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Cultural Change Reduces Gender Differences in Mobility and Spatial Ability among Seminomadic Pastoralist-Forager Children in Northern Namibia

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Abstract

A fundamental cognitive function found across a wide range of species and necessary for survival is the ability to navigate complex environments. It has been suggested that mobility may play an important role in the development of spatial skills. Despite evolutionary arguments offering logical explanations for why sex/gender differences in spatial abilities and mobility might exist, thus far there has been limited sampling from nonindustrialized and subsistence-based societies. This lack of sampling diversity has left many unanswered questions regarding the effects that environmental variation and cultural norms may have in shaping mobility patterns during childhood and the development of spatial competencies that may be associated with it. Here we examine variation in mobility (through GPS tracking and interviews), performance on large-scale spatial skills (i.e., navigational ability), and performance on small-scale spatial skills (e.g., mental rotation task, Corsi blocks task, and water-level task) among Twa forager/pastoralist children whose daily lives have been dramatically altered since settlement and the introduction of government-funded boarding schools. Unlike in previous findings among Twa adults, boys and girls ($N = 88$; aged 6–18) show similar patterns of travel on all measures of mobility. We also find no significant differences in spatial task performance by gender for large- or small-scale spatial skills. Further, children performed as well as adults did on mental rotation, and they outperformed adults on the water-level task. We discuss how children's early learning environments may influence the development of both large- and small-scale spatial skills.

Keywords Spatial cognition · Mobility · Gender differences · Child development · Schooling

As with all mammals, humans rely on spatial ability for many tasks of daily life: to search for mates, find food, and avoid predators and other threats. Humans differ widely in this ability, often by age and gender. For example, men generally demonstrate higher

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Extended author information available on the last page of the article mean performance on assessments that measure navigational skill or spatial orientation, especially those required for long-distance travel (Bryant 1982; Galea and Kimura 1993; Henrie et al. 1997; Nazareth et al. 2019). As a result of such findings, identifying the underlying mechanisms responsible for many of these reported differences has been the focus of considerable animal and human research over the past few decades.

Evolutionary hypotheses have been proposed to explain why observed gender differences in spatial ability exist (Geary 1995). Though there is debate over the exact selection pressures responsible, many proposed explanations come from the fields of evolutionary biology and evolutionary psychology and focus on the evolutionary benefits males gain from having larger ranges to meet various navigational challenges. For example, one explanation, which finds evidence in cross-species comparisons with polygynous species, suggests that the selection pressures that may be responsible for improved male spatial ability include the navigational challenges associated with mate seeking (Gaulin et al. 1990; Geary 1995; Jones et al. 2003). Another evolutionary explanation suggests that the emergence of a sexual division of labor in humans during the Pleistocene era drastically altered the mobility and navigational demands for men and women, ultimately driving the selection of gender differences in spatial ability (Silverman et al. 2007).

Consistent with these arguments, earlier work with Twa forager/pastoralists in Namibia found that men ranged much farther than women and did better on some spatial tasks (Vashro and Cashdan 2015; Vashro et al. 2016). Because Twa men with larger ranges were also found to have fathered more children by more women, these findings supported an evolutionary basis for the observed gender differences (Vashro 2015). In this paper, we study the *ecocultural niche* (Weisner 2002) of children in Twa society to see if, and when, gender differences in range size and spatial ability appear during childhood and whether these patterns reflect previous findings among adults. If the observed gender differences in spatial abilities found among the Twa adults are related to gender differences in mobility, these patterns should be responsive to the ecological conditions that children face growing up. If mating competition underlies the previously observed gender difference in range size among the Twa, we might expect these differences to emerge in adolescence, a period in child development marked by accelerated physical growth, sexual maturation, as well as social, emotional, and motivational changes (Forbes and Dahl 2010). On the other hand, if differences are shaped by the sexual division of labor, we might expect to see differences emerge during middle childhood, when children begin participating in gender-differentiated tasks (Bock and Sellen 2002; Stieglitz et al. 2013).

We also consider and discuss recent cultural changes in the region associated with formal education which have directly affected Twa daily life, including children's mobility and spatial experiences, over the past 15 years (UNICEF 2013). For example, unlike the Twa adult cohort, most Twa children have now been exposed to formal schooling. However, the influence of schooling goes beyond what is taught in school. Twa girls and boys also travel substantial distances each week, frequently accompanied only by peers, in order to attend boarding school. These recent travel requirements for children are in stark contrast to the patterns of mobility that Twa adults experienced during childhood. Since children's mobility in nonindustrial societies is often shaped by gender-differentiated tasks, and older Twa girls would have spent more time at home as caretakers for younger siblings (Vashro 2014), the greater participation in schooling by Twa children may also be expected to reduce gender differences in spatial behavior. In order to facilitate a cross-sectional comparison between the previously collected data on range size and spatial abilities among Twa adults (referred to as Twe in those studies) and the current study among Twa children, we use many of the same measures and instruments, and we report on both.

When Do Gender Differences in Spatial Ability Appear?

Given the influence of children's environmental experience on spatial ability (Baenninger and Newcombe 1989; Doyle et al. 2012; Levine et al. 1999), and the marked differences across societies in the nature of that experience, it is worth reconsidering the malleability of gender differences in spatial ability. Though gender differences have been reported in different environments and cultures (Cashdan & Gaulin 2016; Ecuyer-Dab and Robert 2004; Vashro et al. 2016), these differences are not invariant across societies. Further, the vast majority of findings have focused on samples from WEIRD (Western, educated, industrialized, rich, democratic) populations, which can conflate biological, environmental, and cultural drivers (Henrich et al. 2010).

Gender differences do not exist in all spatial tasks, but in WEIRD societies males do better at many of them, including three that we study here: mental rotation (the ability to imagine what an object would look like if it were rotated about its axis), the water-level task (WLT; accuracy at knowing where the water-line would lie in a tipped vessel), and navigation. The gender difference in mental rotation is among the most widely studied and shows the largest gender difference in adults (Voyer et al. 1995). There remains debate about the age at which boys begin to show an advantage at this task, but there is broad agreement from recent studies in WEIRD societies that differences appear reliably in middle childhood, at around 9 or 10 years of age (Neuburger et al. 2011), and possibly earlier.[1] Boys generally out-perform girls in the WLT (Thomas and Turner 1991), with some studies reporting gender difference beginning in middle childhood and increasing in adolescence (Linn and Petersen 1985; Voyer et al. 1995). Studies of gender differences in navigational abilities show more variability, but a recent meta-analysis also found an overall male advantage, although with a small effect size before adolescence (Nazareth et al. 2019). Although small-scale tasks such as mental rotation and large-scale tasks such as navigation in environmental spaces are distinct abilities (Hegarty and Waller 2005), some studies in Western societies have shown a relationship between mental rotation and outdoor navigation ability (Malinowski 2001; Silverman et al. 2000).

Childhood Gender Differences in Range Size and Spatial Experience

In the United States (Hart 1979; Matthews 1987) and several small-scale, nonindustrial societies (Whiting and Edwards 1992) gender differences in range size also appear during middle childhood, beginning at around age 8 or 9. However, the magnitude and

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[1] Some studies have found a gender difference in mental rotation (or its precursors) in preschoolers and even infancy (Levine et al. 1999; Moore and Johnson 2011; Quinn and Liben 2014), although preschoolers often fail at this task (Frick et al. 2013, 2014).

even direction of this difference is shaped, in part, by children's participation in gender-differentiated adult tasks (Whiting and Edwards 1973). In many small-scale societies, gender segregation begins to increase during middle childhood (6–10) and early adolescence (11–13) when children begin participating in adult activities, identifying with adults of their same gender, and imitating their behaviors (Draper 1976; Endicott and Endicott 2008; Flannery 1953; Gallois et al. 2015; Lancy 2014; Wallace and Hoebel 1952). This has implications for mobility and spatial experience. A general pattern found in Whiting and Whiting's (1975) six-cultures study was that girls spent more of their day closer to their mothers and doing responsible work, while boys had more freedom to wander and play farther from home (Edwards 2000). However, the magnitude of this difference varied among the cultures and, by middle childhood, had reversed in one of them (Tarong) (Whiting and Edwards 1992). Among the Tsimane of central Bolivia, both boys and girls frequently engage in activities away from the home (e.g., hunting and fishing) as early as middle childhood (Davis and Cashdan 2020). Likewise, gender differences were minimal among children in the mobile foraging camps of!Kung Bushmen, where children did little work, although these differences became more pronounced in the settled camps as children began to engage in gender-specific tasks (Draper and Cashdan 1988). Thus, although a gender difference in range size appears widely, it has not been found in all societies.

Effects of Environment and Spatial Experience on Spatial Skills

We are interested in whether differences in range size have implications for large- and small-scale spatial abilities. There is compelling evidence that large- and small-scale spatial abilities are separate but correlated skills (Hegarty et al. 2006), which are both affected by environmental experience (Ruginski et al. 2019; Wolbers and Hegarty 2010). For example, in a study of English children, boys ranged farther than girls, and their larger ranges were associated with the ability to draw more accurate and detailed maps (Matthews 1987). However, gender differences in a similar task disappeared when the maps were restricted to areas with which boys and girls had equal familiarity (Webley 1981), suggesting a difference in environmental knowledge but not necessarily spatial ability.

