

Original Article

Sex differences in spatial cognition among Hadza foragers<sup>☆</sup>

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Abstract

This paper describes sex differences in spatial competencies among the Hadza, a mobile hunter–gatherer population in Tanzania. It addresses the following questions: (a) Is the usual male advantage in Euclidean spatial abilities found in this population, where both women and men are highly mobile? (b) Do Hadza women have better object location memory than men, as the gathering hypothesis predicts? (c) Do women who are nominated by others as being good at finding bushfoods excel at the object location memory task? We tested object location memory with a version of the memory game using cards of local plants and animals. This allowed us to also ask whether women and men would have better spatial memory for the plant and animal cards, respectively. We found that Hadza men were significantly better than women in three tests of spatial ability: the water-level test, targeting, and the ability to point accurately to distant locations (the latter only in the less mobile groups). There was a trend toward a male advantage at the object location memory task, in contrast to results found previously in nonforaging populations, and women’s performance at the task deteriorated with age, while that of men did not. The women who were nominated by peers as being good at finding bushfoods were consistently older women. We discuss the probable hormonal causes and functional consequences of age changes in the spatial competencies of female foragers.

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1. Introduction

Spatial ability is immensely practical, and the difference between men and women in some spatial tests is large and robust. This has encouraged speculation about the evolutionary origins of these cognitive specialties and about how they might have been shaped by the demands of living the way our ancestors did, in mobile bands that hunted and gathered for a living. Yet that is difficult to do from the perspective of an urban office, and the ideas are difficult to evaluate fully with people who live in complex societies. We are interested, therefore, in seeing whether these sexual dimorphisms in spatial ability are also found

among mobile Hadza foragers and what role these abilities might play in foraging.

Men in a wide range of societies perform consistently better than women in at least three areas: tasks requiring one to imagine what an object would look like if it were in a different orientation (“mental rotations”), tasks requiring one to identify horizontal and vertical in spite of competing cues (“spatial perception”), and targeting (hitting or intercepting moving objects). The sex differences are large, particularly in three-dimensional mental rotation tasks (Voyer, Voyer, & Bryden, 1995) and targeting (reviewed in Kimura, 2000), where the average man performs nearly a full standard deviation better than the average woman. The difference in spatial perception is smaller, about half a standard deviation (Linn & Petersen, 1985; Voyer et al., 1995), but, like the difference in mental rotations, it has been found cross-culturally.

Various selection pressures have been proposed for the male advantage in these Euclidean spatial abilities. It has

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been argued that males excel where they face greater navigational challenges, for reasons of either polygyny (Gaulin, 1992; Gaulin & FitzGerald, 1986, 1989) or the navigational demands of hunting mobile prey (Eals & Silverman, 1994; Silverman & Eals, 1992). Tasks other than navigation may also have been important selection pressures, particularly the demands of hunting and fighting on accurate targeting and interception of moving objects (Watson, 2001).

Women excel in at least one spatially related task, the ability to remember the location of objects (e.g., Eals & Silverman, 1994; McBurney, Gaulin, Devineni, & Adams, 1997; Silverman & Eals, 1992). Silverman, Choi, and Peters (2007) replicated this sex difference cross-culturally by using an internet version of their original task, in which participants identify which objects in an array have been moved. Silverman and his colleagues, noting that women do most of the gathering in foraging societies, have argued that their proficiency in object location memory evolved in response to the challenge of remembering the location of plant foods within complex arrays of vegetation (“gathering hypothesis”). Across studies, the female advantage appears only under certain experimental conditions (Voyer, Postma, Brake, & Imperato-McGinley, 2007). Men typically do better if the task requires recall of precise metric position rather than relative location (Iachini, Sergi, Ruggiero, & Gnisci, 2005; Postma, Izendoorn, & De Haan, 1998; Postma, Jager, Kessels, Koppeschaar, & van Honk, 2004; Voyer et al., 2007). If objects are moved to new locations rather than being switched or removed from the array, the female advantage disappears (James & Kimua, 1997). A female advantage is also more likely when learning is incidental rather than directed (Eals & Silverman, 1994; Ecuier-Dab & Robert, 2007; Voyer et al., 2007) and short term rather than long term (Honda & Nihei, 2009). This cluster of features—short-term, incidental recall of relative positions—is probably more useful in procuring resources during a single gathering bout than in navigation to and among gathering locations. However, the ability may predispose women to attend to different cues than men do while navigating over longer distances.

It is plausible, therefore, that these sex differences in spatial competencies are associated with another important sex difference, choice of navigational strategies. When giving directions and drawing features on maps, women are more likely to include local landmarks and directional terms (“turn left at the school”), while men are more likely to include Euclidean cues such as distance and cardinal directions (“go north for 3 miles”) (Choi & Silverman, 1996; Dabbs, Chang, Strong, & Milun, 1998; Ward, Newcombe, & Overton, 1986). Similarly, when navigating in real and virtual worlds, women attend more to landmarks, and men to Euclidean cues, and women’s performance is hampered more than men’s when landmark cues are removed (Barkley & Gabriel, 2007; Moffat, Hampson, & Hatzipantelis, 1998; Sandstrom, Kaufman, & Huettel, 1998). Successful route-learning is associated with a landmark

strategy in women (Choi, McKillop, Ward, & LHirondelle, 2006; Choi & Silverman, 1996), which indicates that paying attention to landmarks is a more effective style of navigation for women, not just a fallback for people with poor spatial ability (but see Galea & Kimura, 1993).

