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Analyse évolutionniste des différences intersexes
dans les habiletés spatiales

par

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Résumé

L'existence de différences intersexes dans les habiletés spatiales au sein de plusieurs espèces laisse supposer leur caractère adaptatif et, de là, invite à les analyser dans le cadre de la théorie de l'évolution. Un premier modèle, validé chez plusieurs espèces de rongeurs, se fonde sur l'hypothèse que pour beaucoup de mammifères la supériorité des mâles adultes sur le plan spatial ait principalement évolué pour leur permettre de s'orienter et de naviguer à travers de plus vastes territoires--ou domaines vitaux--que dans le cas des femelles. Formulé plus récemment à l'intention de l'humain, un second modèle propose que certaines des aptitudes spatiales actuelles aient été héritées de celles de nos ancêtres masculins et féminins aux époques où la subsistance reposait sur la chasse et la cueillette. Cette approche a plus particulièrement révélé que les femmes excellent principalement dans une forme de mémoire spatiale qui serait compatible avec la capacité à localiser, au fil des saisons, les plantes comestibles à l'intérieur d'une aire géographique familière.

Dans le premier de deux manuscrits, nous examinons les assises théoriques et empiriques de ces deux champs conceptuels ainsi qu'un ensemble de données provenant de divers animaux. L'interprétation résultant de cette analyse est que, pour plusieurs mammifères incluant spécifiquement des primates, l'évolution aurait adopté un mode particulier de sélection des habiletés spatiales selon le sexe. Chez les mâles, la sélection sexuelle d'une propension à maximiser les opportunités de reproduction les aurait entraînés vers une compétition qui, susceptible de s'exprimer tant dans des déplacements effectués sur une large échelle que dans des comportements agonistiques, nécessiterait un éventail plus diversifié d'habiletés spatiales. Quant aux femelles, la sélection naturelle d'une préoccupation centrée sur leur survie et celle de leur progéniture les

aurait contraintes à limiter les risques physiques en réduisant leur mobilité et en privilégiant les indices spatiaux situés à proximité dans l'environnement. L'évolution d'une division sexuelle dans une espèce donnée semblerait consécutive à l'action de cette double sélection et, en retour, elle pourrait avoir accru les habiletés spatiales sous-tendant la maîtrise de la chasse et de la cueillette. Cette perspective permet, pour diverses espèces, la formulation de plusieurs prédictions quant aux différences intersexes dans les habiletés spatiales.

Le second manuscrit présente l'étude qui visait à vérifier certaines de ces prédictions auprès d'hommes (N = 95) et de femmes (N = 121), âgés de 25 à 45 ans, résidant et travaillant dans une importante agglomération nord-américaine. Nous avons d'abord constaté qu'à l'instar de ce qui est observé dans des sociétés plus traditionnelles ainsi que chez de nombreux mammifères, les domaines vitaux des individus de sexe masculin étaient globalement plus étendus. Il s'agissait ensuite d'examiner si, conformément à l'hypothèse de plus grandes exigences de navigation masculine ancestrale, les habiletés spatiales pouvaient, aujourd'hui encore, se trouver plus diversifiées chez les hommes que chez les femmes. En comparaison des femmes, la performance actuelle des hommes devait alors être corrélée, dans un plus grand nombre de tâches spatiales, à la taille des domaines vitaux. Les résultats confirment que l'amplitude des déplacements masculins est plus souvent reliée au degré de réussite spatiale. Chez les hommes, la taille des domaines vitaux est positivement associée au rendement dans les tâches de rotation mentale, de figures intriquées, de développement de surfaces et de mémorisation de l'emplacement d'objets; chez les femmes, le même lien ne concerne que l'épreuve des figures intriquées. Dans leur ensemble, ces données sont donc compatibles avec une sélection des habiletés spatiales en relation avec les patrons ancestraux de navigation respectifs aux hommes et aux femmes. Elles n'écartent pas néanmoins la possibilité qu'une autre source de pression, qui découlerait d'une

compétition masculine mettant en jeu le lancer et l'interception de projectiles, puisse, en complément de la pression de navigation, ou à la place de celle-ci, rendre adéquatement compte de l'avantage masculin à appréhender plusieurs principes gravitationnels et cinétiques sous-tendant la résolution de tâches spatiales particulières. Généralement cependant, les résultats obtenus témoignent de l'intérêt à associer l'examen du fonctionnement cognitif à l'identification des pressions sélectives qui ont pu marquer l'évolution d'une espèce particulière et de ses catégories sexuelles.

Mots clés : division sexuelle du travail; épreuve d'horizontalité des liquides; évolution; humains; mammifères polygynes; mémoire de localisation; rotation mentale; sélection sexuelle; tâche de développement de surface; tâche des figures intriquées.

Abstract

Two independent approaches focus on the evolutionary bases of respective male or female strengths in the processing of spatial information. Applicable to many nonhuman mammals and humans, the sexual selection model (Gaulin & FitzGerald, 1986, 1989) construes the male advantage in a number of spatial tasks as an adaptive response to male competition for accessing several mates through extended navigation. According to the foraging model (Silverman & Eals, 1992), the female advantage established in humans as to location memory may be explained by the selective gathering role assigned, during hominid evolution, to women under a sexual division of labor.

In the first manuscript presented in this research we examine the theoretical and empirical foundations underlying each of these two perspectives, as well as a corpus of animal data. This suggests that a twofold selection process might account for male and female spatial assets in humans and several mammals, including primates especially, with polygynous features. In males, the sexual selection of a propensity to maximize mating opportunities is likely to have driven them towards a male competition that, in terms of more extended navigation and agonistic displays, would require a diversified scope of spatial abilities. In females, the natural selection of a survival concern would have compelled them to value low risk strategies in restricting navigation and focusing on proximal environmental cues. It follows that, in some species, a form of sexual division in foraging could have partly evolved from such a twofold process and, in turn, could have sharpened preexisting male and female spatial strengths. This standpoint leads to new predictions as to sex differences in spatial abilities among several mammalian species including humans.

The main purpose of the study described in the second manuscript was to verify, among Western humans, some of these predictions. We first showed that, in 25- to 45-year-old participants (N = 216) living and working in a large urban area, navigation extent replicated the pattern of male individuals having larger home ranges in comparison to females, as observed in traditional human societies and in many polygynous mammals. We also examined whether, in harmony with the hypothesis of extended male navigation in ancestral humans, more diversified spatial abilities in present-day men, compared to women, could still be reflected in achievement by a larger number of spatial tasks being correlated with amount of ranging among men. The results are congruent with this perspective. In men, ranging extent was positively correlated with mental rotation, embedded figures, and surface development scores, as well as with location memory performance; in women, it was exclusively associated with proficiency in the embedded figures task. Generally, these findings support the existence of an adaptive linkage between sex-related spatial skills and ranging extent in humans. However, they do not rule out the possibility that another important Darwinian pressure present in male settings that have involved throwing and intercepting projectiles could, in complement to the sex-related navigation pressure or instead of such a pressure, adequately account for male individuals' better understanding of gravity and kinetic principles that underlie the solving of certain spatial tasks. Overall nonetheless, these results bear witness to the interest of jointly inquiring into cognitive functioning and attempting to identify the selective pressures having marked the evolution of a given species and that of its male and female individuals.

Keywords: embedded figure task; evolution; humans; location memory; mental rotation; polygynous mammals; sexual division of labor; sexual selection; surface development; water-level task.

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A la mémoire de mon père,
de ma grand-mère et de mon grand-père,
tous trois disparus durant mes études de doctorat,
et à mon fils, Benjamin,
né au cours de cette période

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Introduction générale

L'existence d'une supériorité masculine dans plusieurs épreuves spatiales[1] est observée parmi diverses espèces animales (p. ex., Joseph, Hess et Birecree, 1978; Williams, Barrett et Meck, 1990) et constitue, chez l'humain, un phénomène solidement documenté dans les sociétés industrielles modernes (Linn et Petersen, 1985; Voyer, Voyer et Bryden, 1995) et modérément étudié au sein de groupes traditionnels (p. ex., Berry, 1976; Mann, Sasanuma, Sakuma et Masaki, 1990). Analyser ces différences intersexes dans le cadre de la théorie de l'évolution permet de s'interroger quant à leurs origines en faisant porter le niveau d'investigation non pas sur l'influence des facteurs ontogénétiques, comme l'apprentissage (dont l'importance n'est pas ici mise en doute), mais sur la valeur potentiellement adaptative de telles différences au cours de la phylogenèse d'une espèce. Cette perspective renvoie d'emblée à la possibilité que, pour une espèce donnée et durant une période donnée de son évolution, des habiletés spatiales particulières aient été respectivement sélectionnées parmi les individus de chaque sexe en fonction des avantages qu'elles leur ont conférés sur le plan de la reproduction ou de la survie. L'entreprise est donc double : d'un côté, elle invite à réactualiser conceptuellement les problèmes susceptibles, dans l'environnement ancestral d'une espèce, d'avoir sollicité différemment la cognition spatiale selon le sexe des individus et, de l'autre, elle consiste à éprouver empiriquement la validité de ces scénarios évolutionnistes.