The benefit of exploration on environmental knowledge is also suggested by the superior maps drawn by children who travel to school on their own, rather than being accompanied by their parents (Rissotto and Tonucci 2002). Overall, less is known about whether larger ranges and freedom to explore in childhood leads to better spatial ability on small-scale spatial tasks, but some provocative results suggest that it does. In two agropastoral populations in Kenya, the Logoli and the Gusii, boys typically ranged farther from home than girls, and children who had larger ranges did better at several spatial tasks (Munroe and Munroe 1971; Nerlove et al. 1971).

Environmental and cultural differences also play a role in the development of spatial abilities. For example, in a comparison of children's visual spatial memory, Kleinfeld (1971) found that Alaskan Native children demonstrated far greater ability than their white school-aged peers. Berry (1966), similarly, noted excellent spatial abilities in a population of Alaskan Native women and men. He attributed the absence of a gender difference, and their high performance generally, in part to the freedom granted to children. Although he does not document mobility patterns, it seems reasonable to infer that spatial exploration by children in this foraging society would be one consequence of their unrestricted upbringing. Children in two tropical forest populations, the Mbendjele BaYaka of the Republic of Congo (Jang et al. 2019) and the Tsimane of Bolivia (Davis and Cashdan 2019), also have excellent navigational skills. Boys and girls in both societies spend considerable time working and playing away from home and demonstrate no gender differences in either range size or pointing accuracy. These findings underlie the important role that male/female socialization practices play in the development and practice of spatial skills. And, to the extent that spatial ability is affected by environmental experience, gender differences in spatial behavior and cognition may be reduced when boys and girls are given equal freedom to explore.

The Present Study

The analysis proceeds in two stages. We first document the pattern of gender on mobility, large-scale spatial skills (navigation), and small-scale spatial skills (e.g., mental rotation task, Corsi blocks task, WLT) among Twa children. We then compare these results with similar data collected earlier on Twa adults.

In the second stage, we evaluate the implications of developmental and environmental differences in spatial experience on spatial abilities during childhood. If larger ranges require greater navigational competence and provide greater environmental experience, we may see gender differences in navigational performance emerge during early or late adolescence. On the other hand, if children show similar patterns of mobility, range size, and spatial experiences during middle childhood and early adolescence, we may find that gender differences in spatial ability remain small.

Because nearly every child in the sample had attended or was currently attending one of two boarding schools (~90%), our study cannot compare the range sizes and spatial abilities of schooled versus unschooled children. We do, however, compare the range sizes and spatial abilities of children (primarily schooled) and adults (primarily unschooled) with a specific interest in the effects that traveling to school may have on children’s spatial experiences.

Population

Participants in this study live in the mountainous desert region near the Kunene River, which separates northwestern Namibia and southwestern Angola. The sample included children from the Twa, Tjimba, and Himba ethnic groups. In contrast, the previous studies (Vashro and Cashdan 2015; Vashro et al. 2016) were done in the same area but included a smaller fraction of Himba than in the current study. However, all three populations are Bantu-speaking groups (Estermann 1981) and practice similar marital and ritual cultures, including patrilocal residence patterns and matrilineal descent-groups (Bollig 2004; Malan 1974). For the purposes of this study, the most meaningful difference between these groups is that Himba tend to own considerably more livestock than the Twa or Tjimba. Across all groups, men and boys are generally responsible for bringing livestock to pasture in distant locations during the dry season and once the local supply of grass is depleted. This has historically resulted in a greater gender difference in mobility beginning at an early age. Except for occasionally hitchhiking to the town, all travel is on foot (or sometimes by donkey).

The more striking differences within the current populations exist between older and younger generations. For example, government-funded schools have become larger and more established throughout the region over the past 15–20 years. Because travel distances between villages and schools can be long—our sample has an average of 13 km walking distance—children are generally provided room and board Monday through Friday at the school and return to their home village on the weekend. School meals most commonly consist of maize meal, though some schools have begun developing their own small garden programs. Unlike in the previous study conducted among Twa and Tjimba adults, nearly all the children in this study had attended, or were currently attending, boarding school. As a result, children's mobility patterns and daily activities are a stark contrast to the daily lives their parents experienced growing up.

Methods

Data collection was conducted with 88 Twa, Tjimba, and Himba children (6–18 years) from the Kunene region. Comparisons were then made with previously published data from adults from the same villages collected between 2012 and 2014, which included 129 adults (18–80 years). Because additional measures were collected in the current study, only two measures of mobility, one large-scale spatial measure, and two small-scale spatial measures were compared between the adult and child cohorts.

Data collection was challenging; it required not only working at schools but also visiting individual households to conduct interviews with parents of recruited subjects; participants and parents were often difficult to locate. The distance from homes and schools to our camp ranged from 1.2 km to 30 km (median = 13.6 km) and required transportation in a 4 × 4 vehicle. Lack of water resources and persistence of drought meant families were often away from home, retrieving water from sand wells or bringing livestock to cattle posts, thus requiring frequent visits to homesites to complete individual and household-level data collection.

Methods outlined below speak specifically to data collection in the fall of 2017 among Twa children. For further details on the same methods and data collection strategies among adults see Vashro, Padilla, and Cashdan (2016).

Age Children's ages were collected during interviews with each child and were confirmed through parent interviews, available census data, and teachers' ledgers. Most analyses use age as a continuous variable. However, for several analyses, children were also categorized into one of three developmental periods: middle childhood (6–10), early adolescence (11–13), and late adolescence (14–18). These stages are differentiated by distinct physical, social, and hormonal changes. Of importance to this study is the potential increase in travel during early mate-seeking years (i.e., late adolescence), which should show variation in travel patterns between boys and girls. Our small sample size precluded creating additional age cohorts.

Mobility

Daily Mobility If participants were currently enrolled in school, they traveled with QStarz BT-Q1000XT GPS data loggers on Fridays and returned them on Mondays.

Children who were not currently attending school while we were visiting the communities were given the GPS data loggers on randomly selected days during the study period since their daily activities were not affected by school's weekly schedule. Each child wore their GPS unit for three days, removing it only to sleep and bathe. To facilitate wearing the GPS device for multiple days, and to ensure that it would not become cumbersome, each GPS unit was placed inside a small travel case and secured to a lanyard so children could carry it around their neck. After three days, participants returned the device and the individuals' tracks were recorded on a laptop using QStarz GIS software. Of the 71 children given GPS devices, 100% had at least two days of GPS data recorded, and 49% had three days of GPS data recorded. Limited battery power and lack of electricity were the primary reasons that some GPS devices were only able to record two days of data before failing.

To supplement the GPS data, children were asked to recall places visited, time spent out of the community, and purpose of travel (e.g., work, school, or play) during the tracking period. The variable of interest in this study was average daily distance traveled and range size (minimum convex polygon).

Annual Mobility In order to capture regional mobility that might be missed by our short-term GPS tracks, participants were asked to recall all full-day and overnight trips taken during the previous 12 months (location and purpose of the visit, and whom they went with). The measure used in analyses is the total number of unique places mentioned over one calendar year. Most young children had little to no travel to other villages, and overnight trips are infrequent.

Lifetime Mobility A list of 30 locations within the region was used to create an ordinal measure of longer-term regional mobility. The measure reflects both number of places and frequency of travel to them. For each location, participants were asked whether they had ever been there, and if so, whether they had been once, a few times, or many times. In this analysis, we did not consider frequency of travel to each location; rather, we scored lifetime mobility as the percent of places ever visited.

Large-Scale Spatial Ability

Pointing Error Pointing error—also referred to as pointing accuracy or dead reckoning—is a frequently used measure of navigational ability. For this study, participants were asked to point to seven locations within the region using a Brunton compass mounted on a tripod, with the sight extended to act as a pointer (Fig. 1). Each participant was trained to point the sight as they would their own finger, and two to three practice rounds were conducted with nearby, visible targets before pointing to the more distant locations that were out of view (distances ranged from 8 to 90 km away). Error was calculated as the difference between the correct bearing and the pointed bearing. Correct bearings were calculated by the DIGIT Lab at the University of Utah using GPS waypoints taken at the origin and target locations (when this was not available from maps), and the pointed bearings were corrected for declination.

Because children were not all tested from the same location, and because not every participant was able to answer all seven questions during the pointing assessment, we

Fig. 1 Satellite image showing study region. Location A indicates the participant's point of origin. In the pointing task, the participant was asked to point to other locations in the region (e.g., location B and location C). In the perspective taking task, the participant was asked to imagine they were at location B and point in the exact direction of location C. Dotted line indicates actual travel path between locations A and B. In the above map, the distance between location A and location B was 60 km; the distance between location A and location C was 44 km

used z-scores to standardize pointing error (and control for distance) across all participants who attempted each unique pointing event (i.e., from the same location to the same target), and we calculated the mean of the standardized scores across all points to obtain one measure of average pointing error.