When should a focus on Euclidean cues be favored? Remembering local landmarks will help you return home by following a route from a place you know, but only a good feel for direction and distance will help you return home if you find yourself in a novel location. Thus, large ranges and unpredictable routes (whether due to polygyny or hunting) should favor good spatial ability and attention to Euclidean cues. This argument gains support from evidence that people who excel at mental rotations also range farther and navigate better in situations where Euclidean cues are necessary (Ecuier-Dab & Robert, 2004b; Malinowski & Gillespie, 2001; Moffat et al., 1998; Silverman et al., 2000). There is, therefore, strong support linking the cognitive skills at which males excel to the navigational style they use and prefer.

When should remembering landmarks be favored? It has been suggested that the female reliance on landmarks while navigating may be related to women’s greater ability to recall object locations (Choi & Silverman, 1996; Dabbs et al., 1998; Silverman & Choi, 2005), and similar selection pressures could be involved. A navigational strategy based on landmarks might plausibly be a direct adaptation to finding bushfood locations, or it might be a by-product of the need to find and remember foods within a patch or a by-product of selection pressures other than gathering (Ecuier-Dab & Robert, 2004a).

An association between a landmark strategy and gathering would gain support from evidence linking the cognitive skill (object location memory), the navigational strategy (preferential attention to landmarks), and the behavior (skill at finding bushfoods). Results do not, as yet, show the clear patterning this hypothesis would suggest. Dabbs et al. (1998) found that women and men who favored landmark cues over Euclidean ones when giving directions had better object location memory, as we might expect—but also better mental rotation skill. Choi and Silverman (1996) found good mental rotation ability in both sexes to be associated with use of landmark cues but not Euclidean ones—the opposite of what might be expected (neither of these studies found a significant sex difference in object location memory).

Does superior object location memory enhance gathering ability? We don’t know, although some studies have incorporated plants into their design in order to bolster ecological validity. Neave, Hamilton, Hutton, Tildesley, and Pickering (2005) found that women were better at remembering target plant locations in static arrays of plants, although not in a related task that more closely resembled foraging (searching in a greenhouse and outdoors for partially obscured target plants). New, Krasnow, Truxaw, and Gaulin (2007) led participants at a farmers’ market to various food stalls using a circuitous route and showed that women were better at pointing to these stalls from a central

location, particularly stalls with high-calorie foods. This is, as the authors note, a Euclidean spatial task, at which males would be expected to excel. It shows that navigating with Euclidean cues is content sensitive, not an inevitable male advantage. Krasnow et al. (2010) explore this content dependence further and show that the female advantage in object location memory, controlling for nonspatial item memory, was found for a food plant but not for other stimuli.

While the gathering hypothesis (or hypotheses) is plausible, supportive evidence remains indirect. The female advantage at object location memory has not been evaluated among people who depend on foraging for a living, nor has it been associated with the ability of female foragers to find bushfoods. In this paper, we present our first results from a study of spatial ability among the Hadza, a population in Tanzania that still depends heavily (and in some areas nearly exclusively) on hunting and gathering.

We wish to determine, firstly, whether the sex difference in spatial abilities described for other populations exists among the Hadza. Although human males are more mobile than females (Ecuyer-Dab & Robert, 2004b; Gaulin & Hoffman, 1988), and this is true for the Hadza also (Marlowe, 2010), both women and men have large ranges in foraging societies. We might, therefore, expect both women and men to have good Euclidean spatial abilities in foraging societies, and sex differences to be enhanced in more sedentary food-producing societies, where women's mobility is often restricted to a domestic sphere.

In a comparison of four traditional populations, Berry (1971) found that mobile hunter–gatherers (Eskimo and Australian) did much better at a block design task than sedentary horticulturalists (from Sierra Leone and New Guinea) and that males performed better than females only in the horticultural groups. A historical review of 18th century travelers' accounts led Fossett (1996, p. 88) to conclude that Eskimo women “were frequently recognized by their own communities and by European travellers alike, not only as equals of the best male cartographers, but in many cases as superior in navigational and cartographic skills.” The block design is not a sensitive test for uncovering sex differences, but the results at least suggest caution in generalizing across populations because sex differences in mobility are likely to increase as foragers settle down and adopt food production. Draper (1975) found that !Kung Bushman women and men both ranged widely in mobile foraging camps, but in the camps that were partially dependent on agropastoralism, men continued to range widely, while women stayed closer to camp, attending to the new tasks associated with food processing and more permanent structures. A similar trend and enhancement of sex differences emerged in Bushman children, with boys more than girls beginning to spend more time away from camp and away from their parents' direct supervision (Draper & Cashdan, 1988). In evaluating the hunting and gathering hypotheses for sexually dimorphic spatial abilities, therefore, it is necessary to demonstrate that they are not

simply an outgrowth of changing sex roles and power relationships accompanying sedentism and stratification.

