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Effects of Age and Gender on Spatial Navigation: Evidence from Samoan Primary School Children

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Abstract

This study examined the effects of age and gender on spatial navigation ability. Samoan Primary School students (N = 40) aged 7-12 years were tested on performance of a Size Test and a Corsi Test, followed by a Spatial Navigation Test. It was hypothesized that older children would perform better at all tasks, especially the Spatial Navigation Test. It was further hypothesized that males would perform better than females at the Spatial Navigation Test and that males would employ more detailed strategies in traversing the spatial navigation space. Lastly, it was hypothesized that increased performance on the Size and Corsi Tests would correlate with increased performance on the Spatial Navigation Test. Results showed that age and gender did not significantly predict spatial navigation ability. Findings suggest that cultural disparities in the constructs of age and gender in Samoa as compared to the United States may have impacted study results. Further cultural specific considerations including language, school system structure, and representational focus are discussed.

Effects of Age and Gender on Spatial Navigation: Evidence from Samoan Primary School Children

The ability to navigate both familiar and unfamiliar surroundings is central to everyday life. As the linchpin of spatial navigation, cognitive mapping involves the conscious and unconscious process of forming mental representations necessary to traverse our surroundings. Previous research has suggested that individuals can navigate in space, even when denied their vision (Klatzky et al., 1990). But is spatial navigation ability which relies upon symbolic representation (Taylor, H., Brunyé, & Taylor, S., 2008) innate – or is it influenced by other demographic, cognitive, and/or cultural factors?

Spatial navigation is widely understood as an individual's ability to distinguish between three types of knowledge involved in forming and using cognitive maps: landmark knowledge, route knowledge, and survey knowledge (Kirsh, 2012; Siegel & White, 1975). Landmark knowledge is accumulated information about specific elements of visual entities at fixed locations; route knowledge refers to the strategy of following a fixed sequence of turns to move to an intended destination; survey knowledge incorporates route and landmark information from various experiences into a single model, such as represented by a standard map (Werner, Krieg-Brückner, Mallot, Schweize & Freksa, 1997). The standardized Corsi block tapping test assesses an individual's memorization and spatial mapping skills through their utilization of symbolic representation (Corsi, 1972). The Approximate Number System (ANS) is a non-symbolic cognitive system which develops over time that supports an intuitive number sense (Libertus, Odic, & Halberda, 2012). Its degree of precision is based on the internal quantity representation often assessed by ratio comparison (Park & Starns, 2015). Although debate persists, substantial research exists evidencing a link between performance on non-symbolic representation tasks and performance on symbolic representation tasks suggesting both skills may play an interrelated role in spatial navigation ability (Verguts & Fias, 2006; McCrink & Spelke, 2010; Buckley & Gillman, 1974; Gilmore, McCarthy & Spelke, 2010; Piazza et al., 2010).

A variety of everyday tasks, ranging from locating objects to basic locomotion, require the mental representation of space. Development of spatial abilities in childhood lays the foundation for solving complex spatial problems in adulthood. In particular, the mastery of symbolic spatial representations, such as maps, significantly bolsters basic spatial capabilities. Moreover, spatial thinking is fundamental for a variety of future STEM professions, including engineers, architects, and chemists (Vasilyeva & Lourenco, 2012).

Prior research suggests that as children develop, they gain a more sophisticated understanding of spatial representation. According to Siegel and White's Theory of large-scale spatial cognition, children progress through three stages of knowledge, each differing in terms of their representation of the spatial environment (Namy, 2005). As previously mentioned, at first, children typically represent large-scale spaces by their *landmark knowledge*, that is their proximity to landmarks. Children in the landmark knowledge stage cannot yet integrate such landmarks. Next, children gain the ability to encode the sequential order of such landmarks along well-known routes. Children in the *route knowledge* stage cannot yet make judgements about all types of routes. Lastly, children acquire the ability to mentally create an overview of their environment. In the *survey knowledge* stage, children can make spatial relations between routes and landmarks. Unlike the earlier forms of knowledge, survey representations are abstract and usually not acquired until middle childhood (Namy, 2005). Evidence also suggests that at approximately 8 years of age, children possess a matured ability to represent spatial information in large contexts. Furthermore, by about 9 years of age, computerized navigation tasks have found similar age-related improvements in spatial navigation ability (Sneider, et al., 2015; Laurance, Learmonth, Nadel, & Jacobs, 2003; Overman, Pate, Moore, & Peuster, 1996).