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[1] Tout au long de cette thèse, les épreuves spatiales auxquelles nous nous référons requièrent principalement que l'information spatiale soit captée de manière visuelle

L'hypothèse d'une sélection sexuelle des habiletés spatiales masculines

Avec l'émergence de la théorie moderne de l'évolution dans le courant des années 1970 ont été formulées les premières interrogations au sujet du bénéfice darwinien afférent aux différences intersexes dans le domaine spatial. Dès 1971, Gray et Buffery supposèrent que, chez plusieurs espèces de rongeurs, la meilleure performance des mâles dans diverses épreuves spatiales était liée au fait qu'ils exploitent en milieu naturel des domaines vitaux généralement plus vastes que ceux des femelles et, ainsi, font davantage appel à leurs habiletés spatiales. De son côté, Dawson (1972) adoptait sensiblement le même raisonnement tout en tentant de le généraliser à des primates, dont l'humain. L'hypothèse de la sélection sexuelle de meilleures habiletés spatiales chez les mâles, surtout observables au sein des espèces où les individus de sexe masculin se déplacent sur de plus grandes distances que ceux de sexe féminin, ne devait cependant être vérifiée qu'en 1986, par Gaulin et FitzGerald, auprès de certains rongeurs. Cette validation donna le coup d'envoi à une série de recherches qui ne se sont cependant pas étendues à l'humain. Certaines visaient à étendre la confirmation de l'existence d'un double avantage masculin, sur le plan du traitement de l'information spatiale et sur celui de la mobilité, à plusieurs espèces de rongeurs (p. ex., Galea, Kavaliers, Ossenkopp, Innes et Hargreaves, 1994; Gaulin et FitzGerald, 1989). D'autres ont permis de repérer des corrélats anatomiques de ces différences intersexes au niveau de substrats neurologiques sous-tendant la cognition spatiale (p. ex., Jacobs, Gaulin, Sherry et Hoffman, 1990).

L'hypothèse d'une sélection naturelle des habiletés spatiales féminines

Prenant appui sur la conclusion de Tooby et DeVore (1987) selon laquelle le passé évolutif humain aurait été fortement teinté d'une division sexuelle du travail, Silverman et Eals ont avancé, en 1992, une seconde hypothèse quant à la phylogenèse d'une différence intersexes relative à une forme de mémoire spatiale. D'après ces auteurs, la capacité à se remémorer l'emplacement occupé par divers objets pouvait avoir été particulièrement sélectionnée chez les femmes afin de répondre aux exigences cognitives imposées par les activités de cueillette majoritairement assumées par les femmes dans l'environnement des premiers humains. Menés en milieu naturel et en laboratoire, les travaux de Silverman et Eals (1992; Eals et Silverman, 1994) ont montré que, par rapport aux hommes, les femmes affichent effectivement une meilleure mémoire de la localisation de différents objets. Reprenant certaines des situations en cause, plusieurs chercheurs ont constaté la même supériorité (p. ex., Barnfield, 1999; James et Kimura, 1997; Montello, Lovelace, Golledge et Self, 1999). Néanmoins, sa robustesse peut sembler discutable en comparaison de la supériorité masculine établie dans diverses épreuves spatiales courantes (Linn et Petersen, 1985; Voyer, Voyer et Bryden, 1995), puisque la meilleure performance des femmes n'a pas été systématiquement observée dans des tâches de mémoire spatiale s'écartant, à des degrés variables, de celles employées par Silverman et Eals (p. ex., Barnfield, 1999; Janowski, Chavez, Zamboni et Orwoll, 1998; McBurney, Gaulin, Devineni et Adams, 1997).

Objectif de la thèse

Malgré la divergence--du moins apparente--de leur schémas explicatifs, les deux précédentes hypothèses évolutionnistes ont la caractéristique d'appréhender respectivement des avantages spatiaux propres aux individus de chaque sexe. En outre, tant les travaux s'inscrivant dans la perspective d'une sélection sexuelle (Gaulin et FitzGerald, 1986, 1988, 1989) que ceux menés sous l'angle d'une division sexuelle du travail humain (Eals et Silverman, 1994; Silverman et Eals, 1992) paraissent avoir produit des avancées globalement significatives quant à la compréhension des modalités de sélection, pour plusieurs espèces, des habiletés spatiales où excellent respectivement les individus de sexe masculin et féminin. Il importe donc d'examiner de façon critique les arguments aussi bien théoriques qu'empiriques sur lesquels reposent ces deux approches, ainsi que de tenter d'identifier les éléments qui, possiblement compatibles avec l'une et l'autre, permettraient d'articuler une explication de l'existence, sur le plan spatial, de telles différences intersexes dans diverses espèces incluant la nôtre.

Structure de la thèse

La thèse comprend deux manuscrits (rédigés en langue anglaise) destinés à être soumis pour publication auprès de périodiques spécialisés. Dans le premier, nous débutons par une définition des habiletés spatiales, puis procédons à une présentation détaillée du modèle de la sélection sexuelle de Gaulin et FitzGerald (1986, 1988, 1989) et de celui de la division sexuelle du travail de Silverman et Eals (1992; Eals et Silverman, 1994). Cet examen préliminaire permet, d'une part, d'analyser les principes généraux sur lesquels se fondent chacune de ces approches et, d'autre part, de discuter des résultats qu'elles ont respectivement mis en évidence. Tant chez l'humain que chez l'animal, plusieurs autres données, portant sur le comportement dans l'espace tridimensionnel ou sur la cognition spatiale en fonction du sexe, sont également prises en compte dans la mesure où elles paraissent soit s'harmoniser soit entrer en opposition avec l'une ou l'autre de ces perspectives. Cette double investigation conduit à la formulation d'une série d'hypothèses intégrant, quant à l'évolution de différences intersexes dans une variété d'habiletés spatiales, les mécanismes d'action de la sélection sexuelle et de la sélection naturelle chez les individus de sexe respectivement masculin et féminin, au sein de l'espèce humaine et de plusieurs autres mammifères.

Le second manuscrit présente l'étude ayant pour but d'évaluer la validité de certaines de ces hypothèses auprès d'un échantillon humain. Dans leur ensemble, les résultats obtenus confortent ces hypothèses; ils sont en effet compatibles avec la perspective selon laquelle la présence de plusieurs différences intersexes dans les habiletés spatiales serait consécutive à l'action de mécanismes évolutifs ayant agi de façon différentielle selon le sexe des individus dans l'environnement ancestral de notre espèce. La robustesse de ces résultats est discutée en regard de plusieurs variables de type culturel et des caractéristiques démographiques et professionnelles propres aux participants.

La thèse[2] se termine par une discussion générale portant sur les principaux éléments identifiés dans les premier et second manuscrits. De ces considérations découlent plusieurs suggestions visant, dans une optique évolutionniste, à améliorer la formulation de modèles explicatifs des différences intersexes quant aux habiletés spatiales et à étendre l'investigation des pressions de sélection de ces habiletés chez divers mammifères dont l'humain.

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[2] Annexés à cette thèse, se trouvent trois appendices : l'**appendice A** contient le questionnaire utilisé auprès des personnes ayant participé à l'étude afin de recueillir les renseignements généraux ainsi que ceux qui sont liés aux indicateurs de mobilité et aux déplacements habituels; l'**appendice B** inclut le questionnaire ayant servi, durant la semaine de l'étude, à collecter chez les participants et participantes toutes les informations relatives à leurs déplacements actuels; l'**appendice C** comprend les formules d'accord de la coauteure de chacun des deux manuscrits.

Manuscrit 1 :

Have Sex Differences in Spatial Ability Evolved From a Male Competition for Mating and a Female Concern for Survival ?

Destiné à être soumis à Cognition

Have Sex Differences in Spatial Ability Evolved From a Male Competition for Mating and a Female Concern for Survival ?

Isabelle Ecuyer-Dab and Michèle Robert
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Running head: HAVE SEX DIFFERENCES IN SPATIAL ABILITY EVOLVED

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Abstract

After examining the theoretical and empirical foundations of two evolutionary models, we argue that, among humans and other mammals with polygynous features, a twofold selection would parsimoniously account for sex-linked advantages in spatial contexts. In males, a superiority as to both solving navigation-related spatial problems and understanding physical principles that apply to the behavior of projectiles could have been inherited from a mating-oriented male competition through extensive ranging and agonistic displays. In females, a superiority in a form of spatial memory may have been shaped in relation to a costly reproduction system compelling them to value survival and, hence, low risk strategies consisting in restricted navigation and concentration on nearby spatial cues. Based on the combined action of competition and survival pressures, we submit new predictions as to spatial sex differences in several species including humans.

Have Sex Differences in Spatial Ability Evolved From a Male Competition for Mating and a Female Concern for Survival ?