The second aim of our research is to begin evaluating hypotheses about sex differences in cognition by seeing whether there is a functional relationship between a particular cognitive skill and success at the real-world activity that is the proposed selective pressure for that ability. In this paper, we focus on the role of gathering and ask whether Hadza women who are nominated by their peers as excelling at finding bushfoods are also women with good object location memory as measured by cognitive tests.

## 2. Methods

### 2.1. Population

The Eastern Hadza are a hunting and gathering population living in northern Tanzania, on the east side of Lake Eyasi. Their history, culture, and subsistence patterns have been described extensively elsewhere and are reviewed in Marlowe (2010). As is the case with foragers elsewhere in Africa, their foraging resource base is being threatened by neighboring pastoralists and, in some areas, trophy hunters. Tourists are also visiting the area in increasing numbers, and the cash they bring, together with alcohol provided by local Tanzanians, is a growing threat to their traditional way of life. Nonetheless, there remain Hadza camps which subsist virtually entirely by hunting and gathering, and even in the more settled areas, foraging is still important both practically and as a part of their cultural identity. They are one of the least acculturated foraging populations in the world today.

This paper is based on data collected among 110 Hadza living in 10 camps in two locations. Two of the Hadza camps were traditional mobile foraging bands away from the direct influence of neighboring pastoralists and tourists. The remainder lived in the Mangola region some 50 km to the north, where interaction with pastoralists and the occasional tourist was a frequent part of their lives. We stayed for an extended period of time at the two mobile camps, but conducted our interviews with the Mangola Hadza in shorter visits from our own home base in the area.

Not all Hadza participated in all the tasks. Nearly all Hadza participated in the water-level and pointing tasks; women from all camps were asked for peer nominations, but only the Mangola camps participated in the object location memory task. A small subset from both areas participated in the targeting task.

### 2.2. Materials and procedure

Interviews and testing were done in Swahili, with the assistance of a trained and experienced Hadza field assistant. This assistant also explained the tasks in the Hadza language to the few individuals (chiefly older women) whose Swahili was poor. A Tanzanian research assistant helped with data collection on two of the four cognitive tasks (pointing and targeting).

We wanted tests of the major spatial factors and abilities that have shown sex differences in other populations: mental rotations, spatial perception, targeting, and object location memory. Unfortunately, we were unsuccessful at devising a mental-rotations task that worked well with the full population, so our results lack this important dimension. The Euclidean spatial tests used include the water-level task, targeting, and pointing accuracy.

### 2.2.1. *Water-level task*

The water-level task is considered to be a measure of spatial perception—the ability to identify horizontal and vertical accurately in spite of competing cues. Subjects are asked to indicate where the water line would be in a tipped vessel. Most incorrect answers indicate a line somewhere between the correct horizontal and the angle formed by the base of the vessel.

There is evidence linking skill at this task to navigational skill and strategy. Skill at the water-level task has been associated with better wayfinding over a large space (Choi et al., 2006, but see Silverman et al., 2000), self-reported use of more geometric (distance and direction) cues during wayfinding (Lawton, 1994), and better vestibular navigation (Sholl, 1989). Men consistently outperform women at the water-level and other tests of spatial perception (Linn & Petersen, 1985; Voyer et al., 1995).

In our version of the water-level task, subjects were shown drawings of four tipped glasses with a horizontal table line under them: one had a water line drawn horizontally, one had a water line drawn parallel to the base of the glass, and two had lines drawn at intermediate angles. Participants were asked which of the four best represented what the water would look like if the glass were tipped. An actual (empty) glass was used as an aid in explaining the question. All subjects appeared to understand and respond to the question without difficulty.

### 2.2.2. *Targeting*

We used an underhand beanbag toss to a fixed target on the ground as a measure of targeting ability. Participants made two attempts to hit the target from 4.3 m, then from 6.7 m, and finally from 9.3 m. Hadza men, who are skilled with bows, have more targeting experience than women. We used an underhand, rather than overhand, toss to minimize that experience as much as possible.

### 2.2.3. *Pointing accuracy and mobility*

The pointing task was used simultaneously as a measure of mobility and a measure of dead-reckoning ability. For each of 12 locations in the region, participants were asked first if they had ever visited the location and, if so, when they had last done so. If they had been to the location, they were asked to point to it with a small dowel. We sighted along the dowel with a Suunto global compass and recorded the compass bearing and compared that with our GPS data to calculate the error. Mangola and bush camps were analyzed separately because a few of the target locations differed between the two regions. The target locations were not

related directly to resource patches, but are on the same scale of distance as camp moves made to access new resources.

There was no overall directional bias to the pointing errors, but there was a directional bias from a few camps to a few locations. This probably does not reflect navigational error but rather people from that camp thinking about a different area within a named location than we had recorded with our GPS data (a more recently inhabited camp perhaps, or a landmark rather than a camp location). Rather than use the raw errors, therefore, we substituted the median bearing between a camp and a target location for the bearing based on GPS data. We then normalized the errors separately for each camp to control for variance due to camp location: we converted the errors to *z*-scores, squared them (to make errors positive), and calculated the average for each person over all the target locations they pointed to. The average of the squared *z*-scores was our measure of pointing error for each person. We used data only from the larger camps for this analysis (three camps in the Mangola region and two bush camps in the area to the south) in order to get reliable estimates.