Prior research has also found that males and females generally differ in their ability to solve spatial tasks. While females tend to rely upon landmark cues to navigate, males tend to utilize more abstract cues, such as Euclidean properties of the environment as well as cardinal directions (Jones & Healy, 2006). Moreover, such sex differences in cue use have been found across a wide variety of spatial tasks, including drawing maps (Spencer & Weetman, 1981), giving verbal directions (Dabbs et al., 1998), moving around a computer-generated virtual maze (Sandstrom et al.,1998), and performing real-world or map-based tasks (Galea & Kimura., 1993). Further evidence suggests that compared to females, males tend to have greater access to specific-spatial promoting activities, such as video games and environmental exploration, which enhances their spatial navigation ability (Galea & Kimura, 1993). Even across several mammalian species, males have been found to outperform females on navigational tasks (Jones & Healy, 2006). In Samoan culture, while males are the given opportunity to wander throughout their environment, females are seldom allowed to engage in adventurous play (Mead, 1928).

A focus on tests that assess an individual's ability to utilize non-symbolic and symbolic representation underlies this research. Three tests were conducted: the Size Test (based on non-symbolic representation, utilization of ANS); the Corsi Test, and the Spatial Navigation Test (latter two based on symbolic representation). We believed that these tests would assess an individual's spatial mapping, memorization, and/or spatial navigation abilities. The unique culture of Samoa provided a desirable setting for this study especially in light of a scheduled future replication in the United States which would highlight cultural influences. Generally, Samoans have lesser access and exposure to sources of symbolic representation (e.g., books, board-games, television, video-games) compared to individuals in the United States (Flood, 2004). Additionally, as a society consumed with technology, Americans tend to rely on cars and navigation systems in order to travel to and from their destinations, while Samoans primarily travel on foot without external directional aid. In Samoa, maps, diagrams, and compasses are largely unavailable. Without access to symbolic tools, their spatial knowledge is necessarily *route knowledge*: practical and non-symbolic. As elaborated upon below, additional cultural contrasts with respect to age and gender roles are of importance to consider with respect to their impact on spatial navigation ability. In particular, the Samoan construct of age is less rigid compared to that of the United States; while Samoans seldom pay attention to childrens' attainment of developmental milestones, Americans tend to stringently classify 'typical' child development (Mead, 1928; MLJ Adoptions, n.d; CDC, 2010). Moreover, the Samoan construct of gender is far more fluid compared to that of the United States; while Samoans fully accept and incorporate, Fa'afafine, a third gender, into their society, gender-norms in the U.S. remain largely binary (Werft, 2016; Witt, n.d).

Importantly, differential performance across cultures may be also associated with disparities in spatial language and representational focus. Lovett and Forbus (2011) suggest that the inclusion of shape names in the English language, may lead Americans to focus more on perceiving shapes when analyzing a visual scene. However, in many other cultures, a lack of exposure to shape language may lead to a greater focus on the parts which make up shapes. Whereas Americans often first focus on individual objects (and possess difficulty reasoning about edges), many other cultures tend to perform well with edges (and possess difficulty evaluating groups of objects). Additional research suggests that using spatial-specific language strengthens children's spatial encodings and spatial mappings (Loewenstein & Gentner, 2005).

Lastly, school system organization in Samoa and the United States is a key cross-cultural consideration. While the education system in Western Samoa is directly linked to demands of University Entrance Examination requirements (with seldom regard for students' individual intellectual growth), the U.S. education curriculum tends to adopt a greater multidisciplinary focus, especially at the collegiate level (Rowman & Littlefield, 1977).