Two apparently competing evolutionary explanations for the existence of sex differences in spatial abilities have received special attention over the last decade. The first one offers a rationale that applies to any species wherein sexes differ in ranging extent: Due to the action of sexual selection in polygynous or promiscuous species, members of one sex—generally the males—usually compete with each other for meeting mates through extensive ranging. Gaulin and FitzGerald (1986, 1989) have reasoned that, in such species, evolution would have selected for a male advantage in a set of spatial skills that would assist navigation. Exclusively directed at humans, the other perspective is based on the position that, with first men and women primarily engaged, during the Plio-Pleistocene, in game hunting and plant gathering respectively, such a sexual division in foraging would have exerted a sex-linked selective pressure on spatial cognition. Silverman and Eals (1992; Eals & Silverman, 1994) have surmised that a women's superiority in a form of spatial memory would have principally evolved to sustain gathering duties. The evidence available in reference to each of the sexual selection and the foraging model is generally conclusive: It demonstrates that the study of spatial sex differences within a given species benefits from the examination of the distinct spatial problems which male and female individuals probably had to solve during evolution. Therefore, it supports the view that spatial ability, which encompasses diversified skills (Caplan, MacPherson, & Tobin, 1985; Linn & Petersen, 1985), fulfils a collection of adaptive functions (Buss, 1999; but see for instance Wynn, Tierson, & Palmer, 1996[1]).

In this article, when referring to spatial abilities, we expand on converging definitions that mainly focus on the processing of spatial information from visual input (e.g., Caroll, 1993; Linn & Petersen, 1985; Lohman, 1994), but we also include that of spatial data that are not visually perceived. Hence, we consider that spatial abilities

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[1] According to these authors, sex differences in spatial achievement would chiefly be evolutionary by-products (i.e., incidental events that have not been selectively designed on the basis of their adaptive value).

designate as diverse mental processing aspects as the apprehending, encoding, storing, picturing, retrieving, manipulating, transforming, and integrating of spatial information as to one or several elements that are part of a two- or three-dimensional space. This information concerns the configuration, orientation, location, or motion of the elements that occur in actual or virtual environments, which are either small- or large-scale, as well as in their mental representations, which may be either realistic or symbolic.

On the one hand, the spatial skills that, for instance, would underlie navigation comprise the capacity to build a cognitive map of an area, and, within this map, to represent the location of a given destination so as to reach it. In keeping with the sexual selection model, male individuals have generally been observed to surpass females in wayfinding tasks. This has been established in several animal species (especially rodents) tested in maze learning tasks (e.g., Barrett, R. J., & Ray, 1970; Beatty, 1992; Dawson, 1972; Galea, Kavaliers, Ossenkopp, Innes, & Hargreaves, 1994; Gaulin & FitzGerald, 1986, 1989; Joseph, Hess, & Birecree, 1978; Roof, 1993; Seymoure, Dou, & Juraska, 1996). The same trend is patent in humans (e.g., Astur, Ortiz, & Sutherland, 1998; Devlin & Berstein, 1995; Moffat, Hampson, & Hatzipantelis, 1998; Schmitz, 1997). On the other hand, a female superiority in remembering the relative positions of common objects has been brought to the fore in humans (e.g., Barnfield, 1999; Eals & Silverman, 1994; Gaulin, Silverman, Phillips, & Reiber, 1997; Hill, R. D., et al., 1995; James & Kimura, 1997; Montello, Lovelace, Golledge, & Self, 1999; Silverman & Eals, 1992), in accordance with the cognitive constraints faced by ancestral women in their predominant gathering activities.

However, it is firstly noticeable that an analogous female asset in spatial memory is likely to support females feeding primarily from stationary food sources in certain nonhuman species, such as chimpanzees (Geary, 1998). Also, among humans (Galea & Kimura, 1993) and nonhumans (e.g., rodents; e.g., Roof & Stein, 1999; Williams, C. L., Barnett, & Meck, 1990; Williams, C. L., & Meck, 1991) females appear to favor a spatial encoding that is oriented towards objects in that they mostly opt for landmarks as spatial referents in navigation-related tasks. Yet, all of these three species do not systematically exhibit sex-related foraging activities. Therefore, a selective pressure somewhat distinct from that of sexual division in foraging has probably acted on female spatial cognition in several species.

Secondly, it is unclear whether male humans outscoring females in spatial tabletop tasks, both in Western populations (e.g., Linn & Petersen, 1985; Voyer, Voyer, and Bryden, 1995) and in several nonWestern ones (e.g., Berry, 1971, 1976; Berry & Annis, 1974; Huang, 1993; Mann, Sasanuma, Sakuma, & Masaki, 1990; Mayes, Jahoda, & Neilson, 1988; Van Leewe, 1978), might have followed from the action of a sex-related navigation pressure over human evolution. According to the meta-analyses performed by Linn and Petersen (1985) and by Voyer et al. (1995) on Western data, starting in adolescence a strong male advantage characterizes those tasks asking to mentally rotate two- or three-dimensional stimuli (i.e., mental rotation tasks), whereas the male asset is moderate in tasks requiring to indicate the orientation of a liquid surface in a tilted container, or to position a rod vertically within a slanted frame (i.e., spatial perception tasks). Contrasting with Linn and Petersen's (1985) report of no significant sex effect in tasks calling for several (successive or parallel) mental operations, such as manipulating two- and three-dimensional data, or identifying a simple shape within a more complex one (i.e., spatial visualization tasks), Voyer et al. (1995) have uncovered a small male superiority in adults. Among all these tabletop tasks, the large variety of those yielding a male advantage, along with the variable magnitude of this advantage, invites considering the possibility that pressures additional to the one pertaining to navigation would have acted on spatial cognition.

Finally, a male advantage is also found among humans in certain classes of spatial processing that, more clearly than those involved in the just mentioned task categories, appear to serve no navigational purposes. Instead, such skills seem to be connected with understanding the behavior of moving objects, as when evaluating their relative speed (e.g., Poduska & Phillips, 1986) and estimating their trajectories (e.g., Kaiser, Proffitt, Whelan, & Hecht, 1992). Moreover, these abilities are unlikely to be exclusive to humans given the observation of nonhuman male primates being adept, more frequently than females, at throwing objects they use as projectiles in agonistic displays (e.g., Essock-Vitale & Seyfarth, 1987 ; Goodall, 1986). Hence, invoking the sex-linked action of a navigation-related pressure may only partially account for the evolutionary component of the male side of spatial cognition.

In sum, we think it is beneficial to seek sex-related evolutionary pressures that encompass the functional origins of both the female and male sides of spatial ability within several species, including humans. Examining the respective theoretical foundations of the sexual selection and foraging models, along with the advances they allow at the conceptual and empirical levels, should provide profitable bases for such an inquiry. Thus, in Section 1 we analyze Gaulin and FitzGerald's (1986, 1989) view that, in polygynous species, male spatial skills would mainly result from sexual selection in relation to navigation. In Section 2, we investigate the position by Silverman and Eals (1992; Eals & Silverman, 1994) according to which a female advantage in object location memory would have evolved from foraging patterns among ancestral humans. Animal and human studies pertinent to each of these two approaches are brought to bear.

This preliminary step strengthens the likelihood that, in certain mammalian species with polygynous features, sex-related problem-solving capacities have been selected by the joint action of two evolutionary mechanisms: In males, spatial cognition would have been shaped mainly by the sexual selection of a propensity to compete for mating via navigation, but also or alternatively, in a number of primate species especially, via agonistic behaviors involving the use of projectiles. In females, it would have evolved chiefly from the natural selection of a strong concern for survival (their own and that of offspring) and, therefore, of low risk strategies for coping with space-related problems. Hence, Section 3 identifies ultimate and proximate mechanisms that have probably been involved in this twofold process, whereas Section 4 focuses on spatial problem-solving systems that might be functionally related to competition and survival issues. Section 5 presents the conceptual and empirical implications of our endeavour, particularly concerning the study of spatial sex differences in reference to the foraging approach. In Section 6, we conclude by proposing a set of predictions to test in humans and nonhuman species.

I The Sexual Selection Scenario

From the sexual selection theory originally proposed by Darwin in 1871, Gaulin and FitzGerald (1986, 1989) have developed a framework affording useful insights into the understanding of adaptive functions of several sex differences in spatial processing. Successfully tested among rodents, this framework is characterized in the present section in order to evaluate its suitability for other species including humans.

The Sexual Selection Process

To begin with, we summarize the principles according to which the disruptive evolutionary process of sexual selection operates. Such process favors the emergence of different phenotypes in males and females of a given species (Trivers, 1972) when the maximum (potential) reproductive rate is not the same across the sexes (Clutton-Brock & Vincent, 1991). Where one sex makes a greater parental investment than the other (Trivers, 1972; Williams, G. C., 1966) and/or finally requires more time to complete a reproductive cycle, its reproductive rate is lower (Clutton-Brock & Vincent, 1991). Thus, finding available reproductive partners should be harder among individuals whose sex has the higher variance in reproductive success, leading to their intensely competing for mates. As a result, the phenotypic characteristics that are the most useful in this competition should be selected. Among mammals, this sex is generally represented by male individuals: Because males complete a reproductive cycle in less time than females, they tend to maximize their reproductive efforts by increasing their copulatory frequency (polygynous mating system). Conversely, female mammals are biologically constrained to invest a large amount of time and energy into gamete production (i.e., ovules), gestation, and suckling. Hence, they may not benefit by increasing copulatory frequency whereas they do gain by being selective in their mate choice through identifying the males best able to guarantee viable offspring and/or to provide valuable rearing resources.