### 2.2.4. *Object location memory*

The object location memory task used was a variant of the commercial memory game. This test was used by McBurney et al. (1997) for a similar purpose because it provided a better analogue to the cognitive demands of gathering than earlier paper-and-pencil tests of spatial memory. Their study showed a large sex difference favoring women on this task. The task is similar in its cognitive demands to the task used by Krasnow et al. (2010) in that the subject must choose among cards whose positions do not move, but the stimulus on the cards is only intermittently visible.

In our version, 10 pairs of picture cards (five of local animals, five of local plants) were shuffled and placed face down on a flat surface. The participant first turned over one card, then another. If the two cards matched, they were removed from the game. If they did not match, the cards were returned, face down, to their original location. The participant then turned over another two cards, and the process was repeated until all cards were removed from play. The number of plant and animal cards that had to be turned over before the deck was cleared was the measure of object location memory. A practice deck using five pairs of cards (three of animals, two of plants) was used for instruction and training.

This task was used successfully with virtually all Hadza, although a few of the older women found it frustrating and sometimes tried to cheat by peeking under the cards. The chief advantage of this task for field use is that it obviates issues of motivation. Although the task was challenging and sometimes frustrating, there was no way participants could “go through the motions” just to get the task over with. The only way to complete the activity was by trying hard and successfully matching all the cards. We attempted several more naturalistic tasks, including two of incidental object

location recall, but ran into problems with them in this field setting (see online Appendix available on the journals website at [www.ehbonline.org](http://www.ehbonline.org)).

### 2.2.5. Peer nominations

We used peer nominations to measure individual differences in ability to find bushfoods. Peer nominations have been used successfully as a measure of hunting skill with many foraging groups, including the Hadza. Women in our study were asked to nominate women who excelled at finding bushfoods (“Which woman is the best at finding bushfoods?” “Anyone else?” “Anyone else?”). We asked specifically about skill at finding bushfoods, not at general gathering ability. All women were able to nominate one person, most named a second when prompted, but only a few named a third. A subset of the sample was also asked to nominate women who were good at looking after children.

### 2.2.6. Analysis

SAS was used for all analyses other than the randomization test, which involved a computer program written for this study. Analysis of variance (ANOVA) was done with proc GLM using the type III (marginal) sums of squares, which calculates the variation attributable to an effect after correcting for all other effects in the model. Although we have predicted the direction of effects, all *p* values presented below are two-tailed.

## 3. Results

### 3.1. Sex differences in Euclidean spatial ability

#### 3.1.1. Water-level task

There were 51 women and 52 men who did the water-level test. As in other populations, men did significantly better than women (Fig. 1), although the magnitude of the sex difference depends on how it is scored. If we look at correct vs. incorrect responses, 42% of the men correctly indicated that the water would be horizontal, as compared to 16% of the women. This difference is significant:  $\chi^2=8.84$ ,  $p=.003$ ,  $\phi=.29$ . However, men also showed more variance, so if one gives “partial credit” for near misses (response 3), the sex difference is smaller.

#### 3.1.2. Targeting

Men were significantly more accurate than women at the targeting task (underhand beanbag toss) at all scales of distance (Table 1), although our numbers for this test were small (19 women, 9 men). Our impression is that many women were hampered at the longest distance by lack of strength, swinging wildly in their attempt to get the beanbag close to the target. However, this did not appear to be a problem at the closest distance, where the sex difference was also large. We used a Wilcoxon Mann–Whitney test to compare women and men and found that men were significantly more accurate at both near ( $Z=-2.91$ ,  $p=.004$ ,  $d=1.2$ ) and middle-distance ( $Z=-2.66$ ,  $p=.008$ ,  $d=.78$ ) targets.

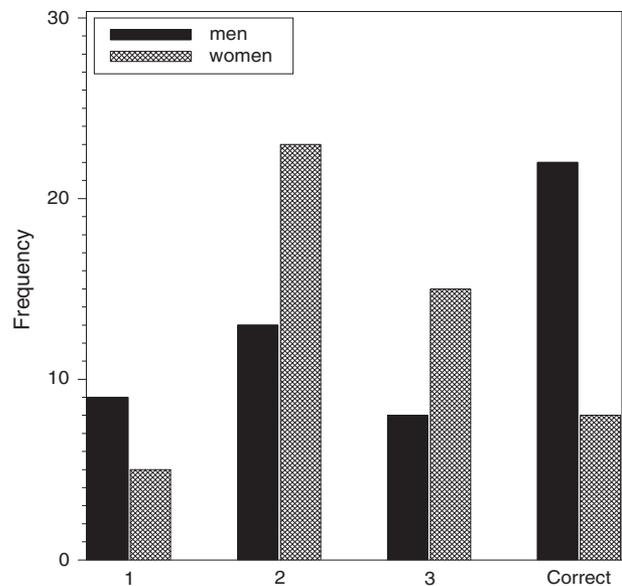


Fig. 1. Water-level task. Response 1 refers to a figure with the water line parallel to the base of the tipped vessel; responses 2 and 3 are intermediate between that and the correct horizontal response.