We expected that a relationship would exist between performance on the Size and Corsi Tests and performance on the Spatial Navigation Test. Additionally, we expected that age and gender would be the primary factors affecting subject performance on the Spatial Navigation Test. The exact procedure outlined below will be replicated in the United States in the Spatial Cognition Laboratory upon arrival at Emory University in Fall 2017. Consequently, the specific hypotheses outlined below exclude culture as an independent variable due to currently limited access to comparable cross-cultural data.

Method

Participants

40 participants completed all conditions of this study: 21 were male and 19 were female. Ages ranged from 7 to 12 years (M_{age} = 8.75 years, *SD* = 1.41 years). Participants were all Primary School students in schools throughout Samoa. 23 participants were tested in Faga, 11 participants were tested in Safua, and 6 participants were tested in Apia. Child age was dichotomized into two age groups using a median split: children below the median split (7-8 years) were characterized as *younger* (n = 21, M_{age} = 8 years, 11 male, 10 female) and children at or above the median age (9-12 years) were characterized as *older* (n = 19, M_{age} = 10 years, 10 male, 9 female). (See Results for rationale underlying division of age groups).

Materials and Procedure

The present study was conducted throughout various schools in Faga, Safua, and Apia, located on the Samoan Islands. Prior to the onset of testing, each subject was interviewed to attain preliminary background information. Subjects were then directed to read the test instructions on paper while an older Samoan student read them the instructions aloud. Instructions were translated from English to Samoan and then back-translated from Samoan to English to ensure accuracy. Rewards (stickers) were given to subjects following every test in order to facilitate their continued engagement with the task. The majority of subjects were tested individually under a closed roof pavilion in their school. When a pavilion was not available, testing occurred outside in the schoolyard. Subjects' behaviors during testing were assessed via experimenters' direct observation along with supplemental video footage of the Spatial Navigation Test. Intense field notes were taken to record subtleties which may have influenced data results. The Size Test and Corsi Test were performed as a precursor to the Spatial Navigation Test as a means of demonstrating each participant's capability to carry out experimental tasks.

Size Test

The instructor presented two abstract shapes and asked the participant to identify which shape is bigger. Each time the subject pointed to a shape, the instructor noted whether the shape was located on the left or the right. Four practice trials were conducted to ensure the subject's comprehension of the instructions and procedure. The stated procedure was repeated for 30 test trials.

Corsi Test

This test was based on the standardized Corsi Test (Corsi, 1972). E1 presented a display of cubical blocks in front of the participant which were numbered on the experimenter's side to facilitate sequence demonstration. E2 then tapped a sequence of blocks and instructed the participant to tap these same blocks in the same order. Practice trials were conducted until the subject demonstrated complete comprehension of the instructions and procedure. The instructors demonstrated the procedure jointly in instances when the subject was still confused after multiple practice trials. Sequences started with two blocks and proceeded up to nine blocks, with sixteen sequences in total. The test was complete when the participant failed three sequences in a row.

Spatial Navigation Test

This test was based on a navigation study led by Klatzky (Klatzky et al., 1990). The instructors created a circle with a 1.5-meter radius (3-meter diameter), placing 5 points along the circle (A-E) and the origin (O) halfway between the chord connecting points A and E. The length of the chords between each successive point was 69.42 inches (1.76 meters) and the origin was marked with an “X”. The circle was made with chalk on concrete when available; otherwise, the circle was created with chalk on wood flooring or with a stone in the dirt. The subject was guided along a series of 10 paths (starting with two, one chord paths; proceeding with four, two chord paths; and concluding with four, three chord paths). For each path, the subject was blindfolded and instructed to keep their eyes closed. The subject started at the “X” and then was guided along a specific path. Upon completion of the path, the subject was instructed to walk back without guidance to the starting point, stopping when they got there. In order to ensure the subject’s understanding of the instructions and procedure, one practice trial was conducted with the subject’s eyes open, and two practice trials were conducted with the subject blindfolded and their eyes closed. In between trials, the subject was spun around in an effort to reduce a potential learning curve. At the conclusion of each path, the instructors recorded the number of inches the subject was from the origin by measuring the distance from the closest part of their foot to center of the “X”.