In short, in species where maximum potential reproductive rate differs from one sex to the other, sexual selection would have produced sex differences in behavior, perception, emotion, and cognition to the extent that these differences have been adaptive that is, have contributed to the enhancement of fitness, or reproductive success, in both sexes. Contrastingly, such sex differences would be absent in species where reproductive rate is comparable in males and females, for example due to the extensive care required from both parents for the survival of offspring. Given that, in such species, neither sex benefits differentially from an increase in reproductive efforts (monogamous mating system), sexual selection towards differing phenotypes for each sex would be weak or nonexistent (Kleiman, 1977).

Sexual Selection, Ranging Extent, and Navigational and Spatial Skills

Central to Gaulin and FitzGerald's (1986, 1989) sexual selection model is the concept of home range which may be defined as the area traveled over by an individual in pursuit of its routine activities, such as food procurement, mating, and caring for the young (Jewell, 1966). Sexual selection has generally compelled males from polygynous mammalian species to invest the greatest part of their reproductive efforts into searching for mates (and/or for resources attractive to them), therefore promoting their traveling across sizeable home ranges (Trivers, 1972). The ethological literature corroborates that, unlike what is found among monogamous mammals, in polygynous and/or promiscuous ones males generally cover a larger home range than females (Brown, L. E., 1966; Chivers, 1974; Greenwood, 1980; Kleiman, 1977; Trivers, 1972). This is typically observed for example in rodents like voles (Gaulin & FitzGerald, 1986, 1989; Ribble & Stanley, 1998) and kangaroo rats (Behrends, Daly, & Wilson, 1986; Randall, 1991), as well as in other mammals including raccoons (Gehrt & Fritzell, 1998) and various carnivores such as stoats (Alterio, 1998; Samson & Raymond, 1998), ferrets (Norbury, Norbury, & Heyward, 1998), caracals (Avenant & Nel, 1998), or leopards (Mizutani & Jewell, 1998).

The male propensity for extended ranging has also been noted among polygynous nonhuman primates, from prosimians (Bearder, 1987) to apes. For instance, at some time during adolescence, the male Japanese macaque ventures out alone on long-distance searches for mates which he may find more than 20 km from his home troop (Baker, R. R., 1981). In orangutans, the males occupy larger and less stable home ranges than those of females (Galdikas, 1988); in chimpanzees, a number of males may share a large home range that comprises the smaller ranges of females (Greenwood, 1980).

If unassisted by direction-giving devices, successful navigation through a given environment necessarily solicits the use of spatial abilities. For instance, the capacity to build large-scale representations of one's environment which take structural complexity into account, and the ability to orient oneself within this environment while paying attention to critical landmarks and their particular configurations are likely to have been evolutionarily selected and have probably contributed to solving some of the longstanding spatial processing problems commonly encountered when navigating. Gaulin and his collaborators (Gaulin & Hoffman, 1988) have thus emphasized the involvement of spatial abilities in navigational behaviors and, accordingly, proposed connecting the reproductive demands imposed by sex-specific traveling extent in order to account for sex differences in spatial skills. Within a given species, males and females generally share an identical ecological niche, and hence are similarly subject to the natural selection of spatial skills adapted to their moving around in an environment. However, pressure towards geospatial mobility in a majority of male mammals from polygynous species could have selected for greater skills with regard to navigation in large home ranges. Under polygynous conditions, each sex would undergo dissimilar selective demands in relation to navigation skills, and sex differences having a clear, adaptive function with respect to reproduction would emerge. Conversely, in species where males and females invest at par in their offspring, committing equal reproductive effort to mate-seeking activity and ranging, there would be no disruptive selection for spatial aptitudes underlying navigation according to sex (Gaulin & Hoffman, 1988; Sherry, Jacobs, & Gaulin, 1992).

Gaulin and FitzGerald (1986, 1989) have hypothesized that spatial skills might have been selected proportionately to the amount of spatial information an animal must process in its usual moving around, and that home range size is a useful indicator of this amount. They then undertook to demonstrate that, during the breeding season, males in polygynous species not only have larger home ranges than females but also outscore them in laboratory spatial tasks. By contrast, in monogamous species, no sex differences in home range size and spatial achievement were expected. Radiotelemetric measures of ranging extent and proficiency in sunburst and symmetrical mazes were recorded in males and females from three related species of rodents, the polygynous meadow voles (Microtus pennsylvanicus) and the monogamous pine (M. pinetorum) and prairie (M. ochrogaster) voles. As predicted, during the breeding season, the meadow vole males ranged more extensively and exhibited superior maze performance in comparison to females, while no significant sex differences were manifest in the two monogamous species irrespective of season.

Supporting Data

Comparing adult prairie voles either captured in their natural habitat or raised under severe spatial experience deprivation, Gaulin and Wartell (1990) have moreover observed that learning symmetrical mazes did not significantly differ as a function of sex and spatial experience. Also, in three rodent species (Rattus norvegicus, Spalax ehrenbergi, and Microtus guentheri) among which both sexes display comparably large home ranges, Kimchi and Terkel (2001) have not recorded significant sex differences in maze learning and retention. However, that Sawrey, Keith, and Backes (1994) did not replicate the male advantage in the polygynous meadow voles using the Morris water-maze task appears explicable. These authors did not specify whether testing was carried out during the breeding season, but their negative results indicate it might have not been the case as suggested by data published by Galea et al. (1994) in deer mice. Through photoperiod manipulation Galea et al. have experimentally induced breeding and nonbreeding states in these other polygynous rodents with sexually different home ranges, before submitting them to the Morris water-maze task. They established a male advantage in the breeding group solely, in conformity with Gaulin and FitzGerald's (1986, 1989) results.

Some direct evidence from both brain and neuron anatomy also dovetails nicely with the sexual selection model. Known to participate in the mediation of spatial performance in rodents (Juraska, Fitch, & Washburne, 1988; Sauvé, Poucet, Foreman, & Thinus-Blanc, 1998), the hippocampus has been found to be larger (after controlling for total brain weight) in males than in females among polygynous meadow voles, but not in monogamous pine voles (Jacobs, Gaulin, Sherry, & Hoffman, 1990). This has also been established in other polygynous rodents where males typically range farther, such as kangaroo rats (Dipomys spectabilis and D. merriami; Jacobs & Spencer, 1994) and Mongolian gerbils (Meriones unguiculatus; Sherry, Galef, & Clark, 1996). In promiscuous rodents as well, such as Sprague-Dawley rats, a greater hippocampal volume and a better navigational performance in water mazes have been measured in males compared to females (Isgor, 1997). Moreover, having replicated meadow vole males' superior maze proficiency, Kavaliers, Ossenkopp, Galea, and Kolb (1998) brought to light the fact that males possessed dendritic branches in both greater number and higher density in the parietal and prefrontal cortices, which are involved in rodent spatial cognition.

It is important, however, to point out that natural instead of sexual selection may also result in a female superiority in hippocampus size when, independent of mating ends, females have to meet higher spatial demands than males. Female birds do not systematically brood their eggs in all species, and this may be significantly linked to the evolution of the neurocognitive system in charge of spatial processing. Indeed, Reboreda, Clayton, and Kacelnik (1996) have conducted sex comparisons as to hippocampus size in cowbird species of the genus Molothrus, based on the knowledge that in some of these species, several days after the females have carefully located appropriate host nests for their upcoming eggs, they return to these nests to lay the eggs, without the males assisting them in either phase. Such a pattern is typical of shiny cowbirds (M. bonariensis), whereas in screaming cowbirds (M. rufoaxillaris) the females search for nests with the males' assistance, and bay-winged cowbirds (M. badius) do not engage in nest parasitism. During the breeding season only (Clayton, Reboreda, & Kacelnik, 1997), both sex and species differences in size of hippocampus have been detected within these birds. First, congruent with the higher requirements faced in terms of navigational complexity and location memory, only in shiny cowbirds were females shown to surpass males in size of hippocampal structure. Second, the two parasitic species displayed a larger hippocampus than the bay-winged cowbirds. The sex differentiation had previously been substantiated in related icterine species as a function of their being brood-parasitic or not (Sherry, Forbes, Khurgel, & Ivy, 1993).

These anatomical and behavioral findings reported in rodents and in cowbirds (pending appropriate spatial ability testing) suggest that covariations exist between ranging extent, brain or neural architecture, and, ultimately, spatial ability. Such cohesiveness supports the hypothesis that, at all three levels, sex differences may have been produced by selection, and particularly sexual selection that is, a powerful process establishing a fit between function and the underlying brain structure (Jacobs et al., 1990). This seems to have been the case for the above-mentioned species, and it may also be for comparable species.

Sexual Selection in Humans

The sexual selection framework formulated by Gaulin and his associates can probably account for several differences in the spatial skills of men and women: As argued below, the human species appears to meet the dual applicability condition that underlies this evolutionary view.

Sex differences in reproductive strategies.