#### 3.1.3. Pointing accuracy and mobility

The pointing data were normalized for each of the five largest camps as described in the Methods section (the error for each person was the average, over the places pointed to, of the squared *z*-scores of their individual errors). These were square-root transformed prior to analysis in order to reduce skew in the distributions.

A few of the bearings we collected in Mangola had large errors. We omitted those greater than  $90^\circ$  from analysis because of concern that they reflected misunderstandings about the location rather than directional ability. All of the bush camp bearings were well within these bounds, as were 97% of the Mangola camp bearings (97.4% for Mangola men, 95.2% for Mangola women).

Because not everyone pointed to all the target locations, we considered using the number of targets pointed to as a covariate in the models. However, the relationship of the covariate to pointing error was very weak, and it disappeared entirely when we removed four people who pointed to fewer than eight target locations ( $r=-.91$ ,  $p=.93$ ,  $n=63$ ). With those four cases removed, we used a *t* test and found that the errors of women were somewhat greater than the errors of men ( $t_{61}=1.70$ ,  $p=.09$ , Cohen's  $d=.44$ ). The mean error score for

Table 1  
Targeting accuracy

	Women		Men	
	Mean	S.D.	Mean	S.D.
Near	35	25	9	11
Mid	57	35	27	45
Far	134	75	54	30

Distance from the target, in centimeters, averaged over two trials.

men was 0.89 (S.D.=0.34,  $n=29$ ), or  $14.5^\circ$  (S.D.=5.5), whereas the error score for women was 1.04 (S.D.=0.34,  $n=34$ ), or  $16.9^\circ$  (S.D.=5.7).

We might expect greater pointing accuracy in the bush camps as a consequence of their greater mobility, and their raw error scores were indeed lower than those of the Mangola camps. However, because they occupy different regions and pointed to different locations, we cannot assume that the tasks were equivalent. Therefore, no attempt was made to compare the relative pointing skill in the two regions. We can, however, see whether there is a greater sex difference favoring men in the Mangola camps. A two-way ANOVA, with sex and group (bush vs. Mangola) as factors, found that the interaction term was not significant ( $F_{1,59}=1.7$ ,  $p=.17$ ). However, power is low due to the much smaller sample size in the bush group. While we cannot make any claims about regional differences, a sex difference in pointing accuracy was found only in the Mangola camps. Men in these camps were significantly better there than women ( $t_{43}=2.43$ ,  $p=.02$ , Cohen's  $d=.74$ ), with male scores averaging 0.84 (S.D.=.26,  $n=19$ ) and female scores averaging 1.07 (S.D.=0.35,  $n=26$ ), while scores among men and women in the bush camps were nearly identical ( $M=0.98$ , S.D.=0.45,  $n=10$  for men and  $M=0.92$ , S.D.=.36,  $n=8$  for women). This amounts to an average error in the bush camps of  $15.0^\circ$  (S.D.=5.9) for women and  $16.0^\circ$  (S.D.=7.3) for men compared to  $17.5^\circ$  (S.D.=5.7) for Mangola women and  $13.7^\circ$  (S.D.=4.3) for Mangola men.

People were asked when they had last been to each of the locations. A comparison of men and women using the full data set indicates a trend towards men having been to more places over their lifetime and within the past 2 years, but the differences were small. Women had seen an average of 8.9 of the 12 target locations over their lifetime (S.D.=3.0,  $n=48$ ), while men had seen 10 of the 12 (S.D.=2.2,  $n=52$ ). Most of the locations had been visited recently: women had visited an average of 7.3 of the locations (S.D.=2.9,  $n=48$ )

within the prior 2 years, and men had visited 8.4 of them (S.D.=2.4,  $n=52$ ).

We used number of places visited in the preceding 2 years as a covariate in an analysis of covariance (ANCOVA) to see whether differences in mobility to the target locations could explain the difference in pointing scores. The covariate and interaction terms were not significant, and the main effect of sex was reduced and not significant when these terms were included in the model.

### 3.2. Object location memory: sex and age effects

Female superiority at object location memory is central to the gathering hypothesis. Good performance at our object location memory task required participants to remember the location of cards they had previously turned over: the more cards they needed to turn over, the poorer the performance. Two very old people, one man and one woman, found the task too difficult and did not complete it.

Fig. 2 shows the number of cards turned over (fewer is better) by age and sex.

The figure omits one outlier, an older woman whose performance was extremely poor. The regression line is shown for women only since age was not related to performance in men. As Fig. 2 shows, the performance of women deteriorated with age. The beta coefficient for the regression of performance on age for women was .77 without the outlier ( $r=.63$ ,  $n=34$ ,  $p<.0001$ ). There were more older women than older men in the sample, but the pattern remains significant even if those over 50 years are removed from the calculations: the change with age in women 50 years and younger remains significant ( $r=.42$ ,  $n=27$ ,  $p=.03$ ), while there is not a significant effect of age on the performance of men. The performance of men relative to women at different ages can be seen more clearly in Fig. 3, which plots the residuals of the male scores from the female regression line.

