The Effects of Video Game Experience and Family Environment on Spatial Memory Development

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How children navigate their world, and what environmental cues they use to build a map of their environment has been extensively studied behaviorally. But, with advances in technology, experimental designs have shifted from real environments to virtual environments. This generates an experimental experience that mimics everyday navigation but is easier to control for any confounding variables. To this extent, it has sparked the question of how video game experience influences individual differences in spatial map formation. The present study addresses how video game exposure impacts spatial memory across 6-12-year-olds and adults. Indices of spatial memory were determined by behavioral measures taken from an object location task (path efficiency, distance error, angular error). Video game experience was collected through a questionnaire that generated scores for active gameplay, virtual layout exposure, and passive watching. An additional factor considered was the effect of family structure on video game experience. This included the amount of family disposable income, parental educational level, and perceived family dynamic. Participants showed a developmental increase in spatial memory accuracy across the age range tested, and participants with greater video game experience demonstrated better spatial memory. However, this was significantly mediated by an interaction with age, whereby only children showed a link between video game experience and spatial memory. While parental education was a significant predictor of video game experience, parental education and perceived family function were not. Additionally, all three measures were non-significant predictors of task performance directly. This study shows that while video game experience is a significant predictor of object location task performance in children, whether social familial factors if any, mediate this relationship are yet to be fully understood.

Introduction:

Spatial memory encompasses how the multi-dimensional structure of our environment is stored in memory and is crucial to how we navigate our world. Through different spatial experiences, we learn the inter-relations between different types of environmental cues to build a cognitive map of our environment. This provides us with spatial knowledge that flexibly guides behavior. For example, at The University of Texas at Austin, when students walk from class at the Visual Arts Center to the Norman Hackerman Building there are different types of environmental information they can use to navigate. UT Tower, despite being in the distance, is a large static environmental cue that provides orientation information of where they are on campus relative to their destination. Additionally, there are more obvious proximal visual landmarks that confirm whether they are getting closer to their destination. For example, whilst walking towards the tower, they will pass the East Mall Fountain, indicating they are halfway up the campus and heading in the correct direction. As they continue walking, they will see The West statue, indicating they have reached Inner Campus Dr. and should turn right and continue to their destination. As spatial knowledge for this environment increases, it provides the ability to not only use more environmental information to make their route more efficient but also enable them to generate novel routes if there is an obstacle in their way.

The notion of a cognitive map is well understood in adults (Buckley et al., 2015; Bullens et al., 2010; Byrne et al., 2007; Doeller et al., 2008a; Epstein & Kanwisher, 1998; Grieves & Jeffery, 2017; Julian et al., 2019; McNaughton et al., 2006; O'Keefe & Dostrovsky, 1971; Spiers & Gilbert, 2015; Tolman, 1948), however, the question becomes how do children build maps of their world? If a child was to navigate the same route, would they necessarily look to the Tower to orient themselves? Or would they just focus on the information close to them as they walk like

The West statue past the East Mall Fountain? These types of questions lead to the investigation of how navigational strategies develop through childhood into adulthood to allow us to create the types of cognitive maps we use to understand where we are positioned in our world.

The Development of Navigational Strategies in Children and Adults

The ability to learn the location of a destination in our everyday environment is fundamental to navigation. Therefore, studying the mechanisms that underpin navigational strategies has been a focus in neuroscience across humans and nonhuman populations. One key aspect of the study of navigational strategy is the use of available, environmental cues that are used to encode a particular location in an environment. Environmental cues can be broken up into two main categories of distal and proximal cues, both thought to rely on two different learning systems. Place learning requires the flexible use of distance and direction of the surrounding environment to learn location (Olton et al., 1979), i.e. distal cues. This type of learning creates an allocentric representation of the environment. Therefore, regardless of where you are placed in the environment, you can identify where you are by finding cues in the distance and understanding your placement relative to them. In contrast, response learning is a rigid navigational strategy, dependent on visible markers to understand the location, reflective of proximal cue use (Olton et al., 1979).

Testing these different navigational strategies was achieved by the experimental design of the Morris Water Maze within the rodent literature (Morris, 1984). The maze consists of a large circular pool in which rats are required to escape from the water by swimming to either a visible, proximal platform or a submerged, distal platform. These studies have shown rats can define their location relative to a proximal cue and use distal cues to orient around the environment (Hamilton et al., 2008, 2009). Proximal and distal cues are thought to rely on two different neural coding systems. It has been shown through rodent experimentation that lesions to the hippocampus result in a loss of place learning, suggesting hippocampal activation reflects learning and remembering of distal cues (Pearce et al., 1998). In contrast, damage to the striatum caused an inability to use proximal cues (Kosaki et al., 2015). Overall, such work has established the use of two dissociable memory systems that are sensitive to different types of environmental cues that facilitate different types of navigational strategies.

The experimental design and hypotheses surrounding the seminal Morris Water Maze has been applied to the human literature. Doeller et. al. (2008a) created a virtual object location task to study adults' ability to learn the locations of objects relative to the boundary and a proximal, visible landmark. Their virtual environment comprised a circular-bounded arena with a proximal intramaze landmark (traffic cone) surrounded by a distal extramaze mountain range Participants learned to remember the location of objects placed in proximity to either a proximal or distal cue (Doeller et al, 2008a,b). Behaviorally, neither performance level or rate of improvement over trials differed significantly between participants' memory for boundary and landmark objects. Nonetheless, imaging results showed that the boundary trials showed greater activation in the hippocampus, while landmark trials showed greater activation in the caudate. This falls in line with the notion of two dissociable neural systems associated with two different navigational strategies in the adult human brain.

While we have an established understanding of spatial navigation in the adult brain, it is also crucial to understand spatial navigation development during childhood. Developmental adaptions of the Morris water maze have been created using large room apparatus mimicking a circular arena (Lehnung et al., 1998), whereby distal cues have been implemented as 2D images on curtains surrounding the room and proximal cues were toys on the ground. Empty paddling pools have also been used to create the circular arena (Bullens et al., 2010; Overman et al., 1996) For example, Bullens et al. (2010) surrounded the empty pool with distal cues consisting of LED arrays or cardboard mountains placed at cardinal directions and one landmark cue of a traffic cone within. Such experimental designs create a tangible environment that children can easily move around in and encourages them to be more engaged with their surroundings and the task at hand. However, the use of a real-life environment does come with limitations. It is possible that the experimental set up (e.g. size of the pool arena) is not large enough. This could lead to the issue that the distal cues are too close and therefore provide information similar to the proximal cues, and participants do not use the distal information provided at all.

As seen in Bullens et al. (2010), the types of objects used as distal cues can also be a problem. Their use of landmark-like objects (e.g. a LED moon or LED star) instead of true distal information (e.g. the mountains used by Doeller et al., 2008a,b) can also confound the type of learning observed. The purpose of using both proximal and distal cues is to be able to use the varying positional and orientation information they respectively provide. However, the amount of orientation information provided from landmark-like objects places around the boundary is limited and can impact the extent to which participants can use a place strategy. Further, all the experiments listed above were carried out in a testing room, which typically has corners. This can lead to the geometry of the room itself being used to navigate as opposed to the environmental cues, also confounding the navigational strategies being tested.

To combat these issues, developmental studies have begun to use virtual object location tasks to test children aged 5-11 years old, and both typically and atypically developed adults (Buckley et al., 2015; Julian et al., 2019; Rodriguez-Andres et al., 2018). Virtual paradigms are becoming increasingly popular as they provide more realistic, larger-scale navigation that allows experimenters to track a wide variety of responses in real-time. Virtual environments can be created to not only mimic everyday navigational movement but also ensure greater experimental control. Experimenters can systematically refine the size of the arenas, and the placement of the environmental cues. For example rendering distal cues to infinity (Doeller et al., 2008a,b), or placing them far enough out of range, maximizes participants' propensity to use the distal cues as experimentally expected. This provides a more systematic way to test the extent to which children of different ages use different environmental cues as a reflection of the development of place and response learning strategies.

As well as the various experimental designs used for testing, different behavioral measures have also been collected. Distance error is defined as the difference between where the goal location is and where the participant remembered the location to be (Bullens et al., 2010; Julian et al., 2019). Angular error is defined as the difference between the angle of a participant's response to the boundary or landmark and the actual angle between the object to the boundary or landmark (Bullens et al., 2010). Other measures have focused on efficiency as opposed to accuracy, recording the length of the path traversed from the spawn location to where participants remember the goal locations to be (Buckley et al., 2015). All measurements reflect participants' ability to finding the goal locations and allow the tracking of developmental improvements in navigational strategies.

Despite differences in the experimental design and experimental measurements, all studies showed a developmental change in children's navigational strategies. Overall, children have shown to gain the ability to locate cues associated to the proximal cue through response learning around the age of 5 to 6 years old (Julian et al., 2019; Lehnung et al., 1998; Leplow et al., 2003a;

Overman et al., 1996) and begin to switch to place learning somewhere between 7 to 10 years old (Burles et al., 2019; Julian et al., 2019; Lehnung et al., 1998; Leplow et al., 2003a). Interestingly, Bullens et al. (2010) found that 5–7-year-olds showed no differences between the two types of environmental cues when locating target objects, but did show that adults were biased towards using the distal environmental cues. Similar to Bullens et al. (2010), Buckley et al. (2015) calculated distal and proximal bias based on the number of time participants traversed in a particular quadrant of the environment and the length of the path traversed to get to the final location. Interestingly, they found that despite age-related differences in performance, young children and adults showed a bias towards using the extramaze distal information to navigate whilst older children showed a bias towards intramaze proximal information. Bias was determined by the amount of time spent and distance traveled in the target quadrant minus the time and distance spent in the other quadrants. This difference was used to calculate bias, with a higher score spent in the correct quadrant of landmark objects resulting in a proximal bias, and vice versa. Through this, they suggested changes in navigational strategies extend further than 12 years old.