According to the basic premise of sexual selection, within a given species any difference between males and females as to parental investment, and finally as to reproductive rate, gives individual members of the sex with the higher reproductive rate the potential of monopolizing the reproductive capacities of more than one member of the other sex. Because the plausibility of a reproduction-related evolution of spatial sex differences in humans is subject to this general rule, we briefly review the reasons warranting the inference of polygyny in our species.

Anthropologists have pointed out that it is difficult to ascertain, across various societies, the respective variance of reproductive success in men and women since the required measures should encompass the entire reproductive life. As claimed by Low (1988) for instance, proxy measures, such as extent of polygyny over shorter periods are but crude indicators of exact reproductive patterns, and thus of the intensity of sexual selection in humans.

As previously mentioned nevertheless, among the important characteristics of sexual selection is the intrasex competition that prevails among members of the sex having the greater potential reproductive rate. In mammals, such a sex is generally male, and control over the resources required for survival and reproduction, or over mates themselves, is generally reached through male-male physical competition for dominant status (Emlen & Oring, 1977). Typically absent in monogamous species (Symons, 1979), sex differences especially in body size, but also in mortality rate, are usually good indicators of such competition in numerous polygynous mammals (Plavcan & van Schaik, 1997). Thus, in many primate species, including Homo sapiens, sex differences are noticeable in anatomical features like stature and muscular mass which are greater in male individuals (Alexander, Hoogland, Howard, Noonan, & Sherman, 1979; Clutton-Brock & Vincent, 1991; Gaulin & Boster, 1985, 1992; Harrison, Weiner, Tanner, & Barnicot, 1977), and in sexual maturity which is delayed in males relative to females (Tanner, J. M., 1990). In addition, higher rates of mortality in male individuals are noted at all ages (Kitagawa & Hauser, 1973; Shapiro, Schlesinger, & Nesbitt, 1968).

Concerning humans more strictly, differential features indicative of the intensity of male competition are recorded in reproductive and social patterns. Men ordinarily engage in more active courtship behavior than women (Daly & Wilson, 1983). They also allocate more time and energy to male-male competition for status (Buss, 1994). Established in research on leadership (e.g., Eagly & Karau, 1991), their interest (whether it was genuine or prompted by social desirability is not directly relevant here) for such competition is likewise apparent in the higher ratings men from 14 countries have attributed themselves on ambition and dominance traits (Williams, J., & Best, 1990).

Finally, it should be noted that, in Murdock's (1981) enumeration, 84% of the 849 human societies for which relevant data are available practice polygyny. Moreover, proxy measures of polygyny such as those taken by Whyte (1978) or Hartung (1982) are strongly correlated. Even socially imposed monogamy, which is the common pattern in

Western countries (Dawkins, 1986)—except for some pockets of dissident Mormons for instance (Altman & Ginat, 1996)—, may benefit men more than women at the reproductive level. On average, men have a greater number of premarital and extramarital affairs than women (Daly & Wilson, 1988; Fisher, 1993). Furthermore, as the probability of serial monogamy is greater for men, at least for those with high social status (Pérusse, 1988), it may contribute to increasing their reproductive success (Geary, 1998). Indeed, compared with divorced women, divorced men are more likely to remarry younger partners and to have children with them (Campbell, 1999).

Thus, while caution is required before inferring polygyny in present-day humans, combined indications of sex-linked reproductive patterns and moderate to intense male-male competition observed in most contemporary populations basically appear to be the product of a natural evolution in favor of a polygynous tendency in humans (Gaulin & FitzGerald, 1986, 1989; Geary, 1998), or that, at least, Homo sapiens evolved from a relatively recent polygynous past (Plavcan & van Schaik, 1997).

Sex differences in ranging extent. For the sexual selection framework proposed by Gaulin and his collaborators to account for spatial sex differences in humans, a second requirement needs to be satisfied. This is that men have ranged more extensively than women over evolution. There is in fact some support for such a difference both in ancestral human groups and in modern societies. With respect to prehistoric humans, Ruff (1987) for instance has brought to the fore fossil evidence that sex differences in the structure of the femur and tibia in the knee region may be presumed in populations from the Middle and Upper Paleolithic periods. He has attributed the pattern of lower limb bone distribution uncovered in these samples to men's relatively greater ambulatory mobility and more frequent running compared to women.

Although contemporary ethnographical data is not abundant, MacDonald and Hewlett (1999) have recently indicated that for the 11 extant traditional groups across the world for which information was available, the average traveling carried out by men over a lifetime exceeded that by women. With more precise measures gathered among the forager Aka pygmies from the Central African Republic, these authors were able to show that exploration and mating ranges were positively correlated in men but not in women. Hance (1970) had previously stressed that in people from several African tribes as well as in Australian Aborigines, solitary long-distance explorations were a traditionally male activity. Even in a large city of North America, we found from our own work with over 200 participants (Ecuyer-Dab & Robert, 2001) that the home range traveled through daily for professional and/or personal purposes was larger in men than in women.

In children, data recorded in preindustrial cultures from Melanesia, Trinidad, Puerto Rico and a number of African countries similarly indicate that larger home ranges prevail in boys (Draper, 1975; Gaulin & Hoffman, 1988; Landy, 1965). For instance, among the polygynous Logoli from Kenya, 3- to 7-year-old boys venture farther than same-age girls in the course of their daily activities (Munroe & Munroe, 1971; Nerlove, Munroe, & Munroe, 1971). Also, among the Baoulé of the Ivory Coast boys spend most of the day away (more than 3 km) from home and cover highly variable distances, whereas girls stay within 200 meters from home most of the time (Dasen et al., 1985). For children from age 4 among industrial societies, Sebba (1994) has come to the same conclusion after having analyzed relevant information going back to the beginning of Western history. But the most direct evidence comes from North American children and adolescents, for whom a consensus emerges as to boys having a home range about twice as large as that of girls (Anderson & Tindall, 1972; Coates & Bussard, 1974; Hart, 1979; Herman, Heins, & Cohen, 1987; Moore & Young, 1978; Van Vliet, 1983; Webley, 1981; Wohlwill & Heft, 1987).

Hippocampal substrate. Given probable sex differences both in human reproductive organization and ranging extent, it appears reasonable to presume the action of sexual selection, throughout the evolution of our species, in accounting for a male advantage in a number of spatial processing cases and, possibly, for the underlying function played by certain brain substrates. Interestingly, a relationship was recently found between hippocampus volume and navigational activity in humans (i.e., London male taxi drivers, Maguire et al., 2000). In keeping with the results obtained in several birds and rodents, this finding supports the navigation-related role of the hippocampal structure for our species as well. In addition, it has been reported that, along with other brain regions, the right hippocampus was activated in both sexes during navigation within complex virtual mazes, but that men also distinctly engaged their left hippocampus whereas women further recruited their right parietal and right prefrontal cortices (Grön, Wunderlich, Spitzer, Tomczak, & Riepe, 2000). This differentiation in brain functioning is in agreement with sex-related pressures over the human evolutionary past. However, it needs to be stressed that there is no consensus as to which sex exhibits the largest hippocampus. For instance, among healthy adults including late teenagers through nonagenarian elderly, Raz et al. (1997) have measured a larger hippocampus in men after adjustment for head size, whereas Murphy et al. (1996) reached the opposite conclusion in terms of percentage of total intracranial volume. It is possible that any measure of global hippocampal volume is not sensitive enough to detect sex differences that might only exist in particular subareas of the hippocampal structure[2].

II The Foraging Hypothesis

In contrast with the previous mating system based conception, a foraging-related view of the evolution of spatial cognition, specifically fit for humans, has been advanced by Silverman and Eals (1992; Eals & Silverman, 1994). These authors have grounded their proposal on the position advocated by Tooby and DeVore (1987), along with other anthropologists, that within ancestral environments men mainly specialized in hunting and women in gathering activities. Assuming that such sex-related foraging prevailed during the Plio-Pleistocene and resulted in the selection of sex-related capacities in our species, Silverman and Eals (1992; Eals & Silverman, 1994) have submitted that part of this evolutionary heritage should still be reflected in the spatial cognitive processes of contemporary Homo sapiens.

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[2] Indeed, it has recently been stressed that global hippocampal size is but a crude indicator of the capabilities of the hippocampus. For example, Hampton and Shettleworth (1996) have demonstrated that the enlargement of the hippocampus shown in certain birds (i.e., food storers) is associated with the enhancement of only a subset of hippocampal functions as opposed to all of them.

We will argue in the present section that the assumption of a selective action resulting from sexual division of labor over the course of human evolution leads to significant conceptual benefits in two ways. As will be examined in detail further, in empirically validating their foraging hypothesis Silverman and Eals (1992; Eals & Silverman, 1994) have indeed improved our understanding of human sex differences in the spatial realm by highlighting a particular spatial skill in which, at odds with men's general spatial advantage, women are superior. In so doing, they have lent credit to the tenability of sexual division of labor during human evolution. The latter support appears substantial considering the thorny matter of what may have been the social organization adhered to by earlier members of the Homo lineage (e.g., H. habilis and H. rudolfensis) more than 2 million years ago, as well as by later ones (e.g., H. erectus, H. neandertalensis, and early H. sapiens) throughout the Pleistocene. While the longstanding existence of gathering as an effective subsistence strategy has been widely accepted (e.g., tool-assisted gathering could be approximatively 2 million years old, see Brain, 1988, and Leakey, 1971), there has been extensive debate in paleoanthropology over the past 20 years as to when and the extent to which our ancestors adopted the additional strategy of hunting. Also, there has been much heated discussion as to whether both sexes engaged in hunting and gathering activities during the Plio-Pleistocene, or whether one sex was chiefly in charge of one type of activity. Although full examination of these two complex issues is clearly beyond the scope of the present paper, it is useful to summarize their main features in order to better appreciate the progress gained from Silverman and Eals' endeavor.