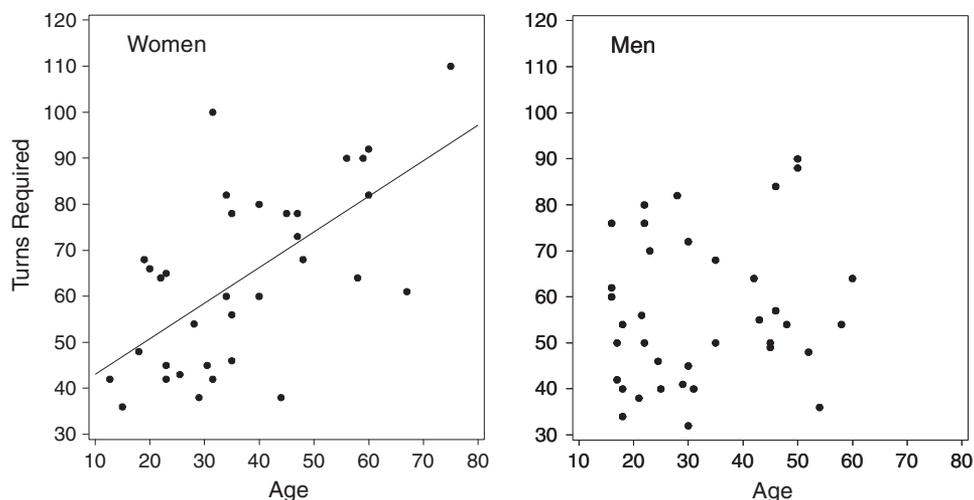


Fig. 2. Memory game by age, with female linear regression line.

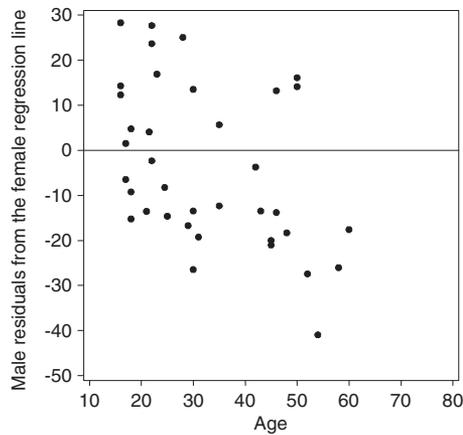


Fig. 3. Memory game: male performance against predicted female performance.

Because lower scores (fewer cards turned over) mean better performance, we can see that older men scored better than predicted for females of that age.

Among people 25 years and older (omitting the older woman whose performance was unusually poor), men were significantly better at this task ( $t_{43}=2.40$ ,  $p=.02$ ,  $d=.72$ ), while the trend across the sample as a whole is in the same direction but shows a smaller difference ( $t_{69}=1.78$ ,  $p=.08$ ,  $d=.42$ ). Among people under 25 years, women had a smaller (better) mean and median score, but this difference did not approach statistical significance. However, power is limited due to the small number of women in this age group.

We might expect Hadza women to have better recall for plant cards than animal cards, as they focus on plants during foraging. The opposite might be expected for men. Half of our memory game cards were of local plants and half were of local animals, and we scored how many of each were turned over before a match was found. The ratio of plant cards to animal cards turned over was 1.20 for men and 1.12 for women (Table 2).

The difference between the cross-products in Table 2 will be zero in expectation if the ratios for men and women are the same. To test this null hypothesis, we performed 10,000 randomization trials. In each trial, the counts of plant and animal cards of each person were exchanged with independent probability 1/2. In 3456/10,000 of these trials (i.e.,  $p=.35$ ), the difference between the cross-products was at least as large, in absolute value, as that observed in the real data. These data, therefore, do not support the hypothesis that the sexes differed in relative recall of plants versus animals.

Table 2  
Mean numbers of cards turned over in the memory game

	Men ( $n=38$ )	Women ( $n=35$ )
Plants	30.9	35.6
Animals	25.8	31.8

Although we were not initially looking for age effects, the deterioration in women's performance on the object location memory task led us to wonder whether performance on our Euclidean spatial tasks also deteriorated with age. We found no significant age effect for any of the other variables tested, in either men or women, with the exception of the long-distance targeting task, where physical strength appeared to influence performance.

### 3.3. Object location memory and ability to locate bushfoods

We asked 44 women to nominate the woman who was best at finding bushfoods. We then asked "any others?" and if they named a second woman, we asked the same question a third time. Most women nominated two such women, and some named a third. There were 30 nominated women in all; we had ages for 18 (2 by eye, 16 were in our earlier database), 5 were from camps we did not visit, and the other 7 were in the camps, but we could not identify them reliably in our database.

The most surprising finding was the age of the women nominated. With only two exceptions, the nominated women on whom we had age data were at least 50 years old, and most were over 60 years old. Fig. 4 shows age by the total number of first or second nominations, including self-nominations; the line is a weighted spline approximation.