The present study uses an adapted version of Doeller et al's (2008a,b) object location task, similar to that of Julian et al. (2019), to study children aged 6-12 years old and adults. Virtual environments pose the most experimental rigor to study developmental differences in spatial encoding. It also benefits from the vast amount of data that can be collected per participant. Whilst previous work has looked at one behavioral measure, typically distance error, this study looks at multiple. For this thesis, distance error (Bullens et al., 2010; Julian et al., 2019), and angular error (Bullens et al., 2010) are compared to show potential developmental differences in response learning and place learning. The measure of path efficiency was also collected, defined as the difference between the path taken by the participant to the object location and the Euclidean distance between the spawn and object locations. This measure is based on the notion that a shorter, more direct path is reflective of a more accurate understanding of an object's location (Buckley et al., 2015). Overall, these measures will show how accurately and efficiently a participant can navigate to the location of the object and shows that with an increase in age comes an increase in both accuracy and efficiency.

Video Game Experience and the Development of Spatial Memory

Virtual paradigms have become an important tool to study spatial navigation in a more realistic setting with greater ecological validity, experimental control, and more sensitive behavioral measures (Diersch & Wolbers, 2019). Virtual paradigms also make up a vast amount of video game experiences and to this extent, it has sparked the empirical idea of how video game experience (VGE) influences individual differences in the encoding and flexible retrieval of memory representations of the world we navigate through.

Research into the study of VGE on spatial memory has primarily focused on older populations, and conclude that video games help reduce signs of cognitive deterioration (Anderiesen et al., 2015). Spatial navigation is one of the earliest indicators of progression from healthy aging to Alzheimer's dementia, linked to the neurodegeneration of structures in the medial temporal lobe (Diersch & Wolbers, 2019). A recent meta-analysis (Ballesteros et al., 2014) concluded that video games in particular exergames (games based on exercise and physical activity) can be used as an intervention to slow advances in cognitive impairments in clinical populations and reduce the decline associated with diseases such as Alzheimer's.

Video games apps are also being used to collect vast amounts of data on how the general population navigates as a way to compare to those who potentially suffer from cognitive decline.

For example, Sea Quest (Coutrot et al., 2019, 2018) is an app that involves navigating a boat in a virtual environment to search for sea monsters to take a picture of them. This task features both wayfinding and path integration: the wayfinding task requires interpreting a map to plan a multi-stop route plan for future navigation, while the path integration task involves navigating a turning river to find a flare gun and then choose the correct direction as remembered from the map to get back to the starting point. These two tasks together capture a wide range of processing used in spatial memory. This has created a vast bank of general population data to create a greater understanding of what typical navigational behavior in the population encompasses, and how such apps may be used as a form of cognitive training easily available to the general population.

These findings are crucial to understanding the decline in spatial cognition across the life span and types of interventions that can be implemented. However, it's also important to focus on the other end of the spectrum: understanding the development of spatial memory in children and how this development may be facilitated by VGE. Task analyses of video games led to early speculation that they could be a tool for the development of spatial skills (Greenfield et al., 1994; Lowery & Knirk, 1982). A study on the effect of video game practice on spatial abilities showed video game practice was more effective for children who started with relatively poor spatial skills and suggested that video games may be useful in equalizing individual differences in spatial skills, including those associated with gender (Subrahmanyam & Greenfield, 1994).

This correlational relationship between VGE and visual-spatial abilities led to a more detailed investigation into age- and gender-related differences in VGE and its influence on navigation. Current studies (Murias et al., 2016; Rodriguez-Andres et al., 2018; Ventura et al., 2013) have converged on the conclusion that an increase in VGE is correlated to increased navigational ability. Both Ventura et. al. (2013) and Murias et. al. (2016) showed this in adult participants. Ventura et. al. (2013) inquired solely on the time spent playing video games by asking "How often do you play video games? (Jackson et al., 2012), as well as asking ppts how similar the navigation task was to video games they normally played. Even when controlling for task-game similarity, the correlation between video gameplay and task performance persisted, indicating that the type of video games an individual regularly used did not modulate the relationship between video gameplay and task execution. Murias et. al. (2016) took this a step further by categorizing games previously played and controlling for increased dexterity usually associated with game control. This was taken in addition to the question of "For how many years have you played video games?" and "How often do you play video games that involve navigation, walking, or driving in hours per week?" Their findings confirmed that individuals with a long history of video game play performed better on navigational tasks and this effect was strongest in participants who played video games with a navigational component such as shooter and racing games.

Rodriguez-Andres et. al. (2018) tested typically developing children between the ages of 5 to 12 years old, extending the VGE and object location task performance correlation to children. Their VGE was measured by asking the questions "How often do you play with videogames on a PC or smartphone?" and "How often do you play videogames with a gamepad?" Developmental increase in task accuracy converged with the original developmental literature (Bullens et al., 2010; Burles et al., 2019; Julian et al., 2019; Lehnung et al., 1998; Leplow et al., 2003a; Overman et al., 1996; Rodríguez-Andrés et al., 2016). Additionally, an increase in video game use was correlated with an increase in efficiency of the spatial orientation task performance but not accuracy. This suggested that being less experienced in videogames does not influence the overall virtual object location task ability of a participant, but it does influence the efficiency in which children complete the task.

The finding that more than one type of game genre may affect spatial learning (Murias et al., 2016) converges with a study using Minecraft, a popular city-building game played in both first- and third-person perspectives (Clemenson et al., 2019). Using an adapted version of the game, they constrained the environment to encourage adult participants to focus on either spatial exploration or building, which promoted greater levels of engagement through various goal-oriented building activities or left players to their own devices respectively. It was determined that the degree to which participants explored and searched for objects in the virtual environment was related to improvement in hippocampal-dependent memory measured by a mnemonic similarity task. Additionally, the degree of exploration was measured by calculating roaming entropy (RE), a measure of spatial exploration previously used to measure the exploratory behavior of mice (Freund et al., 2013). Participants who actively built based on goal-oriented tasks showed an improvement in hippocampus-associated memory, in contrast to those who spent their time building freely with no goal-oriented activities. This suggests that active, interactive play is required for improvement in hippocampal memory. Additionally, the increase in task performance also correlated with an increase in RE, suggesting that as active city-building tasks grow and buildings become more complex, players must increase their exploratory behavior as their cities become more spatial, resulting in hippocampal memory use.

In addition to trying to understand the effects of passive and active engagement, Clemenson et al. (2015) also addressed the effects of game perspective, particularly training in a pseudo-3D game (Angry Birds) versus 3D game (Super Mario). A pseudo-3D game is one that is 2D but shadowing mimics the set-up of a 3D game, which includes not only width and height as a 2D game does, but also depth. The goal was to test whether the addition of the depth to gaming led to significant differences in a virtual water maze task. Three groups of video-game naïve participants were trained in either no game, the pseudo-3D fame, or 3D game for 2 weeks, participants trained in the 3D showed improvements in an object location task, suggesting the type of perspective a player uses to navigate an environment may influence hippocampal spatial behavior.

To better understand the aspects of the gameplay mentioned, the present study uses a VGQ to assess the overall amount of time participants spend playing video games. Also, the questionnaire specifically asked participants for the top games played to analyze their perspective and genres (Clemenson et al., 2019; Clemenson & Stark, 2015), as well as the amount of time spent specifically playing virtual layout games and passive time spent watching others play. The aim here was to not only expand upon the previous work analyzing the impact of different genres and perspectives on large-scale spatial navigation but also the notion of whether active versus passive video game interaction impacts navigational behaviors. Together, all of this data was used to gain a more detailed account of how VGE affects spatial navigation.

The Effects of Familial Environment on Cognitive Development

The environment a child is raised in, including familial socioeconomic status and living conditions, exerts a major influence on their cognitive development (Bradley & Corwyn, 2002; Engelhardt et al., 2019; Schoon et al., 2012). Income level, parental education, and family stability are closely interlinked and have been shown to have a significant correlation to the cognitive development of children, particularly within the domain of episodic memory (Fomby & Cherlin, 2007). Engelhardt et al. (2019) showed that parent socioeconomic status (SES) significantly predicted cognitive outcomes such as IQ, verbal comprehension, and reading ability, independent of other predictors such as age and gender. Given this literature, the goal of the present study is looking at both video game usage and family environment as possible independent predictors of performance on spatial memory. Finding one's way around an environment (e.g. Hartley et al., 2003) and remembering the episodic events that occur across contexts (e.g. Schlichting et al., 2015; Schlichting et al., 2017) are crucial cognitive abilities that have both been linked to the hippocampus. What is meaningful of both processes occurring in the hippocampus is that this region of the brain is also particularly susceptible to environmental stress (e.g. Hanson et al., 2011; Kim et al., 2006), and this stress in children can also affect the neurodevelopment of the hippocampus (Andersen & Teicher, 2004; Gould & Tanapat, 1999). To further build upon our understanding of the impact of family environment on cognitive development. this project aims to examine the extent to which SES and family function shapes the development of spatial memory.

The family environment has also been shown to relate to video game usage. The amount of disposable income a family has, as well as the parental education level both correlated with the presence of technology in a household and video game exposure (Jackson et al., 2011; Li & Atkins, 2004). Video games can act as a source of validation for children in difficult home environments. Studies have been published on the link between video games and flow, a state of being pleasantly and completely absorbed by a goal-driven activity (Inal & Cagiltay, 2007). Studies such as Sherry (2004) posits that certain visual-spatial skill-based games such as Super Mario and Bumpy's Arcade Fantasy create a type of goal-oriented behavior that children find rewarding. In essence, when feelings of appreciation and reward are lacking in familial environments, children seek it out in video game environments. Jackson et al. (2011) also found that when gender and age were controlled for, video game playing predicted higher visual-spatial skills, and familial SES status predicted video game playing. These results suggest that an association between video games and spatial memory might be somewhat influenced by family environment variables.

To better understand whether family structure affects not only exposure to video games but also spatial memory development, this project aims to examine income level, parental education and perceived family function, and its relation to both variables. This will allow a closer look into whether external environmental factors need to be considered in more detail when examining the role of technology in the household and its influence on the development of spatial memory.

Current Study

In summary, this project sought to investigate the link between spatial memory, VGE, and family structure in children aged 6-12 years old and adults. Together, this allows for the testing of three main hypotheses that (1) object location task performance and spatial navigation ability increases with age with the maturation of proximal cue-based response learning occurring before the maturation of distal cue-based place learning; (2) object location task performance and spatial navigation ability will be positively associated with greater VGE, specifically 1st perspective and city-building games that require a more navigational approach to play, and (3) object location task performance and spatial navigation ability will be positively associated with parental education, per person income, and positive self-perceived family function as measured by the SCORE.