Hunting and Sexual Division of Labor Among Early Humans

The most obvious difficulty with regard to any attempt at reconstructing the social patterns that may have predominated in our distant past lies in the fact that only fossils and artifacts, but not behaviors, have come down to us. Because of this information gap, inferences as to the socioecological repertory of extinct human species have been made from models resting on interpretations of archeological analyses (e.g., Isaac, 1978; Potts, 1987), on homology with living forms such as nonhuman primates (e.g., Tanner, 1987) and extant hunter-gatherers (e.g., Teleki, 1981) or both (e.g., Zihlman, 1989), and on deductive reasoning according to the principles of evolutionary theory and behavioral ecology (for a review, see Rose & Marshall, 1996). Given that Silverman and Eals (1992) endorsed Tooby and DeVore's (1987) conclusions, and that the latter authors mostly relied on the third approach to develop their position, we proceed in reference to some of their key arguments and, when possible, we compare this position to that ensuing from archeological and homologous analyses.

Hunting

We firstly consider the question of the prime subsistence strategies of earlier types of humans throughout the Plio-Pleistocene. Whereas Tooby and DeVore (1987) have partaken of the consensual acceptance of the ancient existence of gathering to provide plant food primarily, they have built various lines of reasoning for the view that hunting rather than scavenging was our ancestors' main strategy to obtain meat. One of these lines is that hunting parsimoniously accounts for a large number of typical traits of hominid adaptation that is, traits that are unparalleled among nonhuman primates and for which any adequate model of human evolution must account. According to these authors, the systematic use of stone tools, the intensity of paternal investment and male cooperative behaviors, and the penetration of temperate and even periglacial habitats exemplify some of these uniquely human features. Tooby and DeVore (1987) have thus objected to scavenging carnivore kills as having been a major strategy adopted by first humans to acquire meat. They have pointed out that animal protein requirements would not but occasionally have been met through opportunistic scavenging by humans since, like present-day African carnivores, those from the Plio-Pleistocene could have been rarely disposed to abandon partially eaten kills, and in those few cases where they had actually left meaty carcasses, early humans could have incurred risks in consuming potentially decayed flesh. These authors conceived that the frequent confronting of ferocious carnivores to steal their kills would also have involved costs, with regard to first humans' safety and welfare, that are likely to have exceeded those related to tracking and killing far less dangerous animals, from rodents to medium-size herbivores.

Consequently, such hunting, along with occasional opportunistic scavenging, would have had the highest probability of being selected over human evolution.

Support for Tooby and DeVore's (1987) view as to first humans engaging in hunting may be found in the large number of knapped stones throughout the game slaughter and butchery sites archeologically identified in Africa. Such primitive tools, approximately dated 2 million years old, may have been suitable for throwing at small animals (Calvin, 1983; Isaac, 1987; Leakey, 1979), though preservational bias could explain why more sophisticated but perishable hunting weapons of comparable age have not yet been found[3]. Interestingly, a series of wooden spears have been dated 400, 000 years old (Thieme, 1997) that is, antecedent to the emergence of H. neandertalensis and H. sapiens. In parallel, early meat procurement through scavenging has been supported by sophisticated analyses of Plio-Pleistocene faunal remains (for a review, see Bunn & Ezzo, 1993). These findings have given impetus to the suggestion that hominids scavenged carnivore kills to a greater (e.g., Blumenschine, 1991) or lesser extent (e.g., Potts, 1988; Sept, 1992). However, the debate is far from settled: What is still controversial (Lewis, 1997; Stanford & Bunn, 1999) pertains to whether scavenging was mostly opportunistic or confrontational (e.g., Blumenschine, 1991) and whether the largest meat yield came from scavenging or hunting (e.g., Clark, 1996; Rose & Marshall, 1996) or, more exactly, which human populations got hold of which prey species chiefly through scavenging or hunting (Lewis, 1997; Marean & Assefa, 1999). Looking at how contemporary hunter-gatherers appropriate meat provides, to a certain degree, some homologous references.

It may obviously be presumed that archaic humans substantially differed from modern ones in body size, brain capacity, learning ability, technology, and socioecological environment, in such a way that any parallel between the two types of humans may fail to capture the adaptiveness of a given behavior for the extinct species. Granted this reservation, the demonstration of the feasibility of humans acquiring meat through both hunting and occasional scavenging nonetheless sheds light on the current debate. Such twopronged meat procurement has indeed been observed among extant

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[3] Recent analyses of plant remains on the working edges of stone tools have suggested that rudimentary wooden spears may have been fabricated 1.5 million years ago (Dominguez-Rodrigo, Serrallonga, Juan-Tresserras, Alcala, & Luque, 2001).

African hunter-gatherers (Isaac & Crader, 1981). As an illustration, the Hadza from Tanzania are skilled hunters who scavenge 20% of their total meat ingestion: Typically, men approach kills armed with bows and poisoned arrows, shoot nonretreating carnivores, and eat them along with the kills (Bunn, Bartram, & Kroll, 1988; O'Connell, Hawkes, & Blurton Jones, 1988). Yet, women armed with mere digging sticks can steal a leopard's kill (O'Connell et al., 1988). Though practicable then, confrontational scavenging is definitely dangerous, and all the more so when unarmed, as shown by Treves and Naughton-Treves' (1999) recent analysis of casualty reports in rural Uganda over the last 80 years. Having also concluded that the rate of fatal injuries to humans was markedly higher in human-carnivore encounters involving lions instead of leopards, these authors have contended that the first hominids might have more often directed their confrontational scavenging attempts at leopards than at lions. Likewise, the shy cheetah and jackal should have been paying options (Blumenshine & Cavallo, 1992). It is also probable that our ancestors' opportunistic scavenging may have benefited from similarly judicious evaluations, such as when gauging the possibility of the absent leopard coming back to consume its typically tree-stored kill. For several hours, leopards' hidden kills may actually be left unattended, in some cases with flesh and marow totally intact (Blumenshine & Cavallo, 1992). However, appraising the risk level that is likely to have been associated with any type of scavenging by early Homo is problematic. On the one hand, the behavioral repertoires of current African carnivores may not be representative of those that prevailed during the Plio-Pleistocene as the prehistoric predecessors of these predators may have encompassed a wider diversity of species (Lewis, 1997; Rose & Marshall, 1996). First humans thus had to draw on a wider knowledge base to decide on the scavenging technique that would best fulfill both success and safety requirements. On the other hand, as over the same period both herbivore and carnivore densities were probably higher (Hawkes, O'Connell, & Blurton Jones, 1992; O'Connell et al., 1988), likewise the chances of coming across prey carcasses, abandoned or not by carnivores, could have been higher. Considering the above arguments, whereas it appears plausible that scavenging and hunting have constituted complementary strategies for meat procurement, it is difficult to estimate, with some precision, what may have been the respective frequency and yield of each strategy.

Sexual Division of Labor

Silverman and Eals (1992) also endorsed Tooby and DeVore's conclusion (1987) that, among our early ancestors, hunting was mostly performed by men and gathering of plants and other collectible foods primarily by women, while some of both tasks were carried out in a cross-sex fashion. From males engaging in hunting more intensively than females among chimpanzees and baboons, Tooby and DeVore reasoned that the more extreme differentiation of foraging observed in extant traditional human societies is not workable without the co-occurrence of between sexes food sharing and reciprocity which are two other typically hominid traits that need to be explained within any coherent model of human evolution. These authors emphasized that, therefore, the currently existing sexual division of labor accounts for such traits and is likely to have been selected among the various foraging systems possibly adopted by early humans.

Unfortunately, the hominid fossil record (Zihlman, 1991) and archaeological evidence (Whelan, 1991; Willoughby, 1991) have until now disclosed little as to the sex allocation of foraging activities over the Plio-Pleistocene period. Consequently, though with the same caveat as the one previously mentioned when discussing meat provision, some indications may be extracted from present-day hunter-gatherer societies as to their variability in terms of sexual division of labor. This survey tends to illustrate the nearly universal existence of such division (Hawkes, 1996; Lancaster, 1985; Leacock, 1978; Murdock & Provost, 1973; Sassaman, 1992). Across a wide range of modern foragers, the main gathering responsibility is indeed women's, while men are mostly found to gather opportunistically (Hawkes, O'Connell, & Rogers, 1997; Hayden, 1992) as among the Bushmen from Botswana (Silberbauer, 1981), the Aché from Paraguay (Hawkes, 1993), or the Aborigines from Australia (Gould, 1981). In less typical groups, men collect plants at par with women: This is the case among the Tiwi from Australia (Goodale, 1971), and the Agta from the Philippines though gathering is no major subsistence strategy for this population (Estioko-Griffin & Griffin, 1981, 1985).