Small-Scale Spatial Abilities

Mental Rotation Task (MRT) We measured mental rotation ability because of its large gender difference in Western societies, and because there is some evidence of its relationship to navigation. We used a MRT of our own design, which has been used successfully with Twa adults (Vashro et al. 2016) and with Tsimane children (Davis and Cashdan 2019); see Fig. 2. The design is well-adapted for field use and minimizes other (nonrotational) strategies and factors that inflate the gender difference in some widely used tests (Hegarty 2018). The task uses two sets of images presented in separate blocks, one of a human figure with an outstretched arm (one block each of front and back bodies), the other of a bent twig. The images are displayed on a touchscreen, with the rotated target image at the top of the screen (images were rotated in the picture plane in increments of 60° and displayed in random order) and two images at the bottom, one of which is the same as the target and the other, its mirror image. Participants are asked to touch the one that is the same as the target. To explain "same" and "different" nonverbally, training trials show the target image at the top rotating to match the orientation of the correct image.

Corsi Blocks Task (CBT) The CBT is a test of visuospatial short-term memory. We did not anticipate a gender difference in this task (Kessels et al. 2000), but we included it because it may partially explain performance in other spatial abilities. The apparatus consists of nine blocks arranged in an irregular pattern. The researcher sits opposite the participant and taps the blocks, beginning with a sequence of two. The participant then is asked to tap those blocks in the same order and is given two trials to do it correctly. If at least one of those trials is correct, the sequence is lengthened by one block, and the process is repeated, adding a block to the sequence each time, until there are two incorrect trials in a row.

Water Level Task (WLT) The WLT also shows a gender difference favoring males, not only in Western societies but also among adult Twa (Vashro et al. 2016) and Hadza foragers (Cashdan et al. 2012). In our implementation, subjects were shown four images of a tipped glass, with water lines varying between horizontal (Fig. 2, option 4) and parallel to the base of the glass (Fig. 2, option 1). They were asked to choose which was correct.

Statistical Methods

To investigate the effects of gender and maturation on mobility and spatial ability, we use both frequentist null hypothesis testing (NHT) and Bayesian analyses. Both methods rely on a series of underlying assumptions and calculations, but whereas frequentist analyses only use conditional distributions of data given specific hypotheses, Bayesian analyses weigh evidence and model uncertainty by a probability distribution over hypotheses (Schönbrodt and Wagenmakers 2018). When only the frequentist approach is used, inferences can be made that gender or age has an effect on mobility and spatial mobility, but inferences cannot be made from nonsignificant results. Thus, in order to aid interpretation of nonsignificant associations, we calculated Bayes factors to distinguish evidence for no effect from data insensitivity. Further, because Bayesian analyses do not assume large samples, data can generally be analyzed without losing power as is often the case in Maximum Likelihood estimations (Hox et al. 2012; Lee and Song 2004).

We first report means (*M*) and standard deviations (SD), as well as medians (Mdn) and interquartile ranges (IQR), for each variable of interest by gender and provide details about samples sizes by gender and by developmental group (see “Methods”). We also report details about the distribution of Twa adults by age and sex.

Because sample sizes for boys and girls were uneven and the data were nonnormally distributed, we use the two-sample Mann-Whitney U test to assess gender differences. We report both the frequentist effect size, using the rank-biserial correlation (r), and the Bayes Factor (BF). Effect sizes for *r* range from 0 to 1. The BF provides evidence for the null (BF01) or the alternative (BF10) hypotheses. Values for BFs can be organized as follows: if the value of BF is >3, the evidence is only anecdotal; if the value range is $3 < \mathrm{BF} < 10$, the evidence is moderate; and a BF value >10 indicates strong evidence (Jeffreys 1998).

The effect of gender among Twa adults was reported using Cohen’s *d* because sample sizes in the adult cohort were approximately equal and normally distributed. To compare the adult and child cohort, we report BFs. In order to ensure an accurate

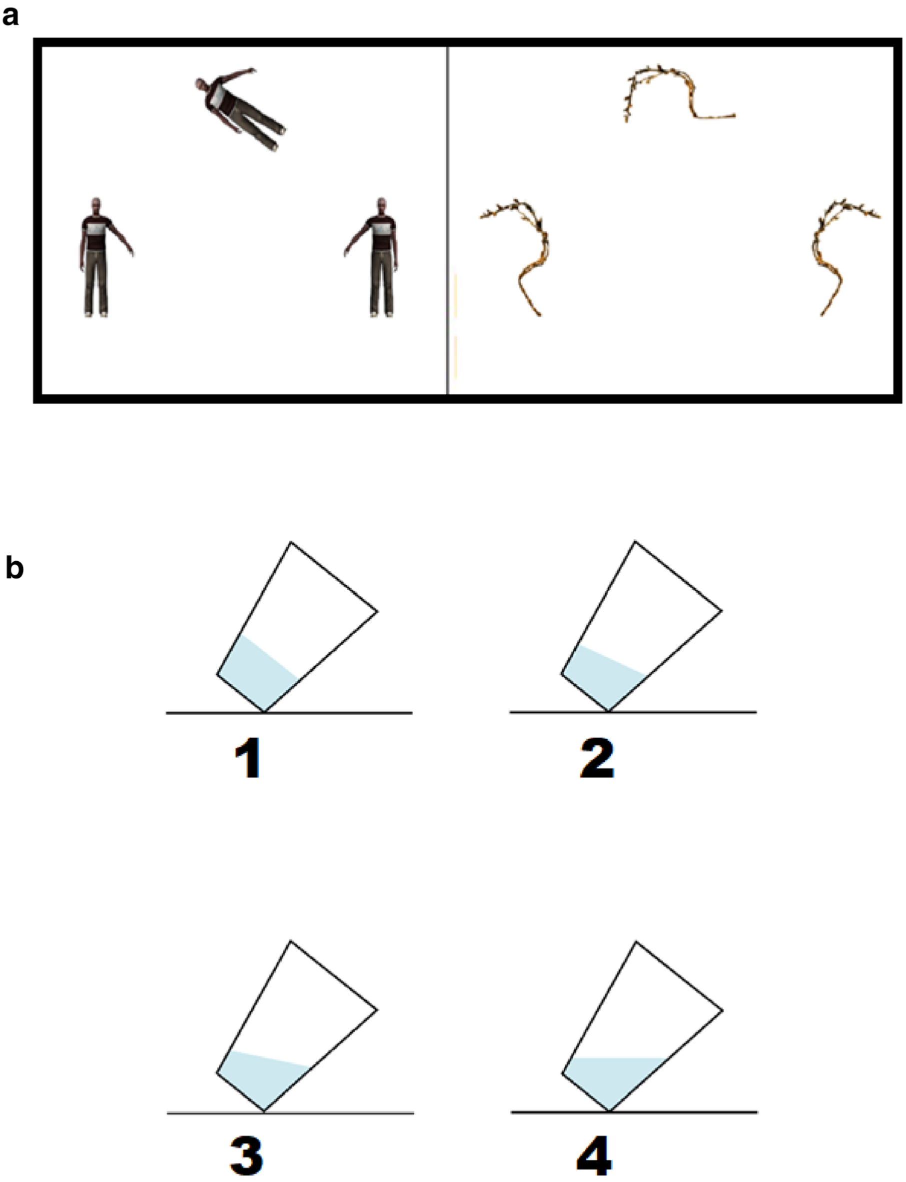


Fig. 2 (A) Images from the two mental rotation tasks used in this study. The participant was asked to identify which of the two images on the bottom matched the rotated object above. They made their selection using a touch screen laptop computer. (B) Water-level task presents four options of fluid in a tipped vessel. The participant was asked to select which of the glasses accurately depicted the water's level inside the tipped vessel

comparison with previous studies of large-scale spatial abilities among Twa adults, pointing error was first averaged across all trials, and a single score was calculated for each participant (Vashro et al. 2016; Vashro and Cashdan 2015).

Following Jang et al. (2019), and after conducting the descriptive analyses and comparisons by gender and by cohorts, we log-transformed age, daily mobility, lifetime mobility, pointing error and distance from camp to target location, MRT performance, and CBT performance. We then normalized the quantitative independent variables to improve interpretability using a *z*-transformation (Schielzeth 2010). Because the annual mobility and WLT variables consisted of count and binomial data, respectively, they were not log-transformed (O'Hara and Kotze 2010), and we relied on more flexible models for analysis.

We ran frequentist and Bayesian ANCOVAs to assess the effects of age and gender on each of the log-transformed and normalized predictor variables. Effect sizes (η^2) and BF01 are reported for each analysis to provide evidence for the alternative and evidence for the null, respectively. Though there are some limitations, using the default prior distribution in Bayesian analysis is frequently advocated for in the literature (e.g., Wagenmakers et al. 2018). Given the lack of consensus in the literature regarding age and gender trends in mobility and spatial ability, we primarily rely on default priors in this study.

