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ORIGINAL PAPER

The Hunter-Gatherer Theory of Sex Differences in Spatial Abilities: Data from 40 Countries

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Abstract This study used some of the data from the BBC Internet study to assess the universality of sex related spatial competencies, as these are described in the terms of Silverman and Eals' (1992) hunter-gatherer theory of human spatial sex differences. As predicted, men scored significantly higher than women on a test of three-dimensional mental rotations in all seven ethnic groups and 40 countries used. Close to prediction, women scored significantly higher than men on a test of object location memory in all seven ethnic groups and 35 of the 40 countries. The data were discussed in terms of their implications for research approaches in this area and a paradigm for future studies was proposed, based on the interaction of innate and environmental factors in the ontogenetic development of spatial sex differences.

Keywords Sex differences · Spatial abilities · Evolutionary theory · Hunter-gatherer · Mental rotations · Object location memory

Introduction

The Hunter-gatherer theory of spatial sex differences

Studies spanning the last half century have shown a male advantage on spatial tests, with three-dimensional mental rotations (3DMR) yielding the largest and most reliable differences (Kimura, 1999; Voyer, Voyer, & Bryden, 1995). These differences are typically described in linear terms, with males occupying a higher place on the scale of general spatial abilities. Silverman and Eals (1992), however, presented an evolutionary theory, with the conclusion that spatial sex differences may be more accurately explained in terms of qualitatively different competencies between the sexes rather than quantitatively different ability levels. According to this theory, the critical factor in selection for human spatial sex differences was division of labor during the Pleistocene era, whereby males functioned primarily as hunters and females as gatherers of plant food.

Evidence for the relationship between spatial skills and hunting, particularly in primitive times, comes from two sources. For one, studies have demonstrated a positive relationship between spatial test scores and throwing accuracy, a critical skill for felling a potential prey (Jardin & Martin, 1983; Kolakowski & Malina, 1974; Watson & Kimura, 1991). Other studies found a positive relationship between 3DMR and wayfinding by orientation (i.e., without the aid of landmarks), an essential ability for tracking or pursuing an animal on a random trail through unfamiliar terrain while maintaining the spatial orientation necessary to take the most direct way home (Moffat, Hampson, & Hatzipantelis, 1998; Silverman et al., 2000). Moffat et al. employed a virtual maze, while Silverman et al. used an actual forested area, where individual participants followed the

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experimenter along a circuitous path and were then required to return to the starting point by the shortest route. In the latter study, regression analysis showed that the male advantage in wayfinding by orientation could be fully explained by sex differences in 3DMR.

Silverman and Eals (1992) contended that if spatial abilities associated with hunting were selected for in males, it is feasible that spatial abilities related to gathering were correspondingly selected for in females. Successful gathering would have entailed locating edible plants within diverse configurations of vegetation and then finding them again in ensuing growing seasons. This, in turn, would have required the capacity to rapidly learn and remember the contents of object arrays and the relationships of objects to one another within these arrays. Success would also be increased by peripheral perception and incidental memory for objects and their locations, inasmuch as this would allow one to assimilate such information non-purposively, while attending to other matters. In support of this analysis, it has been shown that females have larger visual fields than do men; that is, they can see farther out on the periphery while fixating on a central point (Burg, 1968). They are also better than males at scanning, excelling on various tests of perceptual speed (Kimura, 1999).

Based on their theory, Silverman and Eals (1992) compared the sexes on their abilities to learn contents and spatial configurations of object arrays, using various original test situations. In one, developed for group administration, participants were presented with drawings of common objects in an array and asked to examine them for one minute. They were then shown another version of the array in which some items had been relocated and asked to identify which had changed positions.

Another method used an actual array. Participants were solicited for an experiment on “perception.” Upon arrival, they were separated from any reading material they may have been carrying and left alone for two minutes in a small room containing a variety of work related and personal items. In one condition, they were instructed to try to learn the objects in the first room and their locations (directed learning). In another, the room was presented as a waiting room for the experiment (incidental learning). Participants in both conditions were then taken to another room and tested for memory of the items and their locations in the first room.