Results

This study examined the effects of age and gender on spatial navigation by assessing participants’ responses to the above tests. The age variable was divided into a younger group (7-8 years old) and older group (9-12 years old) according to the median split in order to achieve similar sample sizes and hence similar power for detecting a significant effect of the experimental manipulation in both groups. Subjects were evaluated by their number of correct responses for the Size Test, number of trials completed for the Corsi Test, and distance from the origin for the Spatial Navigation Test.

Descriptive Statistics

In Table 1, we provide the descriptive statistics for our sample, which was approximately an even distribution between male and female subjects, aged 7 years to 12 years of age.

Tests of Main Hypotheses

An alpha level of 0.05 was used for all statistical tests.

Substantiating Test Measures. All hypotheses tested relied upon the demonstrated capability of participants to perform the experimental tasks. On the Size Test, a significant proportion (90%) of participants correctly responded on at least 90% of the trials. This was determined using a binomial test that compares the proportion (36/40) to chance (50/50), which in this case yielded $p < 0.05$. A significant proportion (70%) of participants correctly responded on at least 94% of the trials (incorrect on $\leq$ 3 trials). This was determined using a binomial test that compares the proportion (28/40) to chance (50/50), which in this case yielded $p < 0.05$. Substantial skill was required to discriminate between shapes that were differentiated by minute ratios (even for adult participants). These data support participants' capability to conceptualize abstract shapes. Further, on the Corsi Test participants completed an average of $\approx$ 7.58 trials (up to a 5 number sequence). These results further substantiated participant capability to carry out the experimental tasks, especially in light of the numerable distractions (as set forth in the limitations).

Effects of Age. We expected older subjects to perform better at all tasks, especially the Spatial Navigation Test, as the map-mediated model of large scale space (which allows for survey representations) does not emerge until approximately the age of 8 (Namy, 2005). Moreover, younger children are unable to apply schematic representations in unfamiliar scenes while older children can integrate abstract information containing spatial representations (Cohen, 2013).

Additionally, ANS acuity increases in precision over time (Mazzocco, Feigenson, & Halberda, 2011). A Univariate ANOVA test showed that this effect was not statistically significant: for the Size Test, $F(1, 34) = 0.824$, $p = .370$, $\eta^2 = .024$; the Corsi Test, $F(1, 35) = 0.781$, $p = .383$, $\eta^2 = .022$; and the Spatial Navigation Test $F(1, 33) = 0.610$, $p = .440$, $\eta^2 = .018$.

Effects of Gender. We expected male subjects to perform better than female subjects on the Spatial Navigation Test due to males' innate ability to outperform women in spatial memory tasks (Jones & Healy, 2006) as well as their greater freedom to explore and wander given the nature of the male gender role in Samoa (O'Meara, 1990). A Univariate ANOVA test showed that this effect was not statistically significant, $F(1, 33) = .011$, $p = 0.918$, $\eta^2 < .001$. We also expected male subjects to employ more detailed strategies than female subjects in traversing the spatial navigation space due to the male tendency to focus on Euclidean properties of the environment rather than the female tendency to focus on landmarks within the environment (Saucier et al., 2002). Notably, this hypothesis was based solely on theory and could only be observationally analyzed. Video footage showed that male subjects tended to rotate their heads in an effort to create a mental map and more often retraced their steps in comparison to female subjects.