To quantify the evidence for the null hypothesis (H_0), we rely on the default Cauchy distribution prior-centered on the null with a width of 0.707, and the default effect size of 0 to quantify evidence for the null hypothesis. Large BF are reported in text as LogBF_{10} and in tables as >100 to allow for easier interpretation.

To foster comprehensive analysis of the associations between age and sex on annual mobility, WLT, and the relationship between measures of mobility and spatial mobility, we rely on frequentist and Bayesian generalized linear models. In order to estimate Bayesian model parameters, we relied on four default Markov chains consisting of 2000 iterations each, half of which were discarded. For reported annual mobility, we assess the effects of age and gender using Poisson regression. For the WLT, logistic regression was used to assess whether the data supported the alternative hypothesis that the odds of success on the task decreased with age or by gender.

After we evaluate the effects of gender and age on average pointing error, we then use a linear mixed effects model to conduct a more detailed analysis using each individual trial on the pointing error assessment. Specifically, we examine the associations between pointing error and three independent variables—age, gender, and travel distance to each of the target locations. Because each individual participant pointed to multiple locations, individuals were entered as a random effect into the model to address issues of nonindependence. The Bayesian mixed model had weakly informed priors, which provide some information on the relative a priori plausibility of the possible parameter values, such as ruling out extreme negative or positive values, and can reduce posterior uncertainty (McElreath 2020).

Finally, evidence for correlations between mobility and spatial ability were evaluated using frequentist and Bayesian analyses; Pearson's *r* and BF are reported.

Analyses and graphical productions were conducted using lme4, car, stan, brm, stargazer, and ggplot2 packages (Bates et al. 2015; Bürkner 2016; Fox et al. 2012; Hlavac 2018; Stan Development Team 2020; Wickham 2010) in R ver. 3.6.4, and with JASP (JASP Team, 2020).

Outliers and Data Management Navigational measures from one female and one male were removed from the pointing error data because of recording errors in the field. In addition, scores worse than chance on the MRT (i.e., less than 50% correct) were removed from the dataset during analysis.

Results

The results start with analyses of mobility and spatial performance in boys and girls. We then compare the patterns in children with previously reported patterns in adults. This is followed by an assessment of the hypothesized relationships: whether greater mobility predicts better performance on spatial ability. Finally, we evaluate developmental and sociocultural factors that potentially contribute to the observed patterns.

Descriptives

Statistics for boys' and girls' mobility, spatial test performance, and covariates are shown in Table 1 prior to data normalization and log transformation. Across all 87 children the mean age (±SD) was 11.68 ± 3.43 with a median of 12 years. More girls ($N = 57$) participated in the study than boys ($N = 30$). However, the mean age and distribution were similar for girls ($M = 11.79$, SD = 3.57; Mdn = 11 years) and boys ($M = 11.53$, SD = 3.30; Mdn = 12 years). When divided into groups by developmental stages during childhood, the sample size for early adolescence (ages 11–13, $N = 37$) is

Table 1 Descriptives, effect sizes, and Bayes factors for Twa and Himba girls and boys

	Girls (0)			Boys (1)			r	BF_{10}	BF_{01}
	N	Mean (SD)	Median (IQR)	N	Mean (SD)	Median (IQR)			
Age (years)	57	11.79 (3.5)	11.0 (5.0)	30	11.53 (3.3)	12.0 (5.0)	0.01	0.25	4.01
Grade in school	57	3.82 (2.3)	4.0 (4.0)	30	3.90 (2.5)	4.5 (4.0)	0.03	0.24	4.12
Daily Distance (km)	47	8.98 (4.6)	7.7 (5.7)	24	9.47	7.9 (5.3)	0.21 (5.6)	0.27	3.64
Annual mobility (# unique visits)	55	1.58 (0.9)	1.0 (1.0)	30	1.77 (1.2)	1.0 (1.0)	0.05	0.28	3.61
Lifetime mobility (% visited)	55	24% 15%	20% 25%	30	23% 15%	18% 15%	0.03	0.24	4.12
Pointing (error degrees)	55	20.76 (12.6)	18.6 (17.6)	28	20.13 (18.3)	13.3 (10.0)	0.16	0.29	3.37
Mental rotation (% correct)	42	87% 15%	92% 25%	27	85% 13%	86% 24%	0.11	0.29	3.46
Corsi task (# correct trials)	56	6.40 (2.0)	7.0 (3)	29	6.62 (2.1)	7.0 (3)	0.07	0.27	3.70
Water-level task (%)	52	85%		31	76%	0.003	0.31	3.24	

Final columns report results from frequentest (rank-biserial correlation; r) and Bayesian (Bayes factors; BF) two-sample Mann-Whitney U Tests. Here r (the Z value from the test divided by the total number of observations) is reported from 0 to ~1: $0.10 < r < 0.30$ is considered a small effect; $0.30 < r < 0.50$ is considered a medium effect; $r \geq 0.50$ is considered a large effect. A $BF < 3$ is considered anecdotal; $3 < BF < 10$ is considered substantial; $BF > 10$ is considered strong larger than the samples for middle childhood (ages 6–10, $N = 26$) and late adolescence (ages 14–18, $N = 25$).

Among the 129 Twa adults who previously participated (Vashro et al. 2016), the mean age (±SD) was 34.85 ± 16.70. The sample was more evenly distributed by gender (64 women and 65 men).

Effects of Gender on Mobility and Spatial Ability

We next assess the effects of gender on mobility and spatial abilities using both frequentist (r and p value) and Bayesian (BF) Mann-Whitney U tests (Table 1). The BF values reflect the strength of the evidence for the alternative (H_a: there is an effect of gender, where boys and girls have different distributions; BF_{10}) and for the null (H_0: there is not an effect of gender, where boys and girls have the same distribution; BF_{01}). Following Jeffreys (1998), we consider a $BF < 3.0$ to be anecdotal evidence, while values >3.0 provide stronger evidence in favor of the alternative or null hypothesis (see Statistical Methods for further details).

We do not find evidence of an effect of gender on daily mobility ($p = 0.89$, $r = 0.21$), annual mobility ($p = 0.65$, $r = 0.05$), or lifetime mobility ($p = 0.82$, $r = 0.03$); see Fig. 3. A small effect of gender on the large-scale spatial task, with boys having lower pointing error, was not statistically significant ($p = 0.24$, $r = 0.16$). Although girls did better on the MRT, this was also not statistically significant ($p = 0.45$, $r = 0.11$). Only a negligible effect of gender was found for the other two small-scale spatial measures favoring girls, the WLT ($p = 0.30$, $r = 0.10$) and CBT ($p = 0.59$, $r = 0.07$).

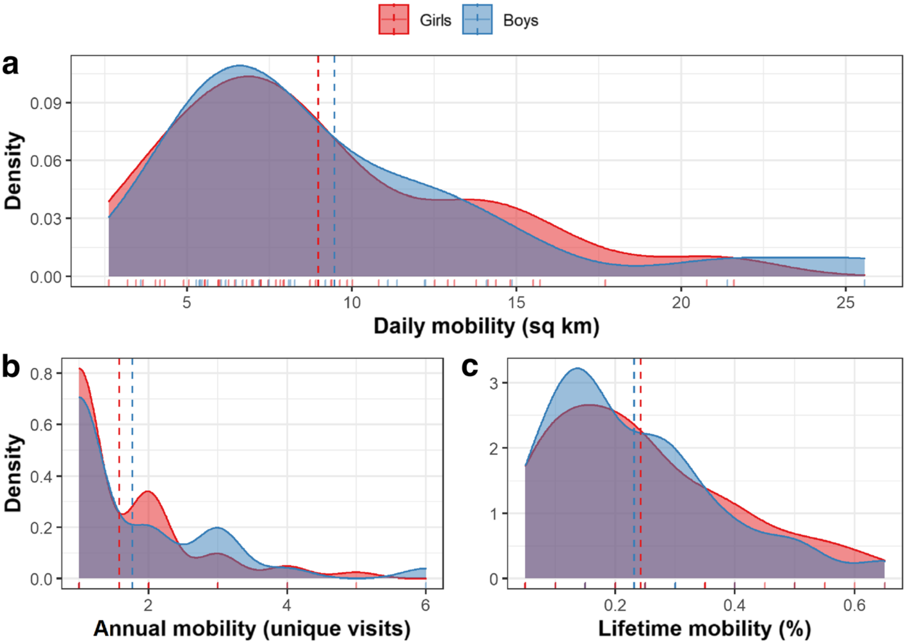


Fig. 3 Density plots display distribution of children's (A) daily mobility, and children's responses to interview questions about (B) annual mobility and (C) lifetime mobility. Dotted lines indicate the mean for boys and girls

Similar to the frequentist results, Bayes Factors provide little evidence to support the alternative hypothesis (Table 1; BF_{10}). However, there was moderate to substantial evidence to support the H_0 hypothesis that there is no effect of gender on the observed distributions (Table 1; BF_{01}).