The gathering hypothesis suggested the prediction that women who were nominated as being good at finding bushfoods would excel at object location memory, but this was not the case in our data. As Fig. 2 shows, older women performed more poorly on the object location memory task than any other age–sex category, yet they were consistently the ones nominated by other women for their skill at finding bushfoods. The nominated women on whom we had memory game data performed, not surprisingly, more poorly than the other women in the sample: the median number of cards turned was 86 for nominated women and 58 for the other women. However, an ANCOVA using age as a

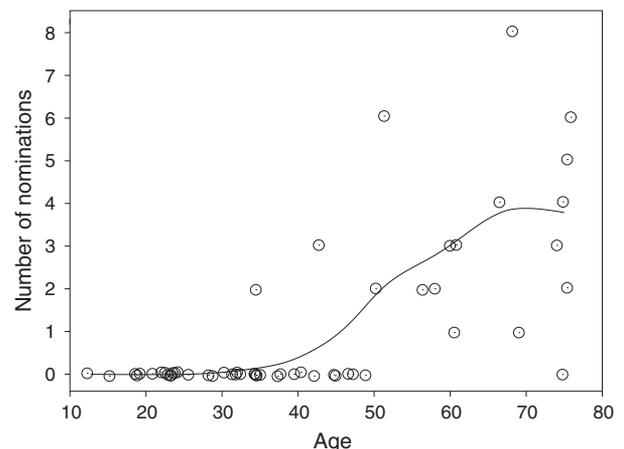


Fig. 4. Age by number of first or second nominations.

covariate showed that their poor performance was a function of age ( $F_{2,31}=.02, p=.88$  for nomination status controlling for age, with the outlier deleted.)

Like older people generally in our sample, however, the nominated women were similar to other women (all ages) in the Euclidean spatial tasks. They were not significantly different in their percentage correct in the water-level task (Fisher's Exact Test  $p=.69, n=51$ ), and there was also no difference between the two groups of women in pointing accuracy ( $t_{32}=.37, p=.71$ ).

### 3.3.1. Are the nominations meaningful?

We considered the possibility that women were nominating older women out of respect, but think this is unlikely because a second nomination task—who is best at looking after children—showed a different result. There was consensus in these nominations also, but the women nominated were younger women, and only one woman appeared on both lists. In the bush camps, where we asked women both questions, four of the five women who were nominated first or second as good child minders were in their 20s or 30s, whereas all of the three women who were named first or second as good at finding bushfoods were over 50 years old, with the highest ranking going to a 68-year-old grandmother. When we asked this woman why she nominated herself, she explained “because I remember where the food is.” Her answer suggests that these nominations reflect what we were trying to measure and that spatial memory plays a role in this ability.

## 4. Summary and discussion

Men typically do better than women at some visual spatial tasks, and our first aim was to determine whether this was also true for the Hadza. We found significant differences in the expected direction for our three tests of Euclidean spatial ability. The difference in the water-level task, a test of spatial perception, was large: men were nearly three times as likely as women to answer correctly, although there were more men at both ends of the distribution. Men were also much more accurate in the underhand beanbag toss at all scales of distance. Men in the less mobile Mangola camps were more accurate than women at pointing to other places in the region. They had also been to more of the locations than the women, although that difference was small and did not explain the sex difference in pointing accuracy.

While Hadza women are very mobile, on a daily basis, Hadza men are even more so: they spend more time out of camp, and they cover more kilometers on their forays (Marlowe, 2006). However, the sex difference in Euclidean spatial ability may not be solely a function of mobility. Men usually hunt alone and so must depend on their own sense of direction, whereas women gather in groups and can rely on each other to keep track of where they are and how to get from one place to the next. This is a common pattern for

human foragers. Sharing navigational skill reduces the cost of errors to female foragers while also posing a collective action problem—and, as with other collective goods, evolution is likely to provide less of it than is optimal. These differences may have played a role in increasing sexually dimorphic spatial abilities.

We were unable to replicate the finding of greater female object location memory in our adaptation of the memory game. There was a slight trend toward female superiority among young people, but overall, there was a trend ( $p=.08$ ) toward better male performance. Women's performance deteriorated linearly with age. Most previous studies of object location memory, including three that used a task similar to ours (Duff & Hampson, 2001; McBurney et al., 1997; Tottenham, Saucier, Elias, & Gutwin, 2003), have used college-aged samples, which could explain the discrepancy in our results. Low postmenopausal estrogen levels may account for some of the poor performance we saw in our older women. Duff and Hampson (2000), using a task similar to ours but more demanding (matched pairs were not removed), found that postmenopausal women who were given supplementary estrogen did much better on this task than women without. Their evidence suggests that this was related to the working memory demands of the task rather than spatial memory per se.

Men gather opportunistically for themselves, whereas women gather more intensively, bringing the plant foods back to camp to share with others. It has therefore been proposed that women's superior object location memory should be strongest for gathering-related stimuli. However, we did not find a significant sex difference in location memory for plant as opposed to animal cards in the memory game. This might be because the plants and animals on our cards were not limited to food species, a limitation we have corrected in a study with a different group of foragers (in preparation).