Methods

Participants

One hundred and fifty volunteers participated in this project split into two age groups: child (*range*: 6–12 years; n = 118, 63 females) and adult (*range*: 19–33 years; n = 32, 17 females). The ethnicity of the sample was broken down into: White (n = 120), Black/African American (n = 6); Asian (n = 11); American Indian/Alaskan (n = 1); and Mixed Race (n = 12). Of all adult and child participants (n = 150) 23.3% identified as Hispanic (n = 35). Child recruitment was carried out using the University of Texas at Austin Children's Research Center participant database. Adult participants were recruited through advertisements to the greater Austin area and REDCap, an adult volunteer database maintained by the University.

Participants completed two testing sessions, which took place at the Children's Research Center and the Biomedical Imaging Center at the University. The consent/assent process was carried out using age-appropriate language following an experimental protocol approved by the Institutional Review Board at the University of Texas at Austin. Consent was obtained from the parent of child participants and adults at both sessions. The data collected for this project were part of a larger neuroimaging project studying developmental differences in the integration and separation of spatial memories. All ppts received monetary compensation of $10 an hour for the behavioral session and $25 an hour for the scanning session.

From the original sample, participants were screened and excluded from all subsequent analyses if the following criteria were met: participants with a clinical range score on either the Child Behavior Checklist (CBCL) for children (Achenbach & Edlebrock, 1993) (n = 0) or the Symptom Checklist 90-Revised (SCL) for adults (Derogatis, 1994) (n = 2); participants who scored below a certain standard cognitive ability on the Wechsler Abbreviated Scale of Intelligence - Second Edition (WASI–II) (Wechsler, 1999) (n = 0); not a native English speaker (n = 2); and a developmental disorder diagnosis (n = 4). Additional issues experienced during testing sessions lead to further exclusions: behavioral exclusion during the first session (n = 6), current orthodontic dental care (n = 2); technical issues during data collection (n = 2); withdrawal during the first session (n = 15); or the second session (n = 9); and incomplete data collection during the scanning session (n = 7). These exclusions yielded a group of 101 participants: children (*range* = 6–12 years;

n = 75, 35 females) and adults (*range* = 19–33 years; *n* = 25, 10 females) (descriptive details in *Table 1*).

Table 1: The mean age and standard deviation for the developmental age range broken down by year, and adults.

	6yr	**7yr**	**8yr**	**9yr**	**10yr**	**11yr**	**12yr**	**Adult**
Mean ± SD	6.74 ± 0.22	7.61 ± 0.29	8.34 ± 0.26	9.50 ± 0.35	10.50 ± 0.20	11.54 ± 0.17	12.46 ± 0.20	21.72 ± 2.83
n	2	15	17	12	9	11	10	25

Task Design and Procedure:

The study consisted of two separate sessions run on two separate days, approximately two weeks apart. The first session was a behavioral screening session, during which participants were tested individually in a quiet testing room for approximately two hours and could earn up to $20 in compensation. This session included the administration of the vocabulary and matrix reasoning subtests from WASI-II, a language map-reading task, perspective-taking tasks (Hegarty et al., 2004; Kozhevnikov & Hegarty, 2001), and practice of the object location task. Screening forms were also collected during this session: the CBCL (Achenbach & Edlebrock, 1993) for children or the SCL (Derogatis, 1994) for adults, VGE questionnaire, sense of direction questionnaires (Hegarty et al., 2002), and demographic information. Adult participants completed the forms themselves, whilst parents completed the corresponding forms on behalf of their children.

During the scanning session, participants first practiced the object location task once more and prepared to be placed into the scanner for the first forty-five minutes. Participants then completed the MRI session itself which lasted two hours and fifteen minutes. The MRI scanning component involved playing the object location task whilst being scanned and taking high-resolution anatomical images. The entire session lasted approximately 3 hours in which participants could earn up to $75 in compensation.

Additional measures were also collected as part of The Little Panda Project, a lab-wide project aimed at providing insight into if the interpersonal dynamics within families influences cognitive development. Adult participants and both child participants and their parent(s) reported about their feelings, experiences, and family environment. The Long Socioeconomic Status (SES) Survey and Systemic Clinical Outcome and Routine Evaluation (SCORE-15) forms from The Little Panda Project were used to address the current study aims. If all Little Panda Project data could not be collected during the two scheduled sessions, an additional follow-up session took place to complete any missing forms. This session lasted a maximum of 30 min with up to an additional $5.00 in compensation.

For this project, an analysis was conducted using the behavioral data from the video game questionnaire, the object location task from the scanning session, and measures of environment collected from The Little Panda Project.

Object Location Task

This task was created using Unity (5.2.2 Unity Technologies, 2017), and run on a 13-inch screen MacBook Air Laptop. The virtual environments were based on Doeller et al., (2008a,b), but adapted to be developmentally appropriate for the age range tested. Two different environments were created to ensure the novelty of the task given during the scanning session compared to the practice version. The practice environment was set in a desert with a square arena, whilst the testing environment was a meadow with a circular arena. Both types of arenas were limited by a boundary wall. The arenas were surrounded by four distal mountain cues placed at North, South, East, and West positions in the environment. Mountains in the practice arena were dark pink, light green, orange, and purple; the mountains in the test arena were light pink, yellow, light blue, and dark blue. Each arena also contained a rotationally symmetrical landmark object (trash can for the practice; traffic cone for the test), placed 45 degrees between two distal mountains.

Participants navigated through the arena by using their right hand to operate the keys 1, 2, and 3 to turn left, move forwards, or turn right respectively. During the practice session, and at the beginning of the scanning session, participants were given three minutes of free exploration to familiarize themselves with the keyboard controls and the virtual environment. Once participants were comfortable with both elements, participants continued to complete the task.

The object location task aimed to find and learn the location of four objects within the circular arena. The four objects comprised nine novel cartoon monsters that participants had no prior exposure to. The task included 20 trials. The first four trials were the learning phase, followed by 12 trials of the finding and feedback phase plus four control trials. The initial familiarization of the four objects and their locations was known as the learning phase. Participants collected each test object once by navigating towards the object and collecting it. Two test objects maintained their location relative to the mountains at the boundary - known as boundary objects - while the other two test objects maintained their location relative to the proximal trash can/traffic cone – known as landmark objects.

Following learning, participants completed the finding phase. Participants completed three trials per test object. Each trial began with the display of one of the test objects on the screen for 2 seconds (s). Following a jittered interval (2-6s), participants were spawned in a random location within the environment and were given one minute to navigate to the remembered location of the object. When participants believed they had reached the remembered location, they indicated such by pressing a button placed in their left hand. This resulted in the object appearing in its correct location. Participants were then instructed that they had one minute to collect the object giving them time to relearn the goal location, which constituted the feedback phase. Within a run, memory for the test object locations was assessed in a randomized order.

Four control trials were also conducted between the twelve trials in which participants were instructed to navigate directly towards the cartoon monster that was visible at all times with no landmark or boundary objects to anchor its location to. This trial provided a direct contrast to the finding phase.

Participants completed a total of six runs. Between each run, the configuration of the four object locations remained constant but was rotated 90 degrees. After completion of runs 1-3, the test objects learned by the participants were changed to include four novel cartoon characters. This tested for the generalization of positional information from runs 1-3 to runs 4-6. The sets of objects used for this task were counterbalanced across participants to ensure performance was not biased by the appeal of certain stimuli over others. For this reason, preference ratings of each cartoon monster were also collected after the session to ensure such a bias was not seen across participants. Different types of behavioral measures were generated for all participants on a trial-by-trial basis: path efficiency, distance error, and angular error. Path efficiency was calculated as the difference between the path taken by the participant to the object location and the Euclidean distance between the spawned and object locations. Distance error was calculated as the difference between where the object was located in the arena and where the participant remembered the object to be. The angular error was calculated as the difference between the angle of a participant's response to the boundary/landmark and the actual angle between the object to the boundary/landmark (Bullens et al., 2010). Mean scores were calculated for each behavioral measure by calculating the mean error across all trials from all included runs. To be included in the analysis, participants had to complete a minimum of runs 1-4, reflective of the adult literature that also included four runs (Doeller et al., 2008a). For this project, all data were collapsed across runs. The data was collapsed as the analysis carried out sought to examine age and condition related differences on performance on the task as a whole.

To assess any inter-relations between performance on this task, VGE, and family environment, an overall object location task performance score was also calculated from the three individual behavioral measures. The z-scores for path efficiency, distance error, and angular error were all calculated separately to normalize each behavioral measure. This z-score was then reverse-scored reflecting that a positive z-score was indicative of better performance. The three behavioral z-scores are then averaged to create an overall object location task performance score.

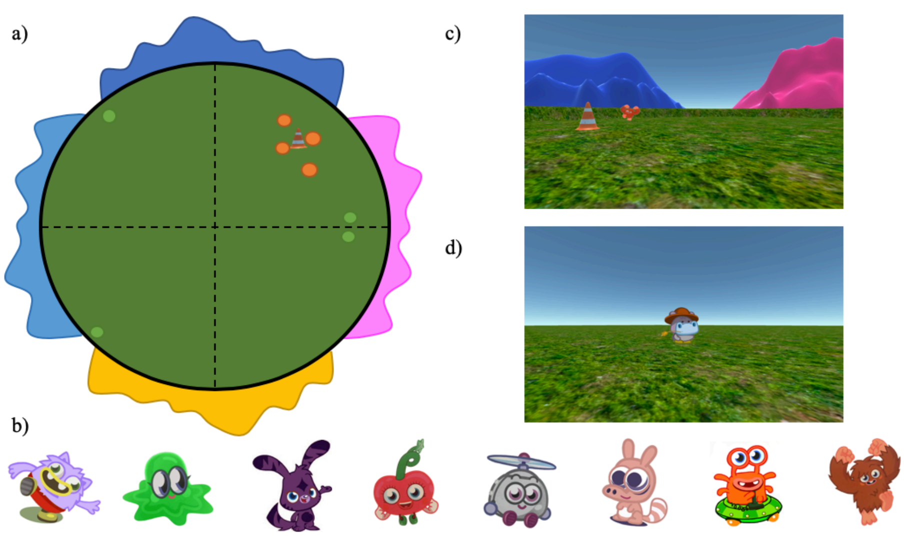

Figure 1: Schematic of the Object Location Task a) an aerial view of the virtual layout with placement of landmark (orange) and boundary (green) objects, b) monsters used as objects c) the participant perspective during the feedback phase of the task d) participant perspective during the control trial.