Conversely, hunting with projectile weapons (e.g., arrows and spears) is usually engaged in by men, large-game hunting being their almost exclusive domain (Hawkes et al., 1997; Kaplan & Hill, 1992; Murdock & Provost, 1973; Webster, 1981). Women's involvement in the capture of small prey, essentially with stationary implements like traps, snares, and nets, is nonetheless frequently encountered. Thus, small prey procurement by women occurs among the Bushmen (Silberbauer, 1981), the Aché (Kaplan & Hill, 1992), the Tiwi (Goodale, 1971), the Matses from Peru (Romanoff, 1983), and the Chipeweyan from Canada (Jarvenpa & Brumbach, 1995). In the latter group, some women also join their husbands in large-game hunting parties wherein both sexes travel long distances and cooperate in locating and tracking moose; yet, the quarry is generally slain by men using guns (Jarvenpa & Brumbach, 1995).

This does not mean however that women are physiologically unable to hunt medium and big game, wielding male weapons. There is evidence of women engaging in such hunting among the Agta (Estioko-Griffin & Griffin, 1981, 1985), as well as the Ojibwa (Landes, 1938) and the Kaska (Honigmann, 1964) from North America, and what is more, these women have met with significant success. As most Agta women hunt, either alone or within teams, they contribute up to 40% of the meat acquired by the group (Goodman, Griffin, Estioko-Griffin, & Grove, 1985), besides being adept at underwater spearfishing (Estioko-Griffin & Griffin, 1981). Some of them even hunt during their peak childbearing years[4]. But it remains that cases of women killing fairly large animals are isolated and seem to occur under special socioecological circumstances

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[4] This data was obtained within Agta from the Cagayan province, a group wherein Estioko-Griffin and Griffin (1985) have found both pre- and post-partum infant mortality to be high. According to these authors, such mortality would not be directly related to women engaging in hunting. Their position concords with the fact that the number of living offspring has been shown to not significantly differ between Cagayan women who hunt and those who do not (Goodman et al., 1985), although such an indicator supplies somewhat different information than that provided by rate of infant mortality. By contrast, in keeping with an evolutionary perspective, Hurtado et al. (1985) have suggested that high infant mortality could constitute one of the costs of hunting by Cagayan women. However, they have put forward the idea that, as the amount of meat procured by Cagayan men may be insufficient to meet the nutritional needs of the entire group, women may have decided to hunt so as to eschew a further decrease in reproductive success for both sexes. Such presumed benefit is indeed congruent with the fact that even higher infant mortality has been reported among Agta from the Palanan and Casiguran provinces where very few women hunt (Kelly, 1995). It thus appears that, under the particular socioecological conditions prevailing in the Cagayan province, fulfilling food requirements through both men and women relying heavily on hunting the relatively abundant game (Goodman et al., 1985), as well as investing only weakly in the gathering of scarce edible plant food (Estioko-Griffin & Griffin, 1981), may have contributed to the preservation of a reasonable level of reproductive success.

(Goodman et al., 1985; Hurtado, Hawkes, Hill, & Kaplan, 1985; Kelly, 1995; Sanday, 1981).

Several authors (e.g., de Leeuwe, 1978; Hayden, 1992; Hurtado et al., 1985; Kaplan & Hill, 1992), as well as Tooby and DeVore (1987), have suggested that it may be more advantageous at the reproductive level for women, who are the customary childcare providers, to favor gathering over hunting. The main reason why medium- and big-game hunting is generally not performed by women could be that it is less congruent with mothering constraints as it frequently imposes long-distance travel and risk taking (Hayden, 1992; Hurtado et al., 1985; Sassaman, 1992; Torrence, 1983). Furthermore, the fact that such hunting is preponderantly assumed by men could finally rest on their deliberate choice resulting from a general adaptive male-male competition pattern oriented towards either reproductive advantages (Betzig, 1997; Geary, 1998; Hawkes et al., 1997) or the settling of social conflicts (Hawkes, 2000).

In sum, while it may be thought that hunting primarily by men and gathering chiefly by women are probably rooted in very ancient human practices, all attempts to reconstruct the socioecological organization embraced by first humans come up against some limits since they are inspired by models that, inevitably, entail a number of speculations about extinct hominid behavioral patterns. As a consequence, searching for paleoanthropological evidence of such patterns that are more refined than those currently available, or probing already collected material with more powerful devices, could provide more precise estimates as to the timing and extent of sexual labor division among our various predecessors, as well as to the importance of hunting versus scavenging for their subsistence. Scientific models being falsifiable, another fruitful avenue consists in designing appropriate empirical tests of their content to be conducted in contemporary humans.

Object Location Memory in Humans

The set of studies conducted by Silverman and Eals (1992; Eals & Silverman, 1994) within their foraging viewpoint has contributed to that end. These authors have reasoned that, over the course of hominid evolution, success in locating appropriate food plants within a given ecological niche would have necessitated, among gatherers, the ability to accurately represent and memorize, from one picking season to the next, the configuration of the locations where these plants grew. Thus, in accordance with their main involvement in gathering that is, an activity dealing with mostly stationary information, women should have specialized in the memory for the relative positions of stimuli within an area. By contrast, distinct spatial advantages should have evolved primarily in men, in response to the geospatial mobility imposed by the tracking of moving animals, as well as to the goal of effectively hitting them with thrown weapons. Proposing that such sex-related evolutionary legacy would still be apparent in contemporary populations and focusing on the gathering side of their view, Silverman and Eals have predicted that women should be more efficient than men at memorizing the configurations and relative positions of objects. Their prediction has in fact been born out in various settings.

More precisely, under a paper-and-pencil format, Silverman and Eals (1992) have shown that, after having examined drawings of common objects (e.g., a chair, binoculars, a clock) spread on a sheet of paper, women outscored men in recognizing, on a second sheet, which objects had remained stationary and which had been relocated. In the same series of studies as well as in a subsequent one (Eals & Silverman, 1994), these findings have been replicated both in incidental and intentional conditions, under an in situ format which involved recalling the place occupied by common objects seen dispersed in a room; the participants had to describe where the objects had been situated and to relocate them in an illustration of the room. Under this realistic assessment format, but with unfamiliar objects (of an unspecified nature), a female advantage was also found for incidental recall (Eals & Silverman, 1994).

Supporting Data

By emphasizing a female cognitive specialization for gathering activities, Silverman and Eals have not however elaborated much on the possible implications of hunting mainly by first men in the selection of a present-day male superiority in several spatial processes, as established by Linn and Petersen (1985) and Voyer et al. (1995) in their meta-analyses. We will see in the final section that a substantial part of this male spatial advantage may be viewed as in tune with the hunting part of the foraging hypothesis, but we limit ourselves, at the moment, to outlining some sex-linked attributes that appear in harmony with the selective role of hunting-gathering during human evolution.

To the point is the indisputable male superiority in throwing, a behavior based on motor and perceptual skills that should be more useful to hunters than to gatherers. From the age of 3, boys are actually able to throw more accurately and at increasingly greater speeds and distances than girls (Thomas, & French, 1985). Even after the contribution of height, weight, hand strength, and sports history has been partialled out (Hall & Kimura, 1995; Watson & Kimura, 1991), men are more accurate than women in hitting a stationary target (Peters, 1990, 1997; Watson & Kimura, 1989; Westergaard, Liv, Haynie, & Suomi, 2000), and make smaller timing errors when intercepting a moving one (Peters, 1997). It is noteworthy that, albeit fairly weak, a positive correlation between throwing skills and spatial achievement has been obtained among male adolescents (Kolakowsky & Malina, 1974), as well as among adolescents and adults of both sexes (Jardine & Martin, 1983) (but see Saucier & Kimura, 1998, and Watson & Kimura, 1991).

In addition, men generally manifest several sensory characteristics that may assist them in both locating prey at a distance and aiming accurately. For instance, they appear well equipped for picking up prey-related auditory cues given that they are more adept than women at detecting sounds within masking stimuli and at spatially localizing them (McFadden, 1998). They also display better visual acuity in detecting static and dynamic targets in the visual field (Baker, M. A., 1987; Burg & Hulbert, 1961). Their striking superiority in visuomotor tracking (Burg, 1966) could moreover bear some connection with their higher recall of dynamic events, such as the path traveled by a stimulus (Vecchi & Girelli, 1998).

By contrast, the following female motor and sensory advantages should enhance targeted food gathering. For example, women generally excel in speeded sequential action (McGuinness, 1985), as well as in fine eye-hand coordination (Thomas, & French, 1985) even after the contribution of finger size has been partialled out (Hall &

Kimura, 1995; but see Peters & Campagnero, 1996, and Peters, Servos, & Day, 1990). This should prove a strong asset for the efficient collecting of nuts, berries, seeds, or insects. Women also report higher vividness for static than for dynamic visual images as well as shorter latency for static images compared to men (Paivio & Clark, 1991). Additionally, that women may be particularly fit for screening between edible and toxic foods appears supported at three levels. To begin with, their lower incidence of color blindness (McGuinness, 1985; Velle, 1987) can contribute to a better discrimination of plants or tubers from subtle tint variations. Similarly relevant are their greater accuracy in smell recognition (Velle, 1987) and higher sensitivity and consistency in basic taste identification (Baker, M. A., 1987; Velle, 1987).