The data for both conditions supported the predicted female advantage, with the most consistent differences occurring for incidental location recall. These findings have been fully or partially replicated in various laboratories, some with novel research designs (e.g., Choi & Silverman, 1996; Dabbs, Chang, Strong, & Milun, 1998; Eals & Silverman, 1994; Gaulin, Silverman, Phillips, & Reiber, 1997; James & Kimura, 1997; McBurney, Gaulin, Devineni, & Adams, 1997; McGivern et al., 1997).

Sex-specific navigational strategies

Consistent with the above, it has been amply demonstrated that males prefer to use an orientation strategy in navigational tasks, while females prefer a landmark strategy. Specifically, males use distance concepts and cardinal directions; that is, north-south-east-west, while females rely more on landmarks and relative directions, such as right, left, in front of, and behind (e.g., Choi & Silverman, 1996, 2003; Dabbs et al., 1998; Galea & Kimura, 1993; Joshi, MacLean, & Carter, 1999; Lawton, 1994, 1996; Lawton & Kallai, 2002; Moffat et al., 1998; Schmitz, 1997).

Investigators have tended to take a similar linear approach to sex differences in preferred navigational strategies as was previously described for other spatial attributes. The assumption, implicit or explicit, is that males are more adept in the Euclidean abilities required for navigation by orientation and females compensate by using landmark strategies (e.g., Galea & Kimura, 1993; Lawton, 1994; Moffat et al., 1998). The hunter-gatherer theory of spatial sex differences, however, suggests that the use of a landmark navigational strategy in females may be an aspect of the same evolved cognitive mechanism, emanating from their role as gatherers, that enables their greater object location recall. Whereas an orienting strategy enables the hunter to navigate across long distances where landmarks are unavailable or distributed far out of sight of each other, a landmark strategy is more efficacious for the gatherer, navigating in a smaller space where the pattern of landmarks can be more readily observed and recalled (Alcock, 1984; Silverman & Choi, 2005).

In support of this contention, Choi and Silverman (1996, 2003) showed that route learning success was predicted by measures of object location recall for females, but not for males, and by Euclidean reasoning for males, but not for females. In the same vein, Saucier et al. (2002) administered laboratory and field navigational tasks in which participants were required, at the direction of the experimenter, to use either an orientation or a landmark strategy. Males fared better with an orientation strategy and females with a landmark strategy although both groups performed at an equivalent level. All of this may suggest that the landmark strategy is not used by females as a default, but as the expression of a well-developed mechanism in itself.

Evidence for evolutionary origins

In addition to the evidence cited above for dual mechanisms mediating human spatial sex differences, there are data that more directly support the proposition that these mechanisms originated and developed as evolved adaptations. These include the findings that the spatial sex differences found in humans extend across species. Studies with wild and laboratory rodents have shown that males consistently outperform females in maze learning tasks (Barrett & Ray, 1970; Binnie-Dawson & Cheung, 1982; Gaulin & Fitzgerald, 1986; Joseph, Hess, & Birecree, 1978; Williams & Meck, 1991). Rats also demonstrate the same sex differences in navigational strategy as do humans. When navigating in radial-arm mazes, males are capable of using distal cues such as the shape of the room, suggesting an orientation strategy, while females require landmarks (Williams, Barnett, & Meck, 1990; Williams & Meck, 1991).

Though cross-species data provide support for an evolutionary approach to human spatial sex differences, they present a problem in generalizing from Silverman and Eals' (1992) hunter-gatherer theory, inasmuch as there is no similar division of labor in the phylogenetic history of the rodent. Ecuyer-Dab and Robert (2004a), however, proposed a revised version of the theory that encompassed cross-species parallels. Within their model, the paramount selection factor for the evolution in females of superior object location recall and a landmark navigational strategy was not success in food gathering (although that is regarded as a by-product); it was the need for physical security for themselves and their offspring. In primal times, this would have required the capacity to learn and recall details of their proximate environment (home range) in order to be alert to cues regarding the presence of predators and other dangers and to quickly find, when needed, possible hiding places or escape routes.