Video Game Experience Questionnaire (VGQ)

This form was designed to assess how much time was spent playing video games, the types of games played, the number of consoles owned, any experience with virtual layouts and the amount of time spent playing such games, and whether participants watched others play games and how much time was spent doing so (sample form found in Figure A1).

The responses not about the types of games played or devices games were played on were scored to create an overall VGE score that reflected a higher experience score with greater exposure to playing video games. The number of years played was multiplied by the score given for the range of hours played per week. The range of hours played per week was broken down into a six-point scale: "0" represented playing video games for 0 hours per week; "1" represented playing 1-5 hours per week; "2" represented playing 6-10 hours per week; "3" represented playing 10-15 hours per week; "4" represented playing 16-20 hours per week; "5" represented playing 20+ hours per week. This provided a level of sensitivity that accounted for the amount of time spent playing video games relative to the number of years participants had played games. This was especially necessary due to the comparison of a wide age range. For example, a participant who had played video games for 5 years for an average of 1-5 hours per week would have a score of 5 while a participant who had played video games for 5 years for an average of 6-10 hours per week would have a score of 10. The same scoring was used to classify participants' experience with virtual layout games and the extent to which they watched others play video games. To calculate the overall VGE score, the score for time spent playing video games, time spent playing virtual layout games, and time spent watching others play was summed together.

In addition to creating an overall VGE score, the top four games played by each participant were also collected. Classification of each game was determined by online research and previous classification of certain games taken from the literature, for example, Minecraft (Clemenson et al.,

2019) and Super Mario (Clemenson & Stark, 2015). From this, the genre and perspective of the first game listed were classified and labeled the participants' "top genre" and "top perspective" played.

The Little Panda Project

The Long SES Survey (sample form found in Figure A2) was adapted from Engelhardt et al., (2019) to evaluate questions about family income and parental education. Income was analyzed based on the average income per person in the household. This was determined by taking the self-reported family income and dividing it by the number of people listed as household residents to calculate capital per person. Parental education was also used for analysis from the self-reported education level of both mother and father. Both the mother and father education were converted to a scale of 1-4 dependent of the highest completion level with "1" indexing "some high school education", "2" indexing "high school graduate/GED", "3" indexing "college graduate", and "4" indexing "graduate degree". The score for both parents was added to create an overall education score per participant.

The Systemic Clinical Outcome and Routine Evaluation (SCORE-15) (Stratton et al., 2014) quantifies family function according to three factors: family strengths, difficulties, and communication. This was used to assess perceived family function (sample form found in Figure A3). For the child version, each of the fifteen questions was answered on a scale of 1-5 with "1" relating to the statement "very well" describing one's family and "5" relating to the statement "not at all" describing one's family. The adult version asked the same questions on a scale of 1-6 with "1" relating to "extremely well" and "6" relating to "not at all". Some questions were reported as a negative statement and the scores of these were reverse-scored so that higher scores reflected better-perceived family function across the form. To account for the discrepancy in the scales of both forms, the total score was summated and divided by the total possible points of the corresponding form to calculate a percentage of overall family function that could be compared across children and adults.

Results

This section is broken down into three sections. Firstly, developmental change on the object location task is reported through age- and condition- related statistical differences in the behavioral measures extracted from participants' performance: path efficiency, distance error, and angular error. The second section examines the extent to which individual differences in VGE are predictive of overall task performance scores on the object location task. Finally, the impact of family income, parental education, and perceived family function are reported to show whether the familial environment impacts object location task performance, video game exposure, or both.

Object Location Task Performance

Three different behavioral measures were used to determine the developmental change in the object location task. As reported in *Table 2* there was a significant medium to strong inter-correlations between all behavioral measures. There were also significant medium correlations between all behavioral measures and age. When age was partialled out, the only correlation that held significance was between angular error and distance error. Therefore, whilst the correlation between distance error and angular error was invariant to age, it did mediate the relationship between path efficiency and distance error and path efficiency and angular error. The child and adult groups were analyzed separately to show that children showed significant correlations between path efficiency and angular error (r = 0.23, p = 0.047) as well as path efficiency and distance error (r = 21, p = 0.046), but this was not the case for the adults data (path efficiency-angular error: r = 0.04, p = 0.921; path efficiency-distance error: r = 0.06, p = 0.763).

Table 2. Correlational matrix between distance error, path efficiency, angular error. top triangle = bivariate correlations between all variables; bottom triangle = partial correlations controlling for age.

	Path Efficiency	**Distance Error**	**Angular Error**	**Age**
Path Efficiency	-	0.34***	0.35***	0.42***
Distance Error	0.13	-	0.97***	0.58***
Angular Error	0.14	0.95***	-	0.58***
Age	-	-	-	-

* p < .05; ** p < .01; ***p < .001

A multiple linear regression was used to reveal that age significantly predicted individual behavioral measures (*Figure 2*). Age was seen to be a significant predictor of path efficiency (R^2 = 0.17, $F(1, 99)$ = 21.18, p < 0.001, β = - 0.69), distance error (R^2 = 0.32, $F(1, 99)$ = 48.97, p < 0.001, β = - 0.73), and angular error (R^2 = 0.33, $F(1, 99)$ = 50.36, p < 0.001, β = - 2.42), showing that an increase in age predicted a significant reduction in error for all three measures.

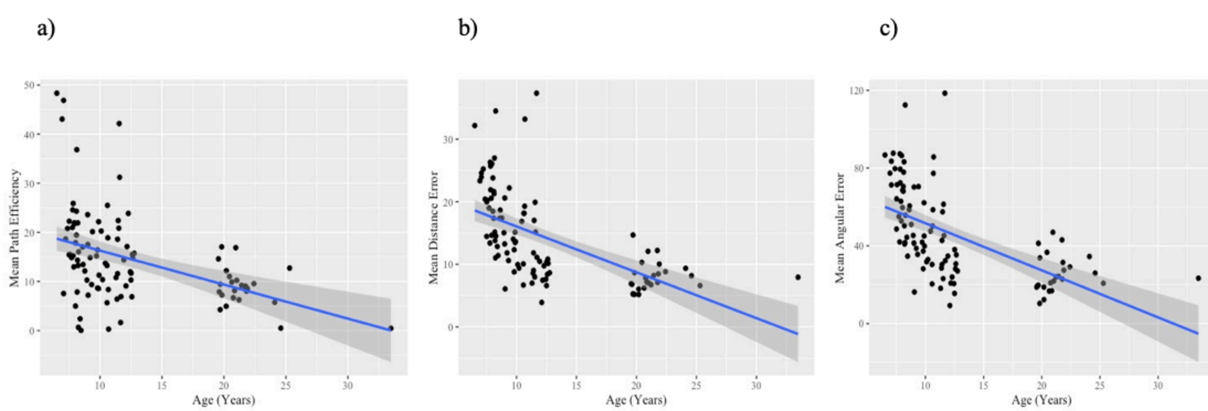

Figure 2. Significant correlations between a) mean path efficiency and age, b) mean distance error and age c) mean angular error and age.

Further analysis was conducted to examine age- and condition-related differences were as a reflection of developmental trajectories for response and place navigational strategies. Therefore, the age range collected was split into four groups: 6-8-year-olds, 9-10-year-olds, 11-12-year-olds, and adults (*Table 3*). A larger age range of 6-8 years was used due to the fact that data was only successfully collected for two 6-year-old participants.

Table 3: The mean age and standard deviation for the developmental age groups and adults

Age Group	**6–8 years**	**9–10 years**	**11–12 years**	**Adult**
Mean ± SE	7.92 ± 0.53	9.93 ± 0.58	11.98 ± 0.50	21.72 ± 2.83
n	34	21	21	25

A 4 (age group) x 2 (condition) mixed factor ANOVA was carried out using each of the behavioral task measures as the dependent variables. The ANOVA for path efficiency showed a significant main effect of age group ($F(3, 97) = 6.17$, $p < 0.001$) and object condition ($F(1, 97) = 55.11$, $p < 0.001$) (*Figure 3*). Post-hoc, Bonferroni corrected multiple pairwise comparisons revealed that adults produced the most efficient path in comparison to all child groups (all *p*s < 0.050). All children groups were shown to traverse relatively equivalent paths, except 9–10-year-olds who generated significantly more direct paths than 6–8-year-olds ($p = 0.023$). Overall, path efficiency for the proximal traffic cone condition ($M = 11.51$ virtual meters (vm); $SE = 0.98$) was significantly lower than the distal boundary condition ($M = 17.47$ vm, $SE = 1.06$); participants followed a more direct and efficient path when finding landmark objects compared to boundary objects. No significant interaction was seen between the two factors ($F(3, 97) = 2.31$, $p = 0.084$), suggesting that the main effect of condition was consistent across all age groups.

The ANOVA for distance error showed a significant main effect of age group ($F(3, 97) = 25.07$, $p < 0.001$) and object condition ($F(1, 97) = 291.77$, $p < 0.001$) (*Figure 3*). Post-hoc, Bonferroni corrected multiple pairwise comparisons revealed that 6-8year olds generated significantly larger distance error than all other age groups (all *p*s < 0.050), however, 9-10-year-olds, 11-12-year-olds, and adults did not differ from each other (all $p > 0.050$). Overall, distance error for the proximal traffic cone condition ($M = 17.73$ vm; $SE = 0.84$) was significantly lower than the distal boundary condition ($M = 10.57$ vm, $SE = 0.65$). However, a significant interaction between the two factors ($F(3, 97) = 8.78$, $p < 0.001$), revealed that when each condition was analyzed separately, there were subtle differences in the developmental patterns. Whilst the traffic cone condition showed the main effect described above, the boundary condition showed a systematic, significant decrease in error across all age groups (all *p*s < 0.050).