Interaction of Performance on Size and Corsi Tests with Performance on Spatial Navigation Test. We expected that subjects' increased performance on the Size Test would correlate with increased performance on the Spatial Navigation Test. We found no significant correlation when running a Persons correlation test, $r(39) = .086$, $p = 0.602$ (see Figure 1 for a graphical representation of this correlation). We also expected that subjects' increased performance on the Corsi Test would correlate with increased performance on the Spatial Navigation Test. Again, we found no significant correlation when running a Persons correlation test, $r(39) = -.012$, $p = 0.944$ (see Figure 2 for a graphical representation of this correlation). As discussed, these hypotheses were based on prior research suggesting that increased performance on non-symbolic tasks (e.g., Size Test) are associated with increased performance on symbolic tasks (e.g., Spatial Navigation Test) (Verguts & Fias, 2006; McCrink & Spelke, 2010; Buckley & Gillman, 1974; Gilmore, McCarthy & Spelke, 2010; Piazza et al., 2010). Similarly, we anticipated that increased performance on a symbolic task (e.g., Corsi Test) would be associated with increased performance of other symbolic tasks (e.g., Spatial Navigation Test). These hypotheses were supported by neuroimaging studies which indicated that symbolic and non-symbolic number processing activate similar brain regions (Fias, Lammertyn, Caessens, & Orban, 2007; Fias et al., 2003).

Discussion

Although the results from the present study are not statistically significant, the following reasons underlie speculations for our findings. A particular focus on the Samoan constructs of age and gender as well as the Samoan school system suggest culturally contextual explanations. Cross-cultural comparisons with the United States are briefly addressed in anticipation of our future research study. Moreover, recent research pointing to a discontinuous relationship between non-symbolic and symbolic representation is considered. It is important to recognize that other factors (besides age, gender, and culture) may play a role in the individual acquisition of spatial navigation ability.

Samoan Construct of Age

"Birthdays are of little account in Samoa." (Mead, 1928). Accordingly, not all participants in this study were aware of their age and/or date of birth. Passage of time is less defined than it is in the United States, as nothing marks year-to-year. As such, in Samoa, cognitive tasks which may contribute to performance on non-symbolic and symbolic tasks are not generally associated with a timeline and may not be as actively concentrated upon as is typical in the United States.

Developmental Milestones. In Samoa, scant attention is given to developmental milestones. Furthermore, developmental milestones may be confounded with other experiences. For example, parents may be attentive to signs of their child's physical growth, but discount elements of his/her private subjective experience (MLJ Adoptions, n.d.). Moreover, students do not have to be of a particular academic ability to advance their level of education (Rowman & Littlefield, 1977). By contrast, in the United States, there are many developmental milestones grouped into specific categories: social and emotional, language/communication, cognitive, and movement/physical development. For example, by five years, children should be able to "count 10 or more things" (CDC, 2010).

Samoan Construct of Gender

In Samoan culture, childhood gender roles are not polarized; boys and girls tend to play with the same toys and games. Additionally, Fa'afafine, a third gender, is a well-accepted and valued part of society (Werft, 2016). In the United States, however, disparate gender roles are largely based on distinct standards created by society. Masculine roles are usually associated with aggression and dominance (e.g, trucks, superheroes), while feminine roles are usually associated with passivity and subordination (e.g., make-up, "house") (Witt, n.d.). Thus, the discrepancy between male and female performance with respect to spatial navigation ability may be diminished in Samoa, reflective of the diminished disparity in their gender roles. Notably, however, to the extent that the variance between male and female spatial navigation ability is innate, the effect of gender would be expected to persist regardless of cultural influence.

Samoan School System

The Samoan school system follows an educational model tailored to the specific requirements of University Entrance Examinations. Academic programs in Samoa are not designed to develop competencies applicable to more comprehensive achievement or to develop skills in other areas. Only one percent of students pass the entrance requirements, relegating the majority of students to advance through the school system regardless of their cognitive capacity to understand the material (Rowman & Littlefield, 1977). The United States educational system, by contrast, is characterized by a broad-based curriculum and intense standardized testing which tracks students' performance and progress throughout their academic careers. The narrow focus of the educational experience in Samoa may have contributed to subject performance.