Both human and animal neurophysiological data also support an evolutionary interpretation of spatial sex differences. Gur et al. (2000) and Jordan, Wüstenberg, Heinze, Peters, and Jäncke (2002) have demonstrated differential brain site activation between men and women when engaged in spatial tasks. In regard specifically to sex related navigational strategies, studies with rats have revealed that discrete types of neurons (place cells) are activated when the animal is solving tasks requiring an orientation strategy (Muller, Bostock, Taube, & Kubie, 1994; O'Keefe & Nadel, 1978; Taube, 1995, 1998; Taube, Muller, & Ranck, 1990). Additionally, a human clinical study reported that two right hemisphere-damaged patients were unable to orient themselves to an enclosure by its shape, but could use landmark cues, whereas two patients with a different right hemisphere lesion site showed the opposite pattern (Pizzamiglio, Guariglia, & Cosentino, 1998).

Furthermore, sex hormones have been implicated in spatial sex differences in both humans and animals, with the most reliable findings showing an increase in spatial abilities in females with decreased estrogen levels (Packard, 1998; Silverman & Phillips, 1998). Hormonal studies have not been reported, however, for the female spatial specializations described here.

Universality of spatial sex differences: The present study

The most telling evidence for the evolutionary origins of a human characteristic is universality across cultures. Most published reports of spatial sex differences, however, are based on North American samples, though there have been replications of the male bias in Japan (Mann, Sasanuma, Sakuma, & Masaki, 1990; Silverman, Phillips, & Silverman, 1996), England (Lynn, 1992), Scotland (Berry, 1966; Jahoda, 1980), Ghana (Jahoda, 1980), Sierra Leone (Berry, 1966), India, South Africa, and Australia (Porteus, 1965). These may suggest universality, though there is no indication of how many unpublished studies in diverse cultures tried and failed to find sex differences. Regarding female spatial specializations, there has been one replication in Hungary of sex differences in navigational strategy using a non-North American sample (Lawton & Kallai, 2002).

The main purpose of the present study was to assess the universality of both male and female spatial specializations across multiple countries and ethnic groups, using the resources of a world-wide Internet study.

Method

Participants

The present data were collected as part of an interactive Internet study hosted by the BBC, comprising more than 250,000 participants in 226 countries across the world and including two tests (described below) contributed by the present authors. The data from 40 countries were used in the present study, yielding total Ns of 128,360 males and 116,533 females for 3DMR and 129,963 males and 117,553 females for OLM. Mean ages were 31 years ($SD = 12$) and 28 years ($SD = 12$), respectively. Countries were included that met the criterion of a minimum of 100 each of males and females completing both tests. The purpose of this criterion was to provide sufficiently large sample sizes, per country, to offset the high degree of demographic variability expected in a participant solicitation process of this nature.

Participants were also divided into self-identified ethnic groups based on categories listed in the demographic questionnaire for the BBC survey. These were: Black/British, Black/Other, Chinese, other Asian (including East Indian), Mid-Eastern, Mixed and White. While this is not a common system for categorizing ethnic groups, it did provide comparative data for a separate test of the universality hypothesis.