The ANOVA for angular error showed a significant main effect of age group ($F(3, 97) = 28.55$, $p < 0.001$) and object condition ($F(1, 97) = 15.28$, $p < 0.001$) (*Figure 3*). Post-hoc, Bonferroni corrected multiple pairwise comparisons revealed that 6-8year olds generated significantly larger distance error than all other age groups (all $p < 0.050$), however, 9-10-year-olds, 11-12-year-olds, and adults did not differ from each other (all $p > 0.050$) as also seen for distance error. Overall, the angular error for the proximal traffic cone condition ($M = 38.51$ vm; $SE = 1.98$) was significantly lower than the distal boundary condition ($M = 45.32$ vm, $SE = 2.63$). A significant interaction between the two factors ($F(3, 97) = 5.14$, $p < 0.001$) meant that subtle differences in the developmental patterns were also seen in terms of angular error. For the landmark angular error, whilst 6-8-year-olds generated significantly larger angular error than all age groups (all *p*s < 0.050), all other age groups did not differ from each other (all *p*s > 0.050). In contrast, the angular error generated from the boundary condition showed a systematic decline (all ps < .050), with exception to 9-10-year-olds and 11-12-year-olds (p = 0.083)

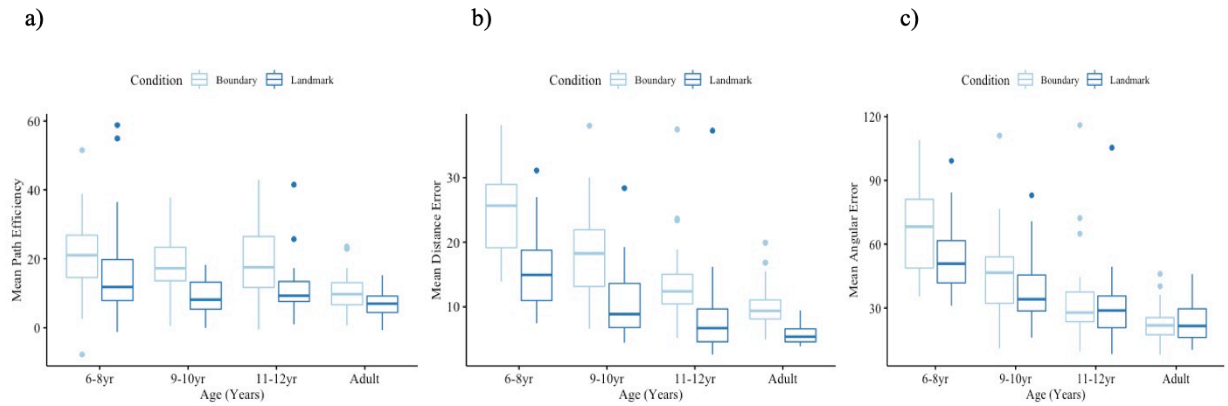

Figure 3. Box plot of the cue and age group interaction for path efficiency (a), distance error (b) and angular error (c).

Individual Differences in Video Game Experience (VGE)

This section analyzes the VGE and overall object location task performance scores to understand the impact of VGE on spatial navigation in children and adults. Due to the collection of incomplete forms (*n* = 8) from the original dataset, 93 participants were used in this analysis. Data from the VGQ showed a total of 127 games played by participants. *Table 4* illustrates the games played by more than two participants, considered the "top games" played by the participant sample. The devices used by participants to play these games were phones (iPhone/android), Wii consoles (Wii/Wii U), Xbox, PlayStation, Nintendo devices (Nintendo DS/Nintendo Switch/Nintendo 3D) and PCs. The top games also covered a variety of genres, which consisted of 1st, 3rd, and pseudo-3D perspectives.

Table 4. Top games played by all participants taken from the Video Game Questionnaire (VGQ)

Game	*N*	Genre	Perspective
Minecraft	27	City-Building	1^{st}/3rd
Mario Kart	16	Racing	3rd
Roblox	12	MMO	1st/3rd
Super Smash Bros	10	Adventure-Fighting	pseudo-3D
Zelda	10	Action	3rd
Fortnite	8	MMO	3rd
Call of Duty	5	Shooter	1st
Clash of Clans	5	Strategy	pseudo-3D
Subway Surfer	4	Platform	3rd

MMO = Massive Multiplayer Online Game

A closer look was taken to see whether the specific genres and perspectives listed above impacted overall object location task performance (summation of distance error, angular error, and path efficiency scores to create an overall performance score). To analyze this, the genre and perspective of the first game listed by each participant, reflective of their favorite game, was used. For this analysis children and adults were run separately as different games are more appropriate for different groups. For example, Minecraft, a city-building game, as well as strategy and platform games were not played by any of the adult participants; just as shooter games were not played by any of the children participants.

Between-subjects ANOVAs were conducted to determine whether genre as an independent variable had a significant effect on the dependent variable of overall object location task performance(*Figure 4*) in both the children (n = 72) and adult groups (n = 19). A significant main effect of genre was not seen for either children ($F(1, 71) = 0.21$, $p = 0.652$) or adults ($F(1, 18) = 0.02$, $p = 0.901$). Similarly, a significant main effect of perspective was not seen for either children ($F(1, 71) = 0.81$, $p = 0.372$) or adults ($F(1, 18) = 0.67$, $p = 0.420$).

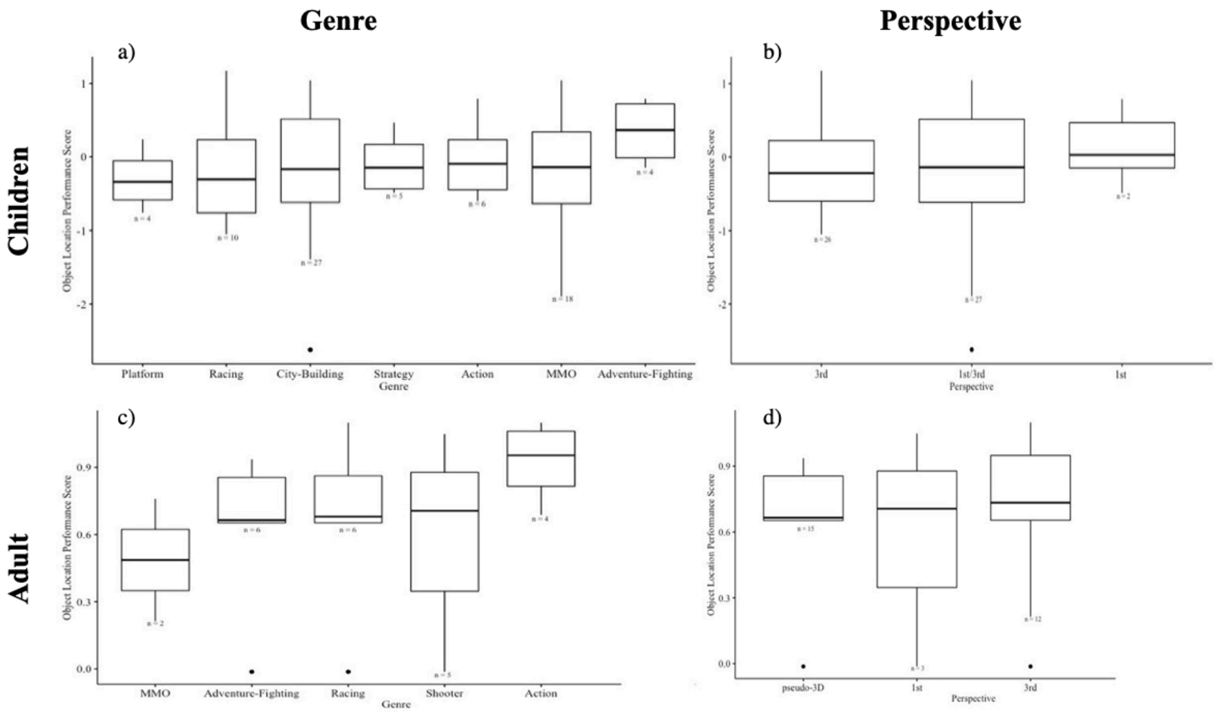

Figure 4. Box plot of the genre/perspective and object location task performance interaction for children (a,b) and adults (c,d)

The next analysis used a multiple linear regression to determine whether VGE and age predicted object location task performance (*Figure 5*). The overall model was significant (R^2 = 0.47, $F(3, 93) = 29.39$, $p < 0.001$) and showed both age ($\beta = 0.06$, $t(93) = 6.40$, $p < 0.001$) and VGE ($\beta = 0.77$, $t(93) = 4.63$, $p < 0.001$) to be significant predictors. A significant interaction between age and VGE ($\beta = -0.03$, $t(93) = -2.94$, $p < 0.010$) revealed that VGE was only a significant predictor for the child group ($R^2 = 0.23$, $F(1, 73) = 23.56$, $p < 0.001$, $\beta = 0.50$) and not the adults ($R^2 = 0.04$, $F(1, 73) = 1.96$, $p = 0.184$, $\beta = 0.09$). This showed that in children, an increase in VGE is predictive of more accurate object location task performance.

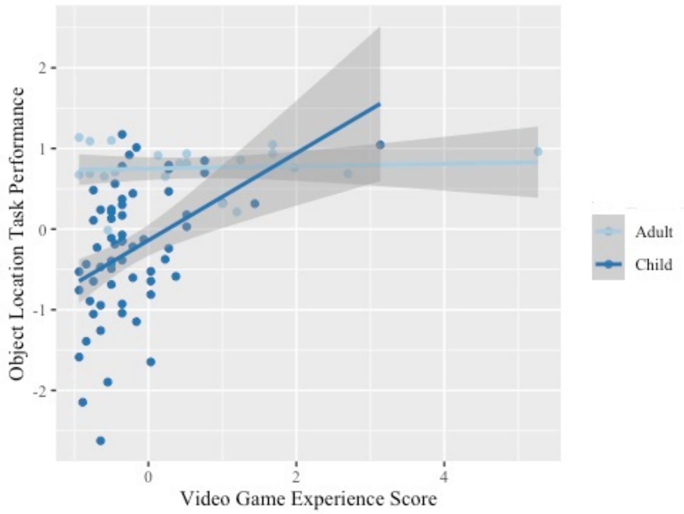

Figure 5. Object location task performance in relation to video game experience (VGE) for the child and adults' groups separately.