Non-Symbolic and Symbolic Representation Associations

Although ample research supports a link between performance on non-symbolic and symbolic tasks (Verguts & Fias, 2006; McCrink & Spelke, 2010; Buckley & Gillman, 1974; Gilmore, McCarthy & Spelke, 2010; Piazza et al., 2010), a number of studies suggest a potential nonlinear association. Specifically, Bonny and Lourenco's (2012) research evidenced a discontinuous relationship between ANS and symbolic math. Moreover, Soltész, Szücs, D & Szücs, L (2010) failed to find an association between ANS and symbolic concepts. Furthermore, Lyons and Beilock (2013) found that the connection between symbolic and non-symbolic number representations is restricted to cardinal processing. Thus, a growing body of research supports a not-so-direct overlap between non-symbolic and symbolic representation tasks and may undermine the reliability of studies inconsistent with these findings. Such evidence may contribute to the insignificance of the correlation between increased performance on the Size Test and increased performance on the Spatial Navigation Test among the subjects tested in the present study. The insignificant correlation between increased performance on two symbolic tasks (e.g., Corsi Test and Spatial Navigation Test) may have been impacted by the cultural context as well as the limitations described below.

Limitations

With the exception of one participant who confessed to seeing through the blindfold during the Spatial Navigation Test, all subjects tested were included in the data analysis. However, unequal variance across villages suggests that confounding variables may have affected our results: First, surrounding noise could not be well-controlled throughout testing. Particularly during recess, participants were subject to external distractions (e.g., students, friends, teachers). Moreover, as stated earlier, for the Spatial Navigation Test, there were deviations across locations with respect to circle construction. Furthermore, chord distance was ±2 inches from points E – A. Landmarks on the floor and over-verbal translators (who may have given subjects hints) must also be noted. Such suspected translators were replaced, and the data obtained during those testing sessions did not statistically impact the results. English proficiency may have also impacted students' comprehension of instructions and procedure and consequently affected their performance. Additionally, our sample consisted of primary school students located in three Samoan villages (Faga, Safua, and Apia), which may not be generalizable to primary school students attending all types of schools in Samoa. Since the present study is correlational, causality cannot be assumed.

Implications

The results of the current study not only contribute to the existing research regarding the effects of age and gender on spatial navigation ability, but also provide an examination of this relationship in an under-researched population. This project addresses a gap in the literature by examining such associations during childhood. Additionally, this study expands our body of knowledge by highlighting potential cultural influences on children's spatial navigation abilities, such as differences in language, school system organization, and representational focus. Further investigation is warranted in order to potentially provide foundational material for parents and teachers intended to increase support for developing children including greater achievements in STEM disciplines.

Conclusions and Future Steps

The effects of age and gender on spatial navigation ability remain unclear. The extent to which biology, cognition, and/or culture impact symbolic representation and spatial navigation ability calls for further examination which includes cross-cultural analysis. Corresponding research in the United States is called for to assess the extent to which relevant factors impact spatial navigation ability. Moreover, although we found null results, this led to a deeper focus on the cultural disparities between Samoa and the United States in preparation for our future study. Also, this study revealed confounding variables which can now be controlled for in our prospective research in America and for other replication studies. Future studies may also explore the effects of other relevant independent variables on spatial navigation ability. Such variables may include students' exposure to maps, mental rotation ability, and technology usage. Lastly, a longitudinal study should be conducted to examine changes in variables of interest over time. In particular, longitudinal data would allow researchers to answer more complex questions regarding the role of age and gender on spatial navigation ability.

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Table 1

Performance on Size, Corsi, and Spatial Navigation Tests as a Function of Age and Gender

	Age		Gender	
	Younger	Older	Male	Female
Size Test (%)	.945 (.060)	.922 (.094)	.933 (.076)	.935 (.081)
Corsi (/16)	7.20 (2.067)	7.74 (1.593)	7.50 (1.906)	7.42 (1.835)
Spatial Nav (in.)	39.403 (20.266)	34.618 (16.323)	37.886 (17.879)	36.122 (19.401)

Note. Standard deviations appear in parentheses below means.