The gathering hypothesis led us to predict that women who excel at object location memory would also excel at locating bushfoods. Yet the Hadza consistently nominated older women, whose object location memory was poorer than that of younger women, as being most skillful. We suggest four reasons for this outcome, which are not mutually exclusive. The first is that our peer rankings may reflect the ability to find bushfoods on a spatial scale too large to be aided by object location memory as measured in our memory game task. Krasnow et al. (2010) argue that non-Euclidean object location memory is helpful in remembering the location of resources in a local patch of vegetation, but not in navigating between patches. Second, because Hadza women forage in groups, it is possible that spatial memory deficits in any one member, including deficits associated with age, are not very serious and are more than compensated by experience. Third, the memory game tests short-term and working memory, which declines with age, but not long-term memory, which remains intact at older ages. Yet the latter, the storehouse of memories

acquired repeatedly over a lifetime, may be more important in successful gathering.

Finally, older Hadza women may be relying relatively less on object location memory than younger women and more on Euclidean spatial skills. The latter did not decline with age in our sample and is especially important when navigating over the longer distances of typical foraging ranges. Estrogen appears to improve performance on the memory game, as noted above, but it reduces performance on Euclidean spatial tasks (reviewed in [Hampson, 2002](#); [Kimura, 2002](#)). Lower estrogen levels associated with menopause may therefore enhance Euclidean spatial ability in older Hadza women or at least protect it from the general cognitive declines of aging. This would be consistent with [Sherry & Hampson's \(1997\)](#) “fertility” hypothesis for the sex difference in spatial ability, which posits that selection has led to reduced mobility and spatial ability in reproductive-aged women in order to minimize their energetic costs and the risks associated with travel, and predicts a lifting of these constraints and consequent increase in female spatial ability in older, postreproductive women. Most studies of cognition and navigational strategies thus far have used young women and men; it would be interesting to replicate these studies in older populations and see whether the sex difference in navigational strategies remains the same.

Hadza grandmothers are apparently not only hardworking, as [Hawkes, O'Connell, and Blurton Jones \(1989, 1997\)](#) have shown, they are savvy as well. These data, preliminary though they are, support the idea that the knowledge and experience of age carry real payoffs for women in gathering. Furthermore, this advantage does not level off or decline after a woman reaches middle age, but continues to increase into old age.

We are acutely aware of the limitations of contrived tasks and peer nominations, and we conducted a pilot study of navigation and landmark recall in outdoor terrain over a moderate distance (1.7 km) as a way to support these conclusions. Unfortunately, methodological problems prevented our ability to use the data and continue the study. We also attempted more naturalistic tests of object location memory, including recall of local and distant landmarks photographed en route during a camp move, and an incidental recall task of items moved in a Hadza-style hut. The landscape recall failed because performance was poor for everyone (including us). The hut task failed because the Hadza were angry about the deception (to test incidental recall, they were not told to pay attention to the items). We describe these experiences in the online Appendix (available on the journals website at [www.ehbonline.org](http://www.ehbonline.org)) in the hope that they will prove instructive to others working to adapt spatial and navigational tasks for field use in traditional populations.

Little is known about what cognitive strategies are helpful to people who rely on foraging for a living. Some people mentioned to us that older women excel at knowing which foods will be ripe or ready to harvest at what time in what local area. Gathering is usually viewed as a three-

dimensional navigational challenge, but the greater cognitive challenge may be how to navigate successfully in a four-dimensional world that includes temporal changes in the spatial distribution of plant resources. Temporal changes can be very local, with berries of the same species ripening at different times in nearby areas. Longer-term changes on a larger scale are probably equally important, such as the ability to predict when the tubers in a harvested area will again be ready to eat, which species in an area hit by fire will have regenerated in 1 year or 2, and so on.

Thus far, human foraging ecology and evolutionary psychology have been largely separate (and sometimes antagonistic) domains, but there is a case to be made for integrating them. It is not obvious what sort of locational cues are useful to a gatherer or how far we can extend inferences drawn from studies in urban areas to foraging ranges, which can be quite large. Most wild plant resources are not spatially predictable in the way urban landmarks are: they spread, die out, and shift over time, even though an individual plant is rooted to the ground. This uncertainty is exacerbated by the temporal unpredictability discussed above (Where will the undushipi berries be ripe today? Can we return to this tuber patch yet, or will the tubers still be too small?). The advantages of relying on landmarks vs. Euclidean cues probably vary systematically by habitat and species since there are systematic differences in the spatiotemporal predictability of both plant and animal resources. Visibility also varies by habitat: where one can see important features of the landscape unimpeded by vegetation, object location memory is likely to be useful over longer distances. It should, therefore, be possible to predict how reliance on different strategies might be favored in different habitats. Consideration of these issues should help us better understand the cognitive demands of finding food in a foraging economy.

### Supplementary Materials

Supplementary data to this article can be found online at [doi:10.1016/j.evolhumbehav.2011.10.005](https://doi.org/10.1016/j.evolhumbehav.2011.10.005).

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