Comparisons between Child and Adult Samples

In contrast to the findings for Twa children, there is moderate or strong evidence of an effect of gender on mobility and spatial ability among Twa adults (Fig. 4). Vashro et al. (2016), found that Twa men have greater daily mobility ($p = 0.002$, $d = 0.99$, $BF_{10} = 8.86$) and report greater annual mobility ($p = 0.002$, $d = 0.72$, $BF_{10} = 25.31$) than women. Men also demonstrate lower pointing error than women ($p = 0.01$, $d = 0.48$, $BF_{10} = 3.98$). For each measure, we find only weak evidence to support the null hypotheses (i.e., $BF_{01} < 3$). In contrast, gender does not explain differences in mobility or spatial ability among children (Table 1; Fig. 4).

When comparing mobility patterns between the adult and child cohorts, we find that average daily mobility for boys ($BF_{10} = 75.54$) and girls ($BF_{10} > 100$) is twice that of Twa women. In contrast, we find little difference in the average daily mobility patterns of Twa men when compared with boys ($BF_{10} = 0.31$) or girls ($BF_{10} = 0.28$). We find little difference in pointing error when comparing Twa women with the child cohort ($BF_{10} = 0.22$). However, men pointed more accurately and there was strong evidence for a cohort effect ($BF_{10} = 16.41$).

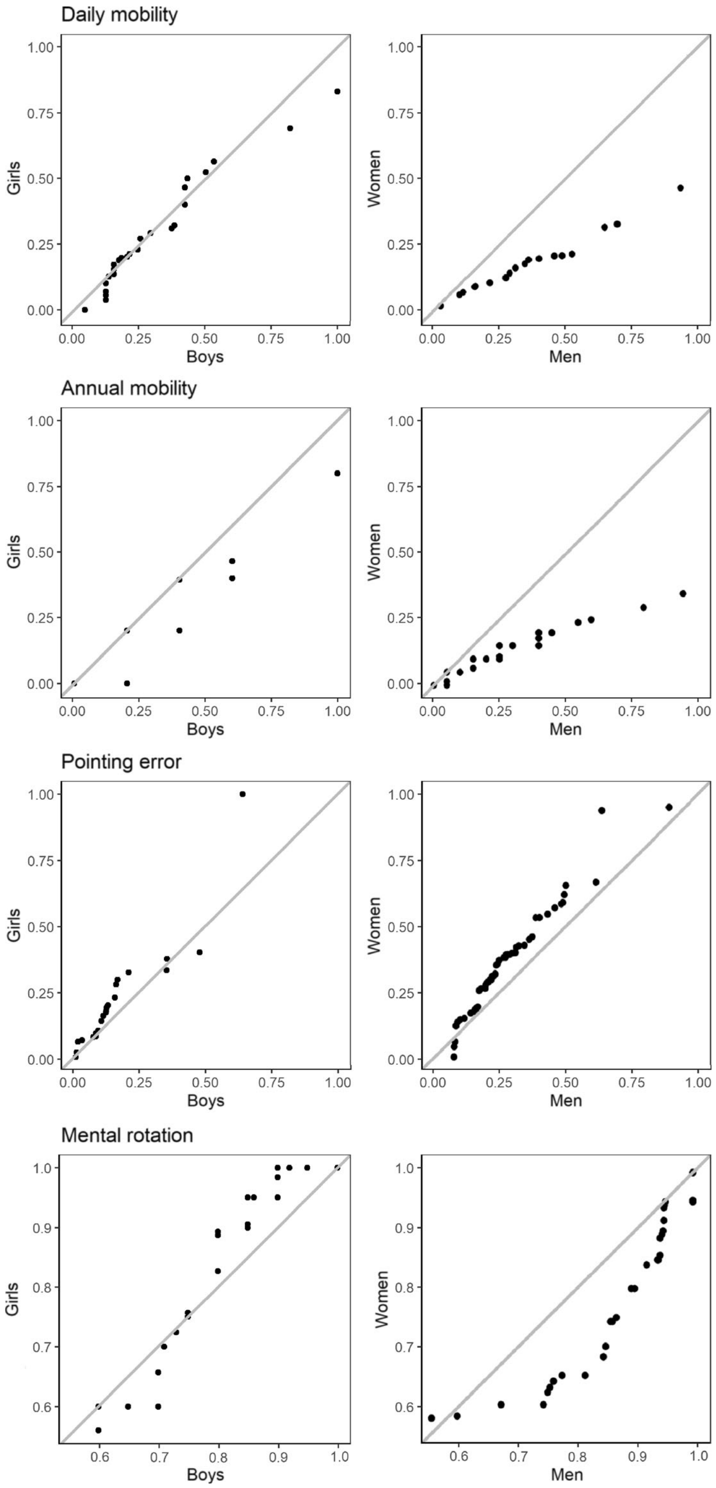
Men also outperform women on the MRT ($p = 0.03$, $d = 0.45$, $BF_{10} = 7.73$), whereas no effect on performance is observed between boys and girls (Table 1). Overall performance on the MRT for both children and adults is approximately equal, with children averaging 85.5% accuracy and adults averaging 86% accuracy.

When directly comparing the adult and child cohorts, we find that children performed better than adults on the WLT. Only 52% of Twa adults chose the correct response (60% men in the sample and 40% of women), whereas children correctly answered the WLT 82% of the time (Fig. 5). Bayes Factor analysis indicates strong support for an effect of cohort on performance ($BF_{10} = 10.17$) but little support for the null of no effect of cohort on performance ($BF_{01} = 0.10$). Parameter estimates of the posterior distribution ($\delta = 0.46$, 95% CI: 0.16, 0.81) indicate less uncertainly regarding the size of the assumed cohort effect on WLT performance.

Developmental Predictors of Mobility

There is strong evidence for a positive main effect of age on children's daily mobility (Table 2). BF analysis reveals the null model is 3.61 times more likely to produce the same results than a model that includes gender. However, there does appear to be a slight trend for greater daily mobility among older boys (Fig. 6), and BFs reveal weak

Fig. 4 Quantile-quantile plots comparing the distributions for boys and girls (left column) and men and women (right column) in daily mobility, annual mobility, pointing error, and mental rotation. This method compares scores at each quantile of the respective distributions for both genders in each sample. When boys/men or girls/females have higher scores, the points are located further from the diagonal line and closer to their respective axes. The data for all four variables were normalized for ease of interpretation by gender across variables and between cohorts ▶


Daily mobility
Girls
Boys
Women
Men
Annual mobility
Girls
Boys
Women
Men
Pointing error
Girls
Boys
Women
Men
Mental rotation
Girls
Boys
Women
Men
0.00
0.25
0.50
0.75
1.00
0.6
0.7
0.8
0.9
1.0

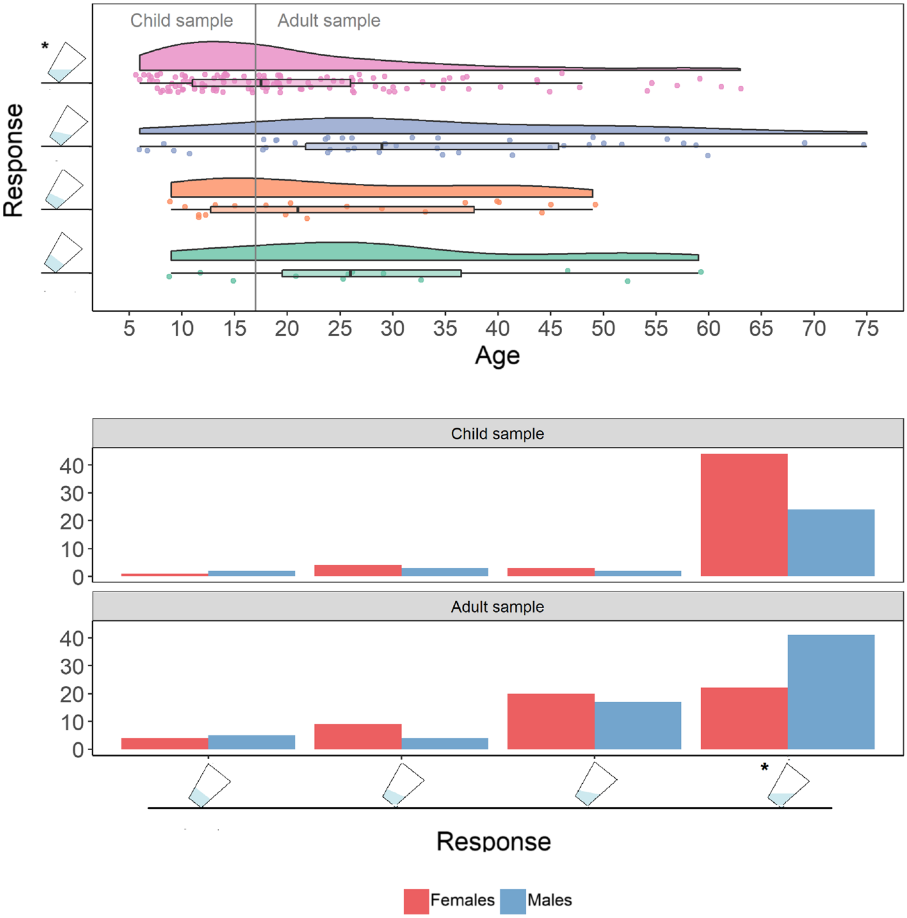


Fig. 5 Results from the water-level task (WLT). The correct answer is indicated with an *. Above: Response to WLT across both cohorts by age. Jittered points indicate individual responses for participants and half-violin denotes the age distribution for each response. For the boxplots, the boxes and the horizontal line inside show the quartiles (1st to 3rd quartile) and the median, respectively. The whiskers denote 1.5 times the interquartile range. The black vertical line denotes the upper age limit for the child sample and the lower age limit for the adult sample. Below: Distribution of WLT choices made by each gender among children (upper) and adults (lower). Overall, more children responded correctly than adults

