely available digital block play apps may be an important and fun source for children's spatial learning. However, in the current study we found that children varied in the amount they engaged in block play based on their characteristics and we did not find that this play engaged children's spatial skills. Therefore, continued research must investigate how to design these apps in ways that best support all children's block play and spatial learning. Given the popularity of digital block play apps and the connection between spatial skills and STEM achievement (Lubinski and Benbow, 1992; Casey et al., 2008; Wai et al., 2009; Mix and Cheng, 2012; Uttal and Cohen, 2012; Uttal et al., 2013; Verdine et al., 2014a,c) these apps have the potential to support children's 21st century skills.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Northwestern University Institutional Review Board. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

NP contributed to the conceptualization, study design, data collection, data analysis, interpretation, and writing editing, and revising the manuscript. BL contributed to the data analysis, interpretation, writing, editing, and revising the manuscript. RF contributed to the conceptualization, study design, data analysis, interpretation, editing, and revising the manuscript. EW and DU contributed to the conceptualization, study design, interpretation, and review of the manuscript. All authors contributed to the article and approved the submitted version.

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