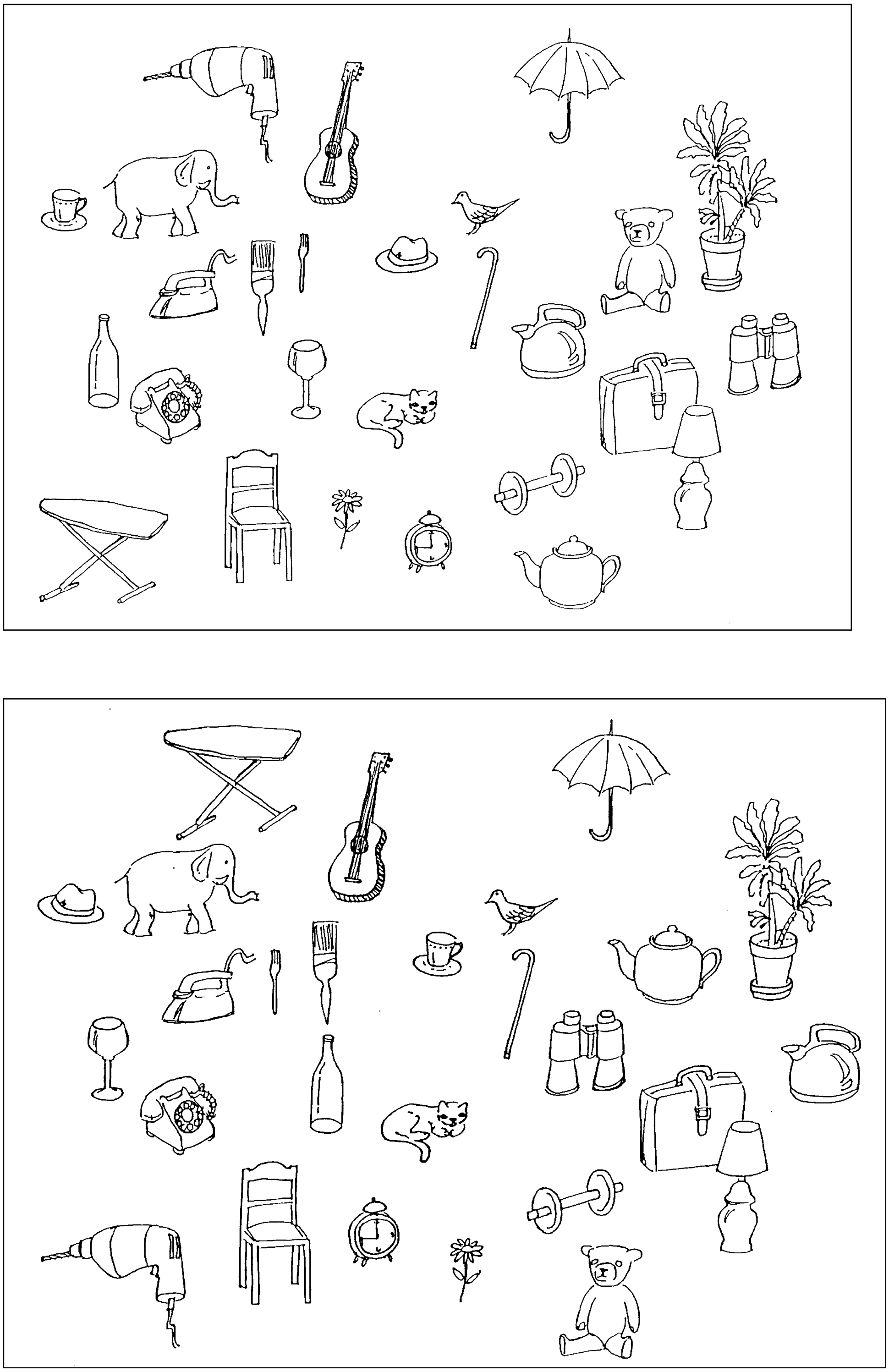

Fig. 1 OLM spatial arrays, in order presented

Measures

The tests used were a measure of object location memory (OLM) adapted from Silverman and Eals' (1992) group test (Fig. 1) and a shortened version of the Peters et al. (1995) version of Vandenberg and Kuse's (1978) group test of 3DMR which, in turn, was based on the quasi-3 dimensional stimuli developed by Shepard and Metzler (1971). The OLM test consisted of two arrays of the same common objects, presented to the participants sequentially, with half the objects in different locations in the second array. The 3DMR test contained six items, varying in difficulty, taken from Peters et al. (1995), each consisting of a target drawing and four test drawings.

Procedure

Procedural details of the BBC Internet survey can be found in Reimers (2007). The survey was divided into six parts, with OLM included in the first and 3DMR in the sixth.

Directions for the OLM test read as follows:

"This task is called 'Spot the difference.' Please read the instructions carefully. This is a timed task and you won't be able to restart once you've begun. What to do:

- You'll have 60 s to view a screen of objects. Study the location of the objects in relation to one another.
- You will then be shown a second screen of exactly the same objects, but about half of them will have moved around.
- Click on the objects you think have moved.
- You'll get one point for choosing correctly, but lose one point for choosing incorrectly.
- You will have 60 s to complete this task."

In order to correct for guessing, OLM scores were calculated by adding the number of correct selections and subtracting the number of incorrect selections.