evidence to support the null. We therefore looked for a potential interaction between age and gender on greater daily mobility. However, there is still only weak evidence for an interaction effect between age and gender on daily mobility ($F_{1, 67} = 1.76$, $p = 0.19$, $\eta^2 = 0.02$, $BF_{10} = 0.85$), but there is also only marginal evidence to support the null that there is no interaction effect ($BF_{01} = 1.18$). When categorized by developmental stages, we find larger range for both boys and girls as children move from early to later adolescence (Fig. 7).

Similar trends for age are found in both annual and lifetime mobility. Results from a frequentist analysis show an association of age ($\beta_{Age} = 0.28$, $p = 0.001$, 95% CI: 0.11, 0.45), but not gender ($\beta_{Gender} = 0.15$, $p = 0.43$, 95% CI: −0.21, 0.47; Table 2), on greater annual mobility. BF analysis further indicated very strong evidence for a model

Table 2 Results from Univariate Analysis of Covariance investigating the effects of age and gender on spatial abilities using frequentist and Bayesian approaches

	F	p	η^2	BF_{10}	BF_{01}
Mobility					
Daily (z-score)					
Age	7.23	0.01**	0.10	4.42	0.23
Gender	0.55				3.61
Age+Gender					0.71
Lifetime (z-score)					
Age	5.26	0.03**	0.08	>100	<0.001
Gender	0.01	0.91	0.001	0.24	4.26
Age+Gender				>100	<0.001
Large- and small-scale spatial abilities					
Pointing error (z-score)					
Age	3.19	0.08*	0.04	0.91	1.12
Gender	1.37	0.24	0.02	0.43	2.34
Age+Gender				2.47	2.68
Mental rotation task (z-score)					
Age	14.13	<0.01***	0.18	73.24	0.01
Gender	0.35	0.56	0.004	0.27	3.68
Age+Gender				21.54	0.05
Corsi blocks task (z-score)					
Age	43.73	<0.01***	0.35	>100	0.01
Gender	0.71	0.40	0.006	0.25	3.68
Age+Gender	0.01	0.91	0.001	>100	0.05

$*$ $p < 0.1$; $**$ $p < 0.05$; $***$ $p < 0.01$

that included age, but not gender ($BF_{01} = 6.82$). Likewise, there is strong evidence to suggest an effect of age, but not gender, on higher lifetime mobility (Table 2). BFs do not provide strong or moderate evidence for an effect of gender on lifetime mobility; however, evidence to support the null is similarly weak (Table 2). When categorized by developmental stages, we find that children in late adolescence report having visited 28% of the 20 locations in the lifetime mobility interview at least once. In contrast, children in middle childhood (the youngest cohort) and in early adolescence reported visiting only 4% and 14% of the locations, respectively.

Developmental Predictors of Large- and Small-Scale Spatial Ability

Children in late adolescence reported knowing 20% more places than children in early adolescence and 35% more places than children in middle childhood during the pointing error assessment. We therefore adjusted for familiarity with the target locations and averaged across the trials to produce a single measure of degrees error per child (see "Methods" for details). However, pointing error does not appear to vary by age and gender (Fig. 8; Table 2). Because older children knew and were able to point to

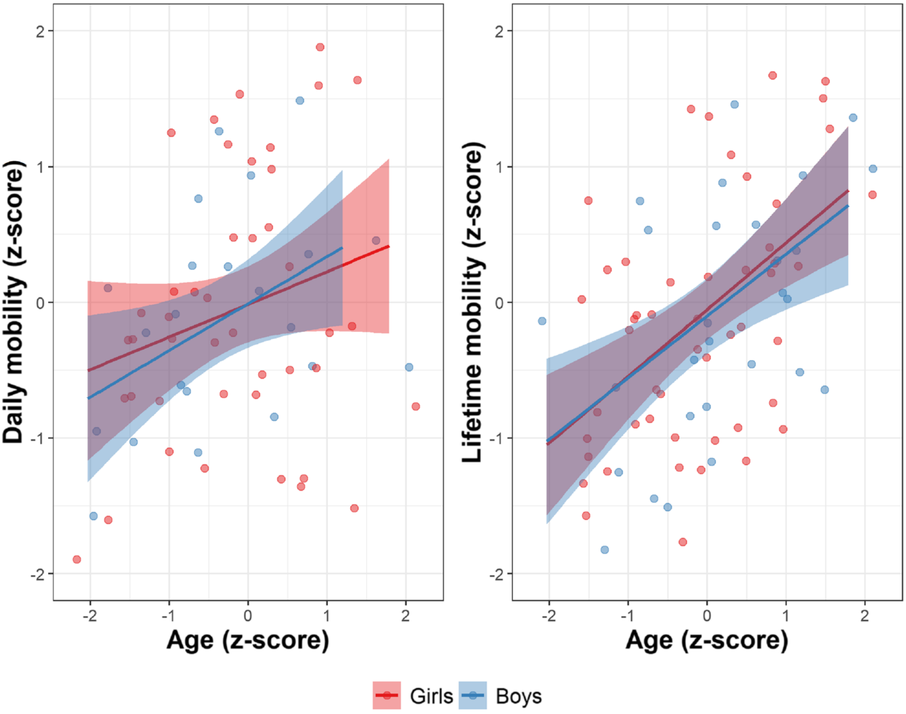


Fig. 6 Scatterplots of children's daily and lifetime mobility by age. Values for each variable were log-transformed and *z*-normalized for ease of comparison across tasks. Shaded areas represent 95% confidence intervals

more distant locations, which may be more challenging, we also analyzed the effect of distance on pointing accuracy. We therefore conducted a linear mixed effects model to assess the effects of distance to the target location on pointing error. To do this, all raw data were aggregated into a mixed effects model, with participants entered as a random factor. Because older children knew and pointed to more locations, age and sex were entered as controls. Results indicate that across aggregated pointing events, distance to the target is a reliable predictor of pointing error (Table 3).

For both the MRT and the CBT, there is very strong evidence for an effect of age, but only weak evidence for an effect of gender, when compared with the null (Fig. 8; Table 2). Though the MRT and CBT both show strong evidence for a model that includes both age and gender, this is only when compared with the null model. In both cases, a model with age alone is considered the best-fit model. We therefore compared each model to the age-only model and found substantial evidence to suggest the observed MRT scores are more likely under a model with age alone than a model with gender alone ($B_{01} > 100$) or with age and gender ($B_{01} > 100$). For the CBT data, we find moderate evidence for a model that includes only age than one with age and gender ($B_{01} = 3.20$), and very strong evidence when compared with a model with gender alone ($B_{01} > 100$).

In the final small-scale spatial task, the WLT, the participant has one correct and three incorrect responses to choose from (see "Methods" for details). Across the sample, 82% of children selected the correct response (80% of girls and 70% of boys;