Discussion

Sex-linked sets of motor and sensory assets are thus consistent with the selective demands for hunting and gathering primarily in ancestral men and in women, respectively. Similarly consonant with the cognitive requirements of women's foraging activities over human evolution is women's superiority in remembering the location of common objects, as ascertained by Silverman and Eals (1992; Eals and Silverman, 1994). Such a superiority, furthermore, seems reliable since it has been substantiated in replications of these authors' in situ procedure where the objects had to be put back in place (Hill, R. D., et al., 1995) or their pictures had to be relocated within an illustrated room (Montello et al., 1999). With the original paper-and-pencil format, women's greater recognition of the locations of common objects was also reproduced (Barnfield, 1999; Gaulin et al., 1997; James & Kimura, 1997).

However, location memory is not invariably to women's advantage as object characteristics and memorization conditions need to be taken into account, especially from a functional perspective that focalizes on the features of the problems to solve over the course of evolution and on the required adaptive solving mechanisms. This raises the complex issues of delimiting the empirical contexts within which better location memory in women does occur, and of identifying the processes responsible for location memory. With regard to the context issue, it is important to stress that there was no sex difference within Eals and Silverman's (1994) in situ, directed-learning setting involving uncommon objects. Interestingly, this appears more attributable to the directed learning condition than to the stimuli being unfamiliar given that, with uncommon objects but an incidental learning setting, these authors found women to outperform men under both the in situ and paper-and-pencil formats (but see Epting and Overman, 1998). As pointed out by Silverman and Eals (1992), it is possible that the selective pressures for better location memory in women have acted, not only on their learning ability per se, but also, or even more so (Eals & Silverman, 1994), on the attentional and perceptual style they adopted while gathering across familiar environments. Such a style could imply that women undeliberately record detailed features of their physical environment, and are subsequently able to retrieve a precise representation of its various circumscribed sectors. Hence, when explicitly asked to attempt to remember stimuli, particularly when these are uncommon, as well as their respective locations, women could opt for an alternative strategy, such as trying to label the stimuli. According to these authors, conflicting with spontaneously attending to surrounding elements, intentional verbal coding could suppress the female advantage.

In view of the plausibility of Silverman and Eals' (1992) suggestion as to how women may deal with uncommon objects, the relevance of the incidental- versus directed-learning variation should be carefully examined. For instance, if directed learning may decrease the female advantage in location memory when applied to unfamiliar objects, then this learning condition could also have an adverse effect in the case of common objects. Whereas such a comparison of the effect of incidental- versus directed-learning instructions has yet to be carried out with common objects, a recent study by Duff and Hampson (in press) provides relevant information. These authors have not reported a significant sex difference in Silverman and Eals' (1992) incidental recognition task with common objects. However, the impact of the incidental instructions may have been overridden by that of the intentional memorization requirements in two previous tasks, one of which specifically involved object locations. In addition, it is useful to note that some authors who investigated directed learning only either did not obtain significant sex differences (Janowski, Chavez, Zamboni, & Orwoll, 1998; Sharps, Welton, & Price, 1993) or reported a female advantage (Crook, Younghjon, & Larrabee, 1990; McBurney, Gaulin, Devineni, & Adams, 1997). But such an inconsistency could be due to a number of procedural differences between the settings involved, some of which insert a delay between presentation and testing (Crook et al., 1990; Janowsky et al., 1998; Sharps et al., 1993) or included a distracting task within this delay (Sharps et al., 1993). As a consequence, even though learning instructions likely affect location memory, at least for uncommon items, it is probable that additional factors are critical in the case of common ones.

We believe that consideration of these factors may be particularly fruitful in leading to a more precise definition of the cognitive processes responsible for location memory, one of the various types of spatial memory. Several authors have insisted that spatial memory should be viewed, not as a unitary cognitive system, but as one that subsumes a wide diversity of processes. For instance, Schacter and Nadel (1991) have argued for the dissociation between spatial memory for objects and that for words, as well as between memory for landmarks and that for configuration. For the present discussion, which advocates the evolved nature of spatial cognition and its functional analysis, it is not trivial to pay attention to the differential processing that is likely to be favored by men and women respectively when memorizing locations. We agree with Barnfield (1999) that women would concentrate on the position of objects relative to one another, and men on the more absolute positions of objects in space. This focusing contrast may be useful in understanding sex-related performances in frequently used location memory tasks, including those devised by Silverman and Eals (1992; Eals & Silverman, 1994). As suggested by Barnfield (1999), men's functioning seems reliable in large-scale contexts but not precise enough in small-scale ones. By contrast, women's processing appears adaptive in gathering situations where different items co-occur within an area which generally is familiar and limited.

Such sex-differential spatial memory processes may also have been at work to produce several findings based on formats departing from those employed by Silverman and Eals. In these authors' paper-and-pencil condition, the recognition test involved some objects that remained in their original location and others that exchanged locations with one another; the initial overall configuration in terms of occupied and empty sectors was thus preserved. By contrast, when a new configuration results from the moved objects being shifted to previously unoccupied sites, no significant sex difference is detected (James & Kimura, 1997). Similarly, as stressed by Barnfield (1999), without being able to rely on other static spatial referents in a given array, memorizing position exclusively could be easier for male than for female participants. Indeed, men have been found to be significantly or marginally more proficient than women when the task demands the encoding of position only (Postma, Izendoorn, & De Haan, 1998; Postma, Winkel, Tuiten, & van Honk, 1999; Vecchi & Girelli, 1998) or when it emphasizes position by requiring the recollection of the locations of common objects shown one by one (Barnfield, 1999[5]; but see Denney, Dew, & Kihlstrom, 1992, with words as stimuli though) or to retrieve a position from verbal directions (Vecchi & Girelli, 1998).

Finally, it is possible that other procedural factors also influence the occurrence of a sex difference in object location memory. One of these is the sex-typing of objects, considering that, under a realistic condition, each sex displays better location memory for sex-congruent objects than for sex-incongruent or neutral ones (Cherney & Ryalls, 1999). But another potentially critical factor is the number of stimuli in addition to, or in interaction with, some already mentioned variables, such as the nature of the stimuli and the learning conditions involved, as well as other aspects like stimuli size[6].

In sum, while understanding sex-related performances with respect to object location memory may require consideration of the above-mentioned elements, there appears to be a good amount of evidence favoring Silverman and Eals' (1992) evolutionary scheme. However, future research aimed at a more comprehensive understanding of the evolutionary foundations of location memory should strive to maximize the ecological validity of the settings in which such memory is evaluated: There should exist a genuine equivalence between these settings and the contexts which may be supposed to have prevailed for gathering activities among first humans. This may help in identifying more precisely the cognitive processes underlying this type of

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[5] The objects were shown in a random order, identical for each participant (A. M. C. Barnfield, personal communication, November 16, 1999).

[6] For instance, presenting either a small (Postma et al., 1998, 1999) or a large (Dabbs, Chang, Strong, & Milun, 1998) number of objects may suppress sex differences by creating ceiling or floor effects depending on whether the setting involves common or uncommon objects that are homogenous or not in size, and on whether learning is incidental or directed.

memory and in discriminating them from those which would have evolved to support other forms of spatial memory.

III Natural or Sexual Selection of Spatial Sex Differences?

We think that the existence, across several species with polygynous features, of respective male and female strengths in the spatial realm would gain from being considered within a twofold explanation. On the one hand, the analysis carried out in Section 1 suggests that the sexual selection framework, as proposed by Gaulin and his associates (Gaulin, 1992; Gaulin & FitzGerald, 1986, 1989; Gaulin & Hoffman, 1988), is powerful enough to account, in polygynous species with sex differential ranging, for the evolution of male advantages in spatial skills that play a part in a male competition involving extensive navigation. It has previously been shown that among polygynous rodent species such male superiority is illustrated in maze learning. As will be emphasized further on, male humans are likewise found to usually outscore females in navigation-related spatial tasks, such as wayfinding (e.g., Devlin & Bernstein, 1995; Holding & Holding, 1989; Lawton & Morin, 1999). However, given that in some species, such as primates (most of which are polygynous), males compete for mating through both ranging extensively and fighting (Geary, 1998; Smuts, 1987), invoking sexual selection in males also appears relevant to explain an additional male superiority in spatial abilities which underlie agonistic patterns expressly. As a result, to embrace the male side of sex differences in spatial abilities, at least in primates, a model based on the action of sexual selection needs to consider two classes of male competition pressures, each of which applies to agonistic and navigation contexts respectively.

On the other hand, by essence a view built on sexual selection theory deals uniquely with the evolutionary mechanisms that would have favored skills in relation with the individuals' mating strategies that is, in our case, spatial skills that mainly assist male competition over mating in polygynous species. Conversely, this view is in no position to postulate a spatial