Further breakdown of participants' VGE score into three sub-scores was also conducted: active time spent playing video games, time spent playing virtual layout games, and passive time spent watching others play. As reported in *Table 5* there were significant medium intercorrelations between all VGE measures. When age was partialled out, all correlations held up with significance, meaning the differences between the behavioral measures is invariant to age-related differences.

Table 5. Correlational matrix between active play, virtual layout game play, and passive watching. top triangle = bivariate correlations between variables; bottom triangle = partial correlations controlling for age.

	Active Play	**Virtual Layout**	**Passive Watch**
Active Play	-	0.58***	0.60***
Virtual Layout	0.62***	-	0.61***
Passive Watch	0.61***	0.60***	-

* $p < .05$; ** $p < .01$; ***$p < .001$

A multiple linear regression was used to determine whether VGE subscores and age were significant predictors of object location task performance. The overall model was significant (R^2

= 0.48, $F(7, 77) = 12.18$, $p < 0.001$). However, age was the only significant predictor ($\beta = 0.08$, $t(77) = 5.92$, $p < 0.001$) showing that an increase in age correlated with an increase in task performance. The three subscores of active play ($\beta = 0.55$, $t(77) = 1.20$, $p = 0.230$), passive watch ($\beta = 0.25$, $t(77) = 0.93$, $p = 0.352$), and virtual layout ($\beta = 0.20$, $t(77) = 0.44$, $p = 0.664$) were not significant, and none of the variables interacted with age.

Family Environment Effect

In order to better understand what may contribute to object location task performance and VGE, family structure was also analyzed. This was broken down into income per person, parental education, and perceived family function (SCORE). Due to incomplete forms or the lack of consent for the Little Panda Project data collection ($n = 23$), 61 of the 93 participants analyzed for VGE were included in this analysis.

Firstly, intercorrelations between family structure variables (per person income, parental education, self-perceived family function), overall VGE score, and overall performance on the object location task were examined. As reported in *Table 6,* there were significant weak correlations between education and income, education and family function, and education and VGE. A significant medium correlation was evident between VGE and object location task, consistent with previous analyses reported. When age was partialled out, the correlation between education and income, and education and family function remained, meaning the relationship between these measures were invariant to age. Age did mediate the relationship between education and VGE as well as VGE and object location task performance. To examine this further, the child and adult groups were analyzed separately. Results showed significant correlations between VGE and task performance ($r = 0.42$, $p < 0.010$) as well as parental education and VGE ($r = - 0.07$, $p <$

0.050) for children. However, in adults neither the correlation between VGE and task performance (r = 0.08, p = 0.771) nor parental education and VGE (r = - 0.39, p = 0.142) were significant.

Table 6. Correlational matrix between object location task performance, video game experience (VGE), income, parental education, and SCORE. top triangle = bivariate correlations between variables; bottom triangle = partial correlations controlling for age.

	Income	**Education**	**Function**	**VGE**	**OLTP**
Income	-	0.32*	0.23	- 0.05	0.08
Education	0.32*	-	0.25*	- 0.26*	0.17
Function	0.23	0.25*	-	- 0.18	- 0.03
VGE	- 0.06	- 0.20	- 0.19	-	0.48***
OLTP	0.09	0.21	- 0.01	0.19	-

* p < .05; ** p < .01; *** p < .001

A multiple linear regression was used to determine whether the familial factors collected and age predicted object location task performance. The overall model was significant (R^2 = 0.34, F(7, 53) = 5.37, p < 0.001). Age was the only significant predictor (β = 0.07, t(53) = 3.81, p < 0.001) showing that an increase in age correlated with greater accuracy at the task. The three scores of income (β = 0.12, t(53) = 0.27, p = 0.793), education (β = 0.40, t(53) = 1.55, p = 0.127), and family function (β = - 0.27, t(53) = - 1.01, p = 0.228) were not significant, and none of the variables interacted with age.

Similarly, a multiple linear regression was used to determine whether the familial factors collected and age predicted VGE. The overall model was significant (R^2 = 0.34, F(7, 53) = 5.36, p < 0.001). Age was the only significant predictor (β = 0.08, t(53) = 3.10, p < 0.010) showing that an increase in age predicted an increase in VGE. The three scores of income (β = - 0.65, t(53) = - 1.14, p = 0.255), education (β = 0.56, t(53) = 1.65, p = 0.104), and family function (β = - 0.22, t(53) = - 0.64, p = 0.524) were not significant.

Further analysis was carried out to better understand the mediating role of age and parental education on the relationship between VGE and the object location task. When age and parental education were partialled out, the link between VGE and object location task performance was no longer significant ($R^2 = 0.03$, $F(1, 59) = 3.13$, $p = 0.078$). This indicates that the relationship between VGE and task performance may be mediated by a combination of age and parental education. In order to further understand whether it is parental education, age, or both that mediates this relationship, a linear regression with age partialled out was run. The link between VGE and object location task performance was no longer significant ($R^2 = 0.02$, $F(1, 59) = 2.07$, $p = 0.263$). Additionally, when just parental education was partialled out, the link between VGE and object location task performance remained significant ($R^2 = 0.26$, $F(1, 59) = 21.84$, $p < 0.050$), indicating that age drives the mediation between VGE and object location task performance, not parental education.

Discussion

In the present study, 6-12-year-old children and adults completed a virtual object location task to learn and find the location of four hidden objects as accurately as possible. Participants had to locate a set of objects using a combination of proximal and distal cues. This allowed for the measurement of participants' ability to orient and navigate as they formed a cognitive map of the novel environment. This project sought to investigate the developmental trajectories of different navigational strategies, and whether this development is linked to individual differences in VGE and family structure effects.

The Development of Navigational Strategies in Children and Adults

First, the examination of the three behavioral measures (path efficiency, distance error, and angular error) showed that as participants got older, they became more accurate at the task, as hypothesized. When the age of the participants was broken up into four different groups (6-8-year-olds, 9-10-year-olds, 11-12-years-olds, and adults), path efficiency showed adults generated more efficient paths than all other age groups. Within the child sample, the paths taken by participants were relatively similar in efficacy, the only difference being between 9-10-year-olds and 6-8-year-olds. Therefore, while some slight shift in spatial learning in terms of efficiency does occur during early childhood, considering all child groups still performed significantly worse than adults, a level of developmental refinement may still occur during adolescence before showing a more adult level of behavior. The accuracy measures reflected in both distance error and angular error showed that whilst 6-8-year-olds generated significantly larger error than all other age groups, by the age of nine years, participants were demonstrating equivalent levels of performance as adults.

The developmental differences reported for the three behavioral measures align with the previous literature (Buckley et al., 2015; Bullens et al., 2010; Julian et al., 2019; Lehnung et al., 1998; Leplow et al., 2003b; Overman et al., 1996). In support of the age-related differences in path efficiency, Buckley et al. (2015) found that adults traveled a significantly shorter path to finding an object than children. Bullens et al. (2010) did not find any differences in angular and distance error between 5 and 7-year-olds, however, adults were more accurate than both child groups. Similarly, Julian et al., (2019) found that significantly lower distance error in typically developing adults compared to children between the ages of 6 to 10 years old. Overall, this shows that and increase in age is correlated to an increase in accuracy and efficiency.

An examination into landmark-associated and boundary-associated goal locations showed differences in the developmental trajectories of participants' performance on each condition. The traffic cone condition generated more efficient paths across the full age range tested. This may be because the traffic cone is visible, and provides explicit directional information in the environment. In contrast, the distal mountain cues provide less obvious information such as orientation, and a global configuration of the environment. Therefore, the traffic cone is used as a more obvious anchor in the environment for participants to directly navigate towards.

Condition-related differences in accuracy in distance and direction to the goal were also evident. For the landmark objects, 6-8-year-olds generated significantly larger distance error and angular error than all other age groups, who did not differ from each other. However, for boundary objects, significant decreases in distance error were seen up to adulthood. The boundary object angular error results varied slightly in which it also showed a systematic decline in error with increases in age except for the comparison of 9-10-year-olds and 11-12-year-olds. This suggests that response strategies and the use of visible, proximal landmarks in a novel environment show a shorter developmental trajectory and mature to an adult capacity by 9 years old. In contrast, the use of the surrounding environmental cues to determine distance and direction follows a longer developmental trajectory that continues to improve into adolescence.

The current findings converge with previous studies (Julian et al., 2019; Lehnung et al., 1998; Leplow et al., 2003b; Overman et al., 1996) who have shown that the ability to navigate using proximal landmarks develops earlier in childhood than the ability to use distal environmental information. Despite Buckley et al. (2015) reporting contrasting results in terms of children's use of proximal and distal information, their findings still concur with the current conclusion that the bias toward using distal cues frequently displayed by adults may be a comparatively latedeveloping process. Bullens et al. (2010) showed that children aged 5-7 years did not display bias to either type of cue and seemed to use both an equal amount. Adults, however, did display a bias toward navigating based on the boundary. Due to these findings, they concluded that younger children and adults alike possess the ability to use both boundary and landmark cues, however with subsequent development the ability to weight environmental cues more effectively increases performance accuracy.

The current studies varying proximity of both landmark and boundary objects to their respective anchoring cue can help answer the question Bullens et al. (2010) has. By isolating landmark and boundary cues to determine their developmental differences, it can be determined whether such changes in weightage are due to adaptation of using the more matured striatal area until the hippocampus matures in children, or if children just lack the ability to integrate different sources of information altogether.