Directions for the 3DMR test were:

"This task tests your ability to mentally rotate an object in your head. Please read the instructions carefully. This is a timed task and you won't be able to restart once you've begun. What to do:

- Match the object on the left with the same object on the right-viewed from a different angle.
- There are two correct matches out of the four possible options. Select both by clicking directly on them.
- There are six objects to match.
- You have 2 min 30 s to complete the task."

A point was given for each correct item chosen.

For both OLM and 3DMR, participants were given their scores after completion of the test.

Statistical analyses

Univariate analyses of variance were applied to mean sex differences for the OLM and 3DMR test, for the overall sample of participants and for countries and ethnic groups. Conclusions regarding the universality hypothesis were based, for each test, on the frequencies of countries and ethnic groups showing significant main effects for sex in the expected directions; that is, male scores higher for 3DMR and female scores higher for OLM. The .05 confidence level, two-tailed, was used for all analyses, and the standard for support of the universality hypothesis was total consistency across countries. Additionally, effect sizes of sex differences were assessed by Cohen's *d*, between individuals, countries, and ethnic categories. The standard formula of mean difference divided by the pooled *SD* was used to calculate effect sizes. Inasmuch as performance scores were irrelevant to the hypotheses and purposes of this study, they were not included in the data summary.

Several additional analyses were performed to explore potential contributions of socialization practices to the sex differences. For one, the correlation (Pearson *r*) between OLM and 3DMR effect sizes across countries was assessed, based on the assumption that these scores would be directly related if sex related spatial competencies were influenced by cross-national differences in socialization for traditional sex roles. A similar analysis was not undertaken for ethnic groups because of the small sample size. In further analyses, correlations were assessed between the Gross National Income of the country for 2004, as reported by the World Bank[1] (2005), and effect sizes for both 3DMR and OLM. This was based on Levine, Vasilyeva, Lourenco, Newcombe, and Huttenlocher's (2005) finding of a lesser male bias on two spatial tasks, including 3DMR, among lower socioeconomic status (SES) individuals. Levine et al. attributed their finding to greater opportunities at the higher SES levels to engage in spatially related play activities (e.g., puzzles, video games), which are more commonly utilized by boys.

Finally, Kolmogorov-Smirnov tests were used to ascertain possible deviations from normal distributions for both 3DMR and OLM, and, due to the truncated nature of the 3DMR scale, an inter-item reliability estimate was calculated.

Results

Table 1 shows main effects of sex and effect sizes by countries and ethnic groups for both 3DMR and OLM. For 3DMR, significant main effects favoring males were found for each of the seven ethnic groups and 40 countries. For OLM, significant main effects favoring females were found for each of the seven ethnic groups and 35 of the 40 countries. Sex differences for the other five countries were in the predicted direction, with one (China) approaching significance at $p = .07$.

For the analyses across individuals, significant sex differences favoring males were found for 3DMR and significant sex differences favoring females were found for OLM, $F(1, 245960) = 13908.19, p < .001$ and $F(1, 247901) = 5786.79, p < .001$, respectively. Effect sizes were .48 and .31, respectively; the first of which is considered in the moderate range and the second in the low range by Cohen's (1988) classification.

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[1] No data were given for United Arab Emirates.

Table 1 Main effects of sex and effect sizes (ES) for male bias on 3DMR and female bias on OLM by country and ethnic group