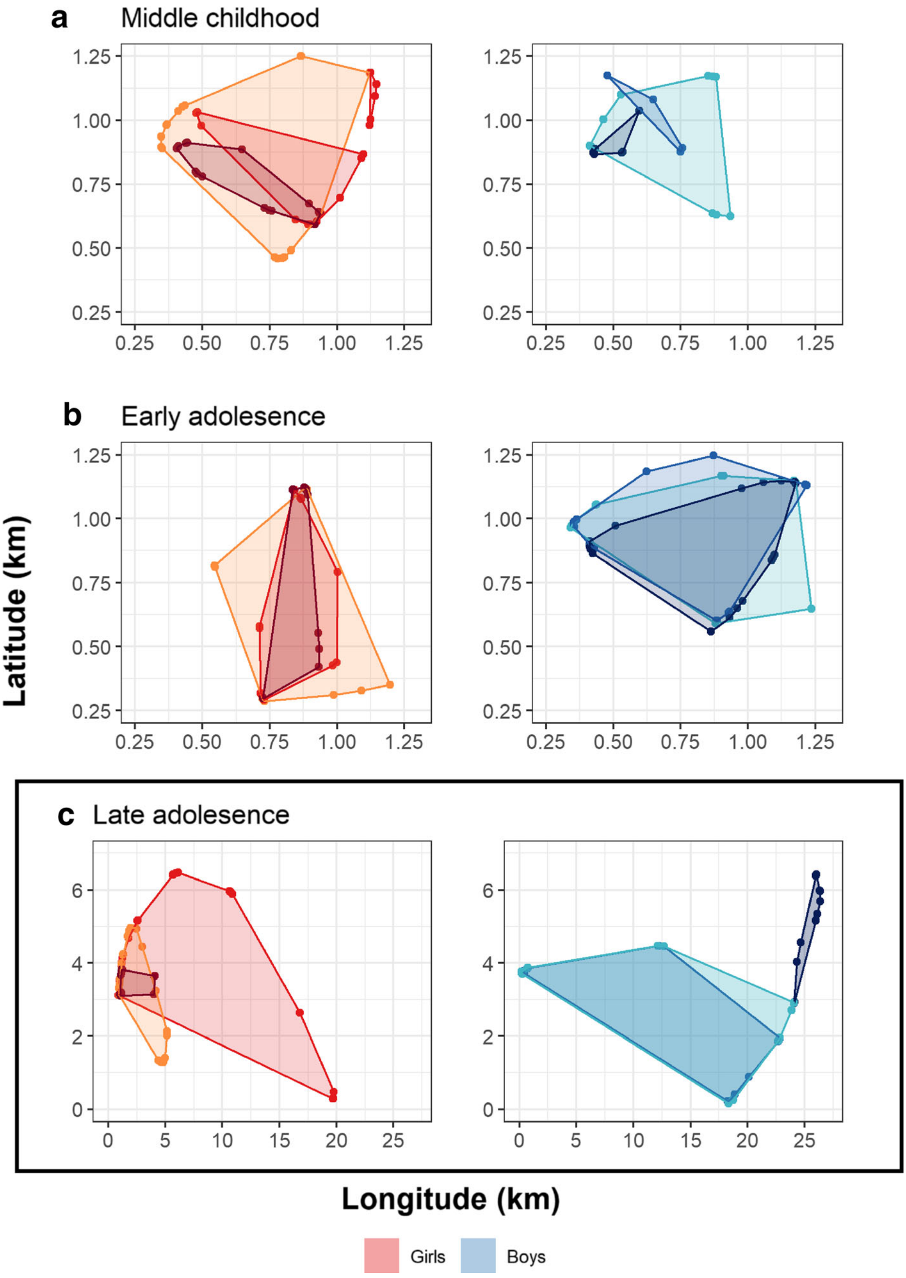
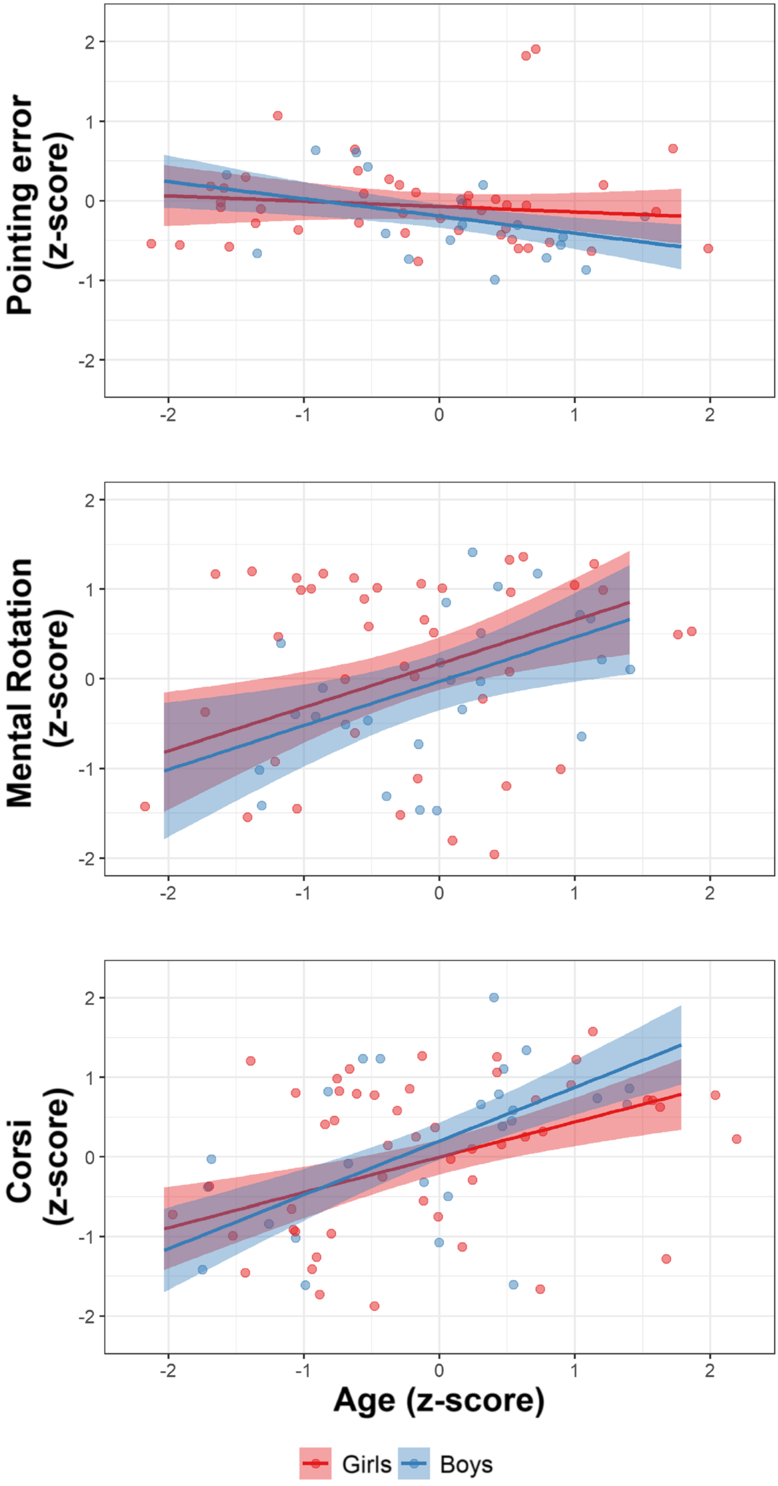


Fig. 7 Examples of range size for girls (left) and boys (right) during (A) middle childhood, (B) early adolescence, and (C) late adolescence. The black box indicates a different scale for late adolescence. Each uniquely colored polygon within each plot represents the range size for a single day and demonstrates variation in daily travel for a given child. X and Y axes measure kilometers traveled longitudinally and latitudinally from GPS starting point. Children in middle childhood and early adolescence show similar travel patterns; thus, their ranges can be shown on the same scale. In contrast, children in late adolescence exhibit a substantially larger range size and display greater distance on the X and Y axes


Pointing error (z-score)
Mental Rotation (z-score)
Corsi (z-score)
2
1
0
-1
-2
-2
-1
0
1
2
Age (z-score)
Girls
Boys

◀ **Fig. 8** Scatterplots of a large-scale spatial skill (Top: pointing error) and two small-scale spatial skills (Middle: Mental rotation, and Lower: Corsi task) by age and gender. Correlation coefficients and significance level for each gender are reported in the upper left region of each graph. Y-axis: values for each variable were log-transformed and *z*-normalized for ease of comparison across tasks. Shaded areas represent 95% confidence intervals

Table 1), with 17% of those who chose correctly being under the age of 9 and 41% being under the age of 12. Unlike for the other small-scale spatial tasks, when the effect of gender was controlled, age did not improve the odds of correctly answering the WLT (OR = 1.32, 95% CI: 0.75, 2.40; $BF_{10} = 0.19$). In all, the observed WLT data were 5.26 times more likely under the null model than under a model with age and gender.

Relationships between Mobility and Large- and Small-Scale Spatial Abilities

When controlling for age and gender, we find a strong evidence that there is a correlation between greater daily mobility and greater lifetime mobility (Pearson's $r_{66} = 0.28$, $p = 0.02$, $BF_{10} = 28.34$), rather than for the null ($BF_{01} = 0.04$). We also find of a correlation between greater daily mobility and greater annual mobility. (Pearson's $r_{65} = 0.39$, $p < 0.001$, $B_{10} = 43.45$), and only negligible evidence to support the null ($BF_{01} = 0.02$). However, lifetime mobility was the only mobility measure that was associated with spatial abilities. When controlling for age and gender, we find that children with higher lifetime mobility demonstrate lower pointing error ($\beta_{\text{Lifetime}} = -0.61$, $p = 0.05$, 95% CI: −1.22, −0.01; $BF_{10} = 15.71$), with negligible evidence in support of the null ($BF_{10} = 0.06$). Using the same controls, we further find a strong correlation between pointing error and the CBT (Pearson's $r_{77} = -0.23$, $p = 0.04$. $BF_{10} > 100$).