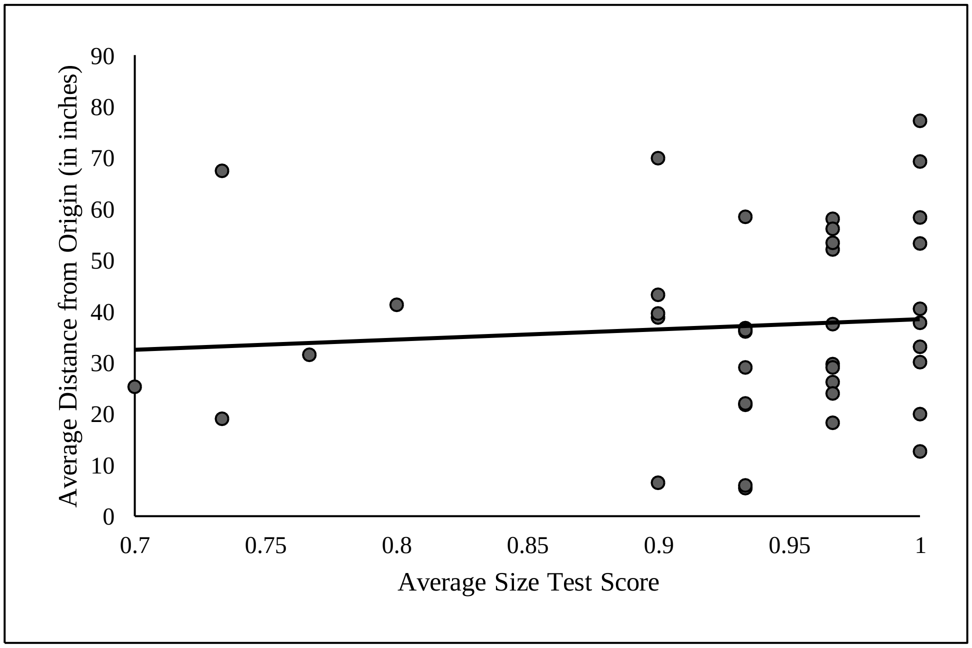

Figure 1. Graphical Representation of Correlation Between Performance on Size and Spatial Navigation Tests. A slight, positive albeit not significant correlation of r = 0.086 is shown by the graph

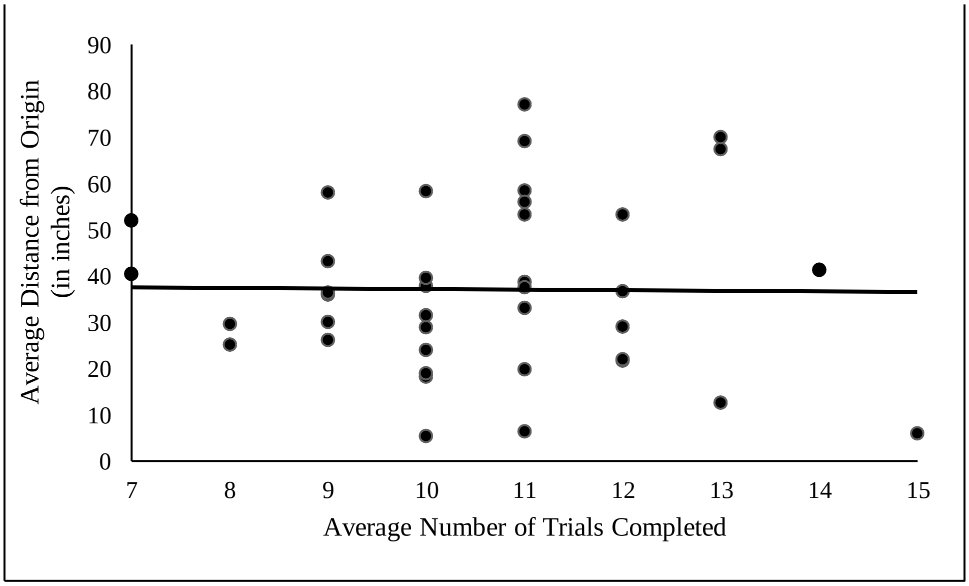

Figure 2. Graphical Representation of Correlation Between Performance on Corsi and Spatial Navigation Tests. A slight, negative albeit not significant correlation of r = -0.012 is shown by the graph.