	3DMR				OLM			
	Males (N)	Females (N)	Main effect for sex	ES	Males (N)	Females (N)	Main effect for sex	ES
Country								
Argentina	163	101	$F(1, 262) = 13.99^*$	.49	164	103	$F(1, 265) = 10.81^*$	.41
Australia	4685	4403	$F(1, 9086) = 464.80^*$	.45	4717	4435	$F(1, 9150) = 189.36^*$	.29
Austria	203	169	$F(1, 370) = 14.94^*$	.40	203	173	$F(1, 374) = 2.06$	.14
Belgium	865	609	$F(1, 1472) = 69.58^*$	.44	871	615	$F(1, 1484) = 74.54^*$	.46
Brazil	195	136	$F(1, 329) = 21.80^*$	.52	197	138	$F(1, 333) = 3.76^*$	.21
Bulgaria	176	184	$F(1, 358) = 39.51^*$	.66	177	187	$F(1, 362) = 10.77^*$	.34
Canada	6715	6455	$F(1, 13168) = 696.17^*$	.46	6750	6502	$F(1, 13250) = 396.54^*$	.34
China	213	187	$F(1, 398) = 53.54^*$	.73	215	188	$F(1, 401) = 3.31$	.18
Czech Republic	166	113	$F(1, 277) = 19.96^*$	.54	167	113	$F(1, 278) = 9.58^*$	.38
Denmark	447	420	$F(1, 865) = 49.95^*$	.48	447	421	$F(1, 866) = 9.69^*$	.21
Finland	1009	813	$F(1, 1820) = 61.84^*$	.37	1016	814	$F(1, 1828) = 85.60^*$	.44
France	618	442	$F(1, 1058) = 96.87^*$	.62	623	446	$F(1, 1067) = 10.66^*$	.20
Germany	986	648	$F(1, 1626) = 60.12^*$	.39	985	650	$F(1, 1633) = 58.35^*$	.39
Greece	456	425	$F(1, 879) = 47.98^*$	.47	456	432	$F(1, 886) = 36.05^*$	.40
Hungary	107	114	$F(1, 219) = 13.29^*$	.49	108	115	$F(1, 221) = 5.08^*$	.30
Iceland	104	109	$F(1, 211) = 13.05^*$	.50	105	110	$F(1, 213) = 5.66^*$	.32
India	2642	686	$F(1, 3326) = 43.64^*$	.29	2670	699	$F(1, 3367) = 26.24^*$	.22
Israel	244	161	$F(1, 403) = 18.09^*$	.44	244	163	$F(1, 405) = .77$	.09
Italy	274	196	$F(1, 468) = 47.98^*$	.65	279	199	$F(1, 476) = 12.16^*$	.32
Japan	312	188	$F(1, 498) = 22.10^*$	.44	314	189	$F(1, 501) = 9.53^*$	.28
Malaysia	328	299	$F(1, 625) = 46.41^*$	.54	330	300	$F(1, 628) = 8.04^*$	.23
Mexico	239	154	$F(1, 391) = 16.22^*$	.42	241	154	$F(1, 393) = 7.94^*$	.29
Netherlands	1365	1018	$F(1, 2381) = 138.86^*$	.49	1378	1030	$F(1, 2406) = 81.85^*$	.37
New Zealand	1080	1063	$F(1, 2141) = 116.38^*$	.47	1089	1070	$F(1, 2157) = 99.28^*$	.43
Norway	390	283	$F(1, 671) = 41.17^*$	.50	392	287	$F(1, 677) = 21.72^*$	.36
Philippines	192	231	$F(1, 421) = 11.38^*$	.33	194	233	$F(1, 425) = 5.84^*$	.24
Poland	235	251	$F(1, 484) = 25.32^*$	.46	236	254	$F(1, 488) = 16.58^*$	.37
Portugal	222	167	$F(1, 387) = 24.62^*$	.51	223	167	$F(1, 388) = 5.12^*$	.23
Republic Ireland	2849	2640	$F(1, 5487) = 314.12^*$	.48	2868	2668	$F(1, 5534) = 90.42^*$	.26
Romania	191	193	$F(1, 382) = 21.97^*$	.48	192	195	$F(1, 385) = 1.04$	.10
Singapore	1105	1214	$F(1, 2317) = 151.74^*$	.51	1110	1233	$F(1, 2341) = 52.86^*$	.30
Slovenia	148	112	$F(1, 258) = 19.55^*$	.55	148	113	$F(1, 259) = 2.44$	.20
South Africa	252	151	$F(1, 401) = 17.85^*$	.44	256	156	$F(1, 410) = 5.20^*$	.23
Spain	538	330	$F(1, 866) = 65.66^*$	.57	543	337	$F(1, 878) = 17.84^*$	.30
Sweden	934	447	$F(1, 1379) = 103.12^*$	.57	939	451	$F(1, 1388) = 33.17^*$	.33
Switzerland	362	225	$F(1, 585) = 24.04^*$	.42	366	228	$F(1, 592) = 15.97^*$	.34
Turkey	704	647	$F(1, 1349) = 55.08^*$	.41	709	659	$F(1, 1366) = 41.33^*$	.35
United States	50773	44969	$F(1, 95740) = 5545.24^*$	.48	51084	45265	$F(1, 96347) = 2761.21^*$	.34
United Arab Emirates	193	129	$F(1, 320) = 5.46^*$	.42	194	133	$F(1, 325) = 7.86^*$	.31
United Kingdom	46384	45451	$F(1, 91833) = 5.89^*$	.52	46763	45928	$F(1, 92689) = 1790.45^*$	.28
Ethnic group								
Black British	795	1010	$F(1, 1803) = 66.71^*$	.38	800	1027	$F(1, 1825) = 28.74^*$	.25
Black other	738	895	$F(1, 1631) = 34.27^*$	.29	749	901	$F(1, 1648) = 8.39^*$	.14
Mideastern	1506	932	$F(1, 2436) = 83.94^*$	.39	1513	946	$F(1, 2457) = 27.57^*$	.22
Mixed	4279	5017	$F(1, 9294) = 451.64^*$	.44	4312	5050	$F(1, 9360) = 211.01^*$	.30
White	109769	99498	$F(1, 209265) = 13477.07^*$	.51	110518	100351	$F(1, 210867) = 5281.32^*$	.32
Chinese	2558	2732	$F(1, 5288) = 349.37^*$	.51	2574	2757	$F(1, 5329) = 121.00^*$	.30
Asian other (including East Indian)	9207	5851	$F(1, 15056) = 210.45^*$	.24	9299	5922	$F(1, 15219) = 207.05^*$	.24