Discussion

The similarity between Twa girls and boys in mobility and spatial performance is striking given the marked gender differences found in these variables among Twa adults. It is also surprising in light of the gender differences in spatial behavior and cognition found among children in WEIRD societies. In our data, we see an increase in

Table 3 Results from frequentist and Bayesian linear mixed effects model of age, gender, and distance to target on pointing error using aggregated data

	Frequentist		Bayesian			
Variable (range)	β	*p*	est.	est. error	CI lower	CI upper
Intercept			0.04	0.13	−0.21	0.28
Age (6–18 yrs.: *z*-score)	0.72	0.67	−0.15	0.07	−0.28	−0.02
Gender (ref group: girls)	−0.25	0.87	0.01	0.15	−0.28	0.31
Distance to target (km: *z*-score)	0.13	0.04 **	0.24	0.08	0.08	0.39

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$; CI = Credible Intervals, which describe and summarize the uncertainty of parameters in Bayesian statistics

range size with age for both boys and girls, especially as children move from early to later adolescence. This appears in both daily distance traveled, as measured by GPS, and in regional (annual and lifetime) mobility, as measured by interview. It is not until late adolescence that we begin to see a trend for males to travel farther than females, and this is not statistically significant in our data.

The age-gender pattern in mobility is broadly mirrored by the pattern of accuracy in spatial tasks. Older children were familiar with more locations and pointed to more locations in the region. Across ages, the accuracy of the children was impressive, with errors on the pointing assessment averaging around 20°. There was strong evidence for an effect of distance on pointing error; neither gender nor age presented strong evidence for an effect on performance. We also identified interesting age-gender patterns in performance on our small-scale spatial tasks: spatial memory (CBT), spatial rotation (MRT), and reasoning ability in spatial relations (WLT). The Twa children did particularly well on the WLT. Though some studies with US samples have shown significant differences in performance, favoring boys (Thomas and Turner 1991), as well as low overall success rates (Li et al. 1999), we found no difference in performance by gender among Twa children.

Given the necessarily small samples of this study, which is typical for work with small-scale mobile populations, we cannot assert that no gender differences exist. However, there are clear differences in this regard between these children and the older Twa who were described in earlier studies. Although the methods and samples were similar, the earlier studies among adult Twa found large gender differences, with men having larger ranges and doing better on these spatial tasks. We consider below some possible reasons for those differences.

We were also interested to know whether individual differences in environmental experience were associated with differences in spatial ability. A relationship between the navigational challenge of large ranges and enhanced spatial ability has been proposed to explain variation in spatial ability, both across species and between males and females in a variety of taxa (e.g., Gaulin and FitzGerald 1986; Jones et al. 2003; Jozet-Alves et al. 2008). These relationships are thought to arise from selection pressures over evolutionary time but are likely to also reflect developmental processes experienced by individuals. Studies in WEIRD societies have shown that spatial skills respond to training (Henrich et al. 2010; Uttal et al. 2013), and that adult spatial ability is correlated with childhood participation in spatial activities (Doyle et al. 2012). Larger ranges have also been associated with enhanced spatial performance (Ecuyer-Dab and Robert 2004; Munroe and Munroe 1971; Nerlove et al. 1971), including among Twa men (Vashro et al. 2016). Among Twa children, we found that those who had spent more time in a diversity of places over the region (our lifetime mobility measure) also pointed more accurately, controlling for age and gender, which supports the hypothesized relationship between environmental experience and navigational ability.

Support for the role of mobility on spatial ability in Twa children must remain tentative, however, because our other mobility measures (yearly travel and daily GPS tracks) did not show this pattern. We think lifetime mobility is the stronger predictor of spatial ability in our data both because of methodological limitations in our GPS tracking (daily travel was limited to two or three days of data collection, with a large individual variance over the three days) and because lifetime mobility assesses travel over a broader regional and temporal scale and hence is more likely to involve unfamiliar locations and routes.

How often and where children travel while growing up is largely influenced by the expectations and limitations set by cultural norms and parental decisions (Bock and Sellen 2002; Davis and Cashdan 2020). For instance, children's daily task assignments help define gender roles (Stieglitz et al. 2013; Whiting and Whiting 1975), which often contribute to observed gender differences in a variety of behaviors, including time away from camp (Draper 1976) and children's range size (Edwards and Whiting 1980). In the case of the Twa, the expectations for children's daily activities has begun to change. The recent settlement of the Twa near more consistent sources of water and the subsequent increase in access to schooling distinguishes contemporary Twa childhoods from previous generations, which may have significant effects on cognitive development (Davis 2014; Davis et al. 2020; Gurven et al. 2017).

Approximately 88% of children in the sample had exposure to formal schooling (i.e., had ever attended school), with 70% enrolled in school during the time of the study. In contrast, only 29% of adults reported exposure to formal schooling. Of those who reported attending school, the adult cohort averaged 45% less time in school ($M = 0.96$ years of schooling, SD = 1.88) compared with the cohort of children ($M = 2.11$ years of schooling, SD = 2.13). Though Twa children, particularly boys, spend the weekends—and sometimes longer periods, seasonally—to take livestock to graze or find water, attending school has produced relatively similar daily travel experiences for boys and girls. Each week, Twa children travel upwards of 20 km to boarding school with their siblings and friends, returning home only on the weekends. During the week they learn in classrooms, sleep and eat at school, explore and play in environments far from their own homes, and visit the nearby communities of their classmates. Increased travel required to attend school may explain why—in contrast to Twa adults (Vashro et al. 2016)—we find no significant differences between boys' and girls' daily, annual, or lifetime mobility. Thus, schooling may also have indirect effects by shaping mobility patterns. For example, among the Tsimane, more schooling was associated with better performance on an abstract spatial rotation (MRT) but worse performance on regional pointing accuracy (i.e., pointing error), probably because spending time in school limited their outdoor spatial exploration relative to peers who did not attend school (Davis and Cashdan 2019). In places where children must travel long distances to school unaccompanied by adults, however, school attendance might instead be associated with enhanced navigational performance, as with the Twa. However, though boys and girls travelled equal distances across similar range sizes during childhood (Fig. 7), we did observe a trend toward increased male mobility. Thus, it is likely that after children age out of school they will begin working within more traditional cultural roles defined by their communities, ultimately affecting their mobility.

Unlike in the adult cohort, there was no significant difference in navigational ability between boys and girls. The cohort of children did as well on the pointing error assessment as the adult women did but not as well as adult men, who also report the greatest amount of annual and lifetime travel (Vashro and Cashdan 2015; Vashro et al. 2016). Because boys in this study trended toward higher mobility and lower error at older ages, it is possible that navigational error may continue to decrease as boys age, widening the gap between genders. On the other hand, the travel requirements associated with schooling mean children are traveling more today (alone or without parents) than the adult cohort did when they were children. Both boys and girls demonstrated very adept navigational skills as early as 7 or 8 years old. It is possible this change in early childhood experiences has increased children's navigational abilities and decreased the previously observed gender difference.

Given the recent increase in children's mobility, it is also important to consider the indirect effects schooling may have on spatial skills. Training in school has been reported to improve the ability to mentally rotate objects and increase accuracy on the WLT. Improvements in mental rotation with training have been observed among German primary school students (Blüchel et al. 2013) and US middle school students (VanMeerten et al. 2019). Greater gender equity in school attendance was also partially responsible for better female performance in a puzzle task, in a comparison of two culturally distinct societies in India (Hoffman et al. 2011). The WLT, like Piaget's conservation tasks (Piaget and Szeminska 1941)—which have been reported to vary due to early childhood experiences (Price-Williams et al. 1969)—also shows variation in performance cross-culturally (Li 2014; Seng and Tan 2002) and in response to formal education (Dasen et al. 2004). Schooling has also been shown to improve performance on the WLT for children between 9 and 17 years old when a combination of instruction and practice, rather than practice alone, is given (Li 2000). We find that children's performance on the two small-scale spatial abilities (mental rotation task and WLT) lacked a gender difference, further distinguishing the child cohort from earlier findings among Twa adults. Further, children performed as well as adults on the mental rotation and outperformed adults on the WLT—with children as early as 8 years old scoring 100% on the mental rotation task and 6 years old on the WLT. We attribute the lack of a gender differences among children—as well as their overall precocious performance—to a direct effect of schooling, where children have become familiar with abstract spatial reasoning, technology, and test taking (Chavajay 2006; Davis and Cashdan 2019).

Though the cross-sectional design of this study limits our ability to make stronger assertions about the observed differences between Twa adults' and Twa children's mobility and spatial ability, it does warrant further investigation. Additional research on spatial abilities among our study population—once they reach adulthood and engage in gender-specific work—could further answer questions regarding the role of early childhood environments on spatial abilities. Likewise, further investigation on the role of mobility on navigation would be a valuable contribution to "use it or lose it" studies focused on cognitive aging (Salthouse 2006) and the effects of technology on navigational abilities (Gramann et al. 2017).

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Code Availability All analyses, figures, and tables were conducted in R-3.6.2 and LaTeX2e. Code is available upon request.

Author Contributions EC designed research; JS and HD performed research; HD analyzed data; HD and EC wrote the paper.

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Declarations

Ethics The office of research ethics at the University of Utah provided approval for this study.

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