However, it is important to note how the current study positioned the mountains to be used as distal cues. This type of environmental cue provides orientation information concerning the proximal cue placed in the arena. Previous physical layouts placed "landmark-based" cues behind a boundary (e.g. Bullens et al. used LED objects), which resulted in the cues not providing optimal orientation information as required by the task design. In contrast, virtual environment studies have created more "distal-based" cues by rendering mountains to infinity (Doeller et al., 2008a,b; Julian et al., 2019). The current study used mountains that followed the structure of the distal cues used in virtual environments, but rather than being rendered to infinity they were placed just behind the boundary. The mountains were close to the boundary to ensure it was obvious to participants that the information that mountains provided was readily available, especially for boundary objects. However, this may have resulted in the mountains providing more obvious positional data based on the details of the ridges of individual mountains themselves as well as orientation concerning the proximal cue of the traffic cone. To check how the implementation of the distal cues affects the developmental trajectory observed, future work would require having participants complete the task with the mountains behind the border and rendered to infinity to observe any possible differences in the performance of boundary objects.

Altogether, these findings support the idea that the development of the behavioral place and response navigational strategies observed here are supported by the development of dissociable neural systems. It is established that place learning as a navigational strategy is linked to hippocampal activation, whereas striatal activation reflects learning and remembering of response strategies (Doeller et. al., 2008a; Hartley et al., 2003; Kosaki et al., 2015; Pearce et al., 1998). Interestingly both systems show different maturation rates. Whilst the striatal system is thought to be mature by around the age of six (Power et al., 2010; Squire, 2004), the hippocampus shows a protracted maturation into adolescence (Boot et al., 2011; Martin & Berthoz, 2002; Schlichting et al., 2017; Squire, 2004). This could help explain why such different behavioral trajectories are evident in how children navigate through the world.

The results of this thesis are part of a larger study that has also collected fMRI scanning data. Therefore, the experimental inference described above can be tested directly by comparing hippocampal and striatal activation during the finding of landmark and boundary objects as well as the volumetric difference in both brain structures over age. It would be expected to find an increase in hippocampal volume with age as established in previous work (Hanson et al., 2011; Schlichting et al., 2017). And while a slight increase in striatal volume will also be seen it will not be to the same degree of increase seen in the hippocampus as the striatum is thought to be fully developed at an earlier age (Schlichting et al., 2015). Any differences in the functional use of each brain region over age and change in volume may be consistent with other suggestions that the weighting of spatial cues changes during development (Newcombe & Huttenlocher, 1992).

Video Game Experience and the Development of Spatial Memory

Examination of the relationship between VGE and object location task showed that in children, an increase in VGE is linked to more accurate spatial navigational performance. This aligns with previous studies' findings that video game usage in children is linked to effective spatial navigation (Greenfield et al., 1994; Lowery & Knirk, 1982; Murias et al., 2016; Subrahmanyam & Greenfield, 1994b; Ventura et al., 2013). The fact that such a relationship between VGE and object location task is not seen in adults' contrasts with the findings of Ventura et al. (2013) and Murias et. al. (2016) who both found that video game use increased the performance on an object location task in college-aged students. This may be because two varying tasks were used to measure navigational abilities. The previous study utilized enclosed rooms and proximal cues only while the present study created the task using an open virtual environment with both proximal and distal cues. This results in different measures of navigation and may explain the difference in the results obtained. Differences in results may also be due to the varying questions asked about VGE. Ventura et al. (2013) only asked the question of "How often do you play video games?" (Jackson et al., 2012). The present studies' questionnaire went into much more detail by not only measuring how often a participant actively played video games, but also the amount of time spent passively watching and the time spent playing games that include a virtual layout.

A closer look was then taken to see whether specific genres and perspectives impacted object location task performance. The results showed that different genre types (city-building, MMO, racing, adventure-fighting, action, shooter, strategy, platform) and different perspectives

(1st, 3rd, pseudo-3D, 2D) were not significantly linked to task performance in children or adults as hypothesized. Specifically, no link was seen with 1st perspective and city-building games, again contrasting with previous literature (Clemenson et al., 2019; Clemenson & Stark, 2015; Ventura et al., 2013). Previous studies have incorporated gameplay into the task design itself, allowing for more experimental and controlled measurement of how participants interact and engage with certain types of games and its comparison to spatial task measures. The present study took an individual differences approach and relied solely on the variability of responses from questionnaire data. Therefore, the sensitivity of VGE as a behavioral measure may have not been fully accounted for.

An additional consideration is the amount of detail collected from the questionnaire. Minecraft can be played in either 1st or 3rd person perspective, However, the current experiment did not ask for this specific information, and was subsequently categorized as 1st/3rd. Therefore, the further breakdown of this perspective category may elucidate perspective differences and its effect on object location task performance

Though many video game genres and perspectives share the same basic game mechanics, the extent to which they are employed or are critical for successful gameplay is not uniform. This study was not able to definitively establish participant engagement in each type of game played. Therefore, future directions should focus on establishing the role of video game genre and perspective on the development of enhanced navigational strategies, and its link to cognitive map formation. This can be established by taking video-game naïve child and adult participants and training them to play city-building and 1st perspective games, similar to Clemenson et. al. (2019). Having participants complete the object location task before and after such video game training would potentially facilitate our understanding of whether specific game genres/perspectives are linked to spatial memory development. Utilizing the current object location tasks provides the opportunity to test the extent to which training facilitates response learning versus place learning navigational strategies during development. As a final measure, testing participants months later (e.g. three months after the end of the study) can help determine if such intervention can show long-term improvements in this type of memory.

Investigating whether video game training facilitates spatial memory improvement can also be done on the other end of the spectrum and applied to aging populations. Collecting data on the ability of an older population to find landmark-based and boundary-based objects before and after video game training can help obtain a greater understanding of whether potential spatial deterioration can be curbed by specific gameplay. Testing the objection location task on older participants can investigate whether the inverse of the developmental trajectory reported is seen in this group. This will also allow for an investigation into improvement pre- and post-intervention and how long such intervention lasts. This could potentially expand knowledge into spatial deterioration and the type of gameplay that could aid in the intervention of neurological diseases such as Alzheimer's (Anderiesen et al., 2015; Diersch & Wolbers, 2019).

The Effects of Familial Environment on Cognitive Development

The family environment was also analyzed to understand its contribution to spatial memory and VGE, which included measures of per-person income, parental education, and self-perceived family function taken from the SCORE (Citation). None of the family environment factors acted act as independent predictors of object location task performance, which suggests that within the sample collected here, such environmental factors did not influence the development of spatial memory. This is in contrast to literature that has found a significant correlation between similar environmental measures and episodic memory (Fomby & Cherlin, 2007). Despite both types of memory being localized to the hippocampus, it is possible that the susceptibility of environmental stress to effect on one type of hippocampal process is not transferable to another.

While no significant link was directly seen between the family environment and object location task, a link was evident with VGE. Of all three familial factors examined, a significant correlation was evident between VGE and parental education in the child sample with an increase in parental education being linked to an increase in VGE. This aligns with the idea concluded by others that parental education level is linked to the amount of disposable income a family has to spend on technology, including videogames, for the household (Jackson et al., 2011; Li & Atkins, 2004). However, no direct, significant correlation was found between income per person and VGE, or income and education. One potential explanation for why you see a correlation between VGE and parental education is the time a child spends engaged with their family versus time spent alone. For example, it is possible households of higher parental education consist of parents who spend more time outside of the home, which may result in children spending more time in front of a screen. This correlation was not found in adults, which may be due to the fact that having moved away from home, and living independently, parental education has less influence on lifestyle and the amount of time spent playing video games.

In contrast to what was expected, perceived family function did not predict VGE or spatial memory. However, previous studies have shown children that lack a sense of appreciation and reward-structure at home tend to seek it elsewhere, such as in video games (Inal & Cagiltay, 2007; Sherry, 2004). Expanding upon the suggested experimental design for VGE outlined previously, a look into perceived familial appreciation before video game experimentation begins may also be indicative of the effect's family environment have on VGE and object location task. The degree to which children report having a less stable family environment may be linked to the degree to which they find playing video games rewarding (Sherry, 2004). This can be tested by comparing the results of family-function data collected from the SCORE to the flow scale questionnaire (Kiili, 2007) used by Inal and Cagiltay (2007) to test the rewarding feeling of playing video games. Those children who find video games more rewarding may not only be more inclined to report a less stable family environment, but also stay more engaged in the intervention, and in turn, may impact their spatial memory performance.

It is important to keep in mind the sensitivity of the data being collected in the current study, and the representativeness of the sample. The collection of such personal information may explain why a greater number of exclusions were reported for this part of the project, resulting in a smaller sample size. The varying degree of comfort individuals feel when providing personal details such as those of the family environment may also lead to sampling bias, whereby the data collected does not accurately reflect the true feelings of the target population. As part of future data collection, it is important to make sure participants are as comfortable as possible. In the present study, this data was collected in paper form in a controlled setting. Online data collection would allow participants to fill out forms in a more comfortable setting (e.g. at home) with a greater sense of animosity, away from the experimenter and testing context.

It will also be important to ensure greater diversity in the population sample included. Of the data collected, the majority of participants identified themselves as a white demographic, with the income per household ranging from $22,000 to $900,000, averaging at $143,444. Therefore, this project only tested a specific demographic consisting mostly of middle-class families. An important future step for the continuation of the Little Panda Project will be the inclusion of a testing sample that is more representative of the general population.

Conclusion

In summary, the present findings reveal developmental differences in dissociable spatial learning strategies. Whilst, response learning matures by at least 9 years old, place learning continues to develop into adolescence. This maturation has also been linked to VGE. In the sample of the study, genre and perspective did not impact spatial memory, but within the children's sample, their overall VGE did predict spatial memory. However, whether the nature of the family environment affects VGE and spatial memory is yet to be understood. Despite no link being found between familial factors and object location task performance, a significant correlation was found between parental education and VGE. Further analysis, however, revealed that this link was mediated by age and did not hold significance on its own. Overall the present study uses novel techniques and factors to understand spatial development and navigation as well as the mediating effect that VGE and family environment have on this development.

Appendix: Sample Forms

Figure A1. Video Game Questionnaire (Parent Version)

Video Game Experience Questionnaire

We are interested in the amount of general experience children have playing video games. This includes a wide variety of different games (from educational games to strategy war games) on different kinds of consoles (cell phones, iPads, consoles, PCs). Please answer each question as accurately as possible about your child's experience.