$^*p < .05$.

The reliability estimate for 3DMR, assessed by intra-class correlation, was .70, $p < .00001$. Kolmogorov–Smirnov tests showed that neither 3DMR or OLM distributions between countries deviated from normality, $Zs = .71$ and .48, $ps > .05$, respectively. The correlation coefficient for effect sizes by country between 3DMR and OLM tests did not reach or approach significance, $r(38) = .097$, $p > .05$, nor did the correlations between effect sizes and GNI rank for either spatial test, $rs(37) = .08$ for 3DMR and .04 for OLM, $ps > .05$.

Discussion

This study unequivocally supported the universality of the male advantage in 3DMR across human societies. Though the same cannot be said for OLM, the data provided a strong suggestion of a universal difference. The reason for the discrepancy between tests may reside in the smaller effect sizes for OLM, which may reflect the greater ecological validity of the 3DMR. The latter directly measures the specific spatial abilities assumed to be involved in navigation by orientation (Silverman et al., 2000) while the OLM is a more contrived measure of the perceptual and memory processes underlying navigation by landmarks.

The test of correlation between effect sizes for male and female biased tests provided no support for the notion that society-based, sex-role stereotyping practices are relevant to sex-related spatial differences. Nor did the correlations for both tests between GNI and effect sizes replicate prior findings of a SES factor. None of this, however, implies the absence of an environmental role in the ontogeny of spatial sex differences. It is well recognized in contemporary evolutionary psychology that innate dispositions always manifest themselves in environmental contexts. The present data, however, might encourage researchers in sex differences that are universally found to abandon the issue of heredity vs. environment and focus instead on "what is inherited" and how it becomes expressed.

In this regard, Gaulin and Hoffman (1988) pointed out that meadow voles and humans, both of which show a male bias in orientation-type spatial tasks, also feature larger home ranges for males (the area within which the individual becomes familiar and regularly visits). In the human case, sex differences in home range size begin in toddlerhood, when the child is first mobile, and are found in diverse cultures (Gaulin & Hoffman, 1988). Thus, males may be innately programmed to explore larger areas than females from an early point in ontogeny, which may represent a critical period in which sex differences in spatial strategies develop in response to the differential requirements for navigating larger vs. smaller spaces. Studies in both children (Munroe & Munroe, 1971; Nerlove, Munroe, & Munroe, 1971) and adults (Ecuyer-Dab & Robert, 2004b) have found positive correlations between home range size and various male biased spatial abilities for males only. This may represent partial support of the theory above, although the question of why the correlations do not occur also for females remains to be resolved.

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