Does your child play video games on a regular basis? Yes No

If **Yes**, how many years has your child consistently played video games (lifetime)? ________________

Approximately how many hours per week does your child spend playing video games?

a. 0 b. 1-5 c. 6-10 d. 10-15 e. 16-20 f. 20+

If **No**, has your child previously played video games on a regular basis? Yes No

How many years did your child consistently play video games (lifetime)? ________________________

Approximately how many hours per week did your child spend playing video games?

a. 0 b. 1-5 c. 6-10 d. 10-15 e. 16-20 f. 20+

Does your child have a device to play video games? Yes No

What type(s)? ____

What are your child's Top 4 (in order) video games that s/he likes to play?

1. ______________________________ 2. ______________________________

3. ______________________________ 4. ______________________________

Circle your Top 3 genres, or video game categories, that your child enjoys playing.

Action	Maze	Role-playing
Adventure Fighting	Military	
Simulators		
Arcade	Music	Space
City-building games	Pinball	Sports
Economic simulation games	Platform	Stealth
Educational	Puzzle	Strategy War
First-person shooter	Strategy	Survival/Horror
Flight	Racing	Vehicular
God games	Real-time and turn-based tactical	
Mass. Multi. Online Games	Real-time and turn-based strategy	
Other (specify):		

Do any of your child's games involve layout of virtual environments? Yes No

Approximately how many hours per week does your child spend playing video games that involve **learning the layout of virtual environments**?

a. 0 b. 1-5 c. 6-10 d. 10-15 e. 16-20 f. 20+

Does your child watch siblings or friends playing video games? Yes No

If **Yes,** approximately how many hours per week does your child spend observing siblings and/or friends playing video games?

a. 0 b. 1-5 c. 6-10 d. 10-15 e. 16-20 f. 20+

Does your child play "Pokémon Go"? Yes No

If **No,** has your child ever played "Pokemon Go"? Yes No

Figure A2. Long SES Survey (Parent Version)

Participant ID: ____________
Respondent: ☐ Mother ☐ Father ☐ Other (describe) ____________
Date: ____________

PARENT VERSION (parents of children ages 6-17)

1. Demographics

(a) List all household residents who are supported by the income reported below. Any person who has slept in your household for the last month is considered a resident. Please list yourself in the first row and the child participating in this study in the second row.

First and Last Initials	Relationship to child (e.g., biological mother, biological father, sister, step-sister, boyfriend of mother)	Age (Years)	Race/Ethnicity	Date Became Part of Family (DD/MM/YYYY)
You:				
Participating child:	*N/A*			

(b) Does this household contain same-sex parents? ☐ Yes ☐ No

Please note, some of the remaining survey items will ask about the child's Mother (or primary female caregiver) and Father (or primary male caregiver). We recognize that this type of family structure is not the only kind that exists, and we want to capture this diversity with our survey. These categories were chosen primarily for logistic purposes of organizing the survey. Please arbitrarily pick one parent to answer first (for the items asking about Mothers) and one parent to answer second (for the items asking about Fathers). By selecting Yes for the previous item, we will analyze your survey responses in light of this information. Your responses are valuable, and we make every effort to interpret your information accurately.

2. Income, Education, and Employment

(a) What was the total pre-tax income of all people in your household over the past year, including salaries and other earnings, interest, and retirements (rounded to the nearest thousand)?

$____________________

(b) What is your current housing? Do you:

- ☐ Own your own house or condominium?
- ☐ Rent your house or apartment?
- ☐ Exchange services for housing?
- ☐ Live in temporary housing or shelter?
- ☐ Not pay for housing?
- ☐ Have another type of arrangement? DESCRIBE:____________________

(c) The next questions ask about forms of welfare or public assistance your family may have received.

1. When the biological mother was pregnant with the participant, did she receive any Women Infants and Children (WIC) public assistance benefits?	Yes	No	I Don't Know
2. Did the participant receive any WIC benefits when s/he was an infant or small child?	Yes	No	I Don't Know
3. In the past 12 months, have you or anyone in your household received Aid to Families with Dependent Children (sometimes called AFDC or ADC) or Temporary Assistance to Needy Families (sometimes called TANF)?	Yes	No	I Don't Know
4. Since the participant was born, have you or anyone in the household ever received Aid to Families with Dependent Children or Temporary Assistance to Needy Families?	Yes	No	I Don't Know
5. In the past 12 months, have you or anyone in your household received food stamps?	Yes	No	I Don't Know
6. Since the child was born, have you or anyone in your household ever received food stamps?	Yes	No	I Don't Know

(d) How far did the participant's mother (or primary female caregiver) go in school?

- ☐ 1st grade
- ☐ 2nd grade
- ☐ 3rd grade
- ☐ 4th grade
- ☐ 5th grade
- ☐ 6th grade
- ☐ 7th grade
- ☐ 8th grade
- ☐ 9th grade
- ☐ 10th grade
- ☐ 11th grade
- ☐ 12th grade but did not get a high school diploma
- ☐ High school diploma or its equivalent (GED)
- ☐ Attended vocational or technical program after high school but did not graduate
- ☐ Graduated from vocational or technical program after high school
- ☐ Some college but did not receive a degree
  (If so, how many years of college did she attend? ________ years)
- ☐ Associate's degree
- ☐ Bachelor's degree
  (If so, how many years did she take to finish her bachelor's degree? __________ years)
- ☐ Some graduate or professional school but did not receive a degree.
  (If so, how many years of graduate or professional school did she attend? ________ years)
- ☐ Master's degree (e.g., MA, MS)
- ☐ Doctoral degree (e.g., PhD, EdD)
- ☐ Professional degree after bachelor's degree (e.g., MD, DDS, JD)

(e) How far did the participant's father (or primary male caregiver) go in school?

- ☐ 1st grade
- ☐ 2nd grade
- ☐ 3rd grade
- ☐ 4th grade
- ☐ 5th grade
- ☐ 6th grade
- ☐ 7th grade
- ☐ 8th grade
- ☐ 9th grade
- ☐ 10th grade
- ☐ 11th grade
- ☐ 12th grade but did not get a high school diploma
- ☐ High school diploma or its equivalent
- ☐ Attended vocational or technical program after high school but did not graduate
- ☐ Graduated from vocational or technical program after high school
- ☐ Some college but did not receive a degree
  (If so, how many years of college did he attend? ________ years)
- ☐ Associate's degree
- ☐ Bachelor's degree
  (If so, how many years did he take to finish his bachelor's degree? __________ years)
- ☐ Some graduate or professional school but did not receive a degree.
  (If so, how many years of graduate or professional school did he attend? ________ years)
- ☐ Master's degree (e.g., MA, MS)
- ☐ Doctoral degree (e.g., PhD, EdD)
- ☐ Professional degree after bachelor's degree (e.g., MD, DDS, JD

(f) The next questions ask about the job experiences of you and your spouse/partner.

1. During the past week, did you work at a job for pay?	No	Yes
2. Have you been actively looking for work in the past 4 weeks?	No	Yes
3. During the past week, did your spouse or partner work at a job for pay?	No	Yes
4. Has your spouse or partner been actively looking for work in the past 4 weeks?	No	Yes
5. Since the participant was born, has there been any time in which the family has had serious financial problems or was unable to pay monthly bills?	No	Yes

6. About how many total hours per week do you usually work for pay, counting all jobs?

__________ hours / week

7. What kind of business or industry do you work in? (e.g., TV manufacturer, restaurant, farming, retail clothing store)

____

8. What kind of work are you doing? (e.g., electrical engineer, waitress, famer, salesclerk)

____

9. About how many total hours per week does your spouse or partner usually work for pay, counting all jobs?

___________ hours / week

10. What kind of business or industry does he/she work in? (e.g., TV manufacturer, restaurant, farming, retail clothing store)

____

11. What kind of work is he/she doing? (e.g., electrical engineer, waitress, farmer, salesclerk)

____

(g) *Food Security:* These questions ask about your family's worries about food.

For your household <u>in the last 12 months</u>, how true are the following statements?	**Often True**	**Sometimes True**	**Never True**
5. We worried whether our food would run out before we got money to buy more.	1	2	3
6. The food that we bought just didn't last, and we didn't have money to get more.	1	2	3
7. We couldn't afford to eat balanced meals.	1	2	3
8. We relied on only a few kinds of low-cost food to feed the participant because we were running out of money to buy food.	1	2	3
9. We couldn't feed the participant a balanced meal because we couldn't afford it.	1	2	3

Figure A3. Systemic Clinical Outcome and Routine Evaluation (SCORE-15)(Adult Version)

SCORE: Child Version (ages 6-11)

We would like you to tell us about how you see your family at the moment. So we are asking for *<u>your</u>* view of your family. When people say 'your family' they often mean the people who live in your house. **But we want you to choose who you want to count as the family you are going to describe.** All the questions are answered the same way: you circle the number that best matches how you see your family. So if a statement was: 'Our family wants to stay together' and you really feel this fits you completely, you would circle 1 on that line for 'extremely well'.

1	2	3	4	5	6

If a statement was 'We are always fighting each other' and you felt this was not especially true of your family, you would circle 5 for 'not well'.

1	2	3	4	5	6

Do not think for too long about any question, it is how they all add up that we will be interested in, rather than any specific answers. But do try to circle one number for each question.

	Very well	**Well**	**A bit**	**Not well**	**Not at all**
1. In my family we talk to each other about things which matter to us.	1	2	3	4	5
2. In my family people often do not tell each other the truth.	1	2	3	4	5
3. In my family every person gets listened to.	1	2	3	4	5
4. In my family it feels risky or scary to disagree.	1	2	3	4	5
5. We find it hard to deal with everyday problems.	1	2	3	4	5
6. We trust each other.	1	2	3	4	5
7. It feels miserable in our family.	1	2	3	4	5
8. In my family when people get angry they ignore each other on purpose.	1	2	3	4	5
9. In my family we seem to go from one big problem to another.	1	2	3	4	5
10. When one of us is upset they get looked after in my family.	1	2	3	4	5
11. Things always seem to go wrong for my family.	1	2	3	4	5
12. People in the family are nasty to each other.	1	2	3	4	5
13. People in in my family interfere or get involved **too much** in each other's lives.	1	2	3	4	5
14. In my family we blame each other when things go wrong.	1	2	3	4	5
15. We are good at finding new ways to deal with things that are difficult.	1	2	3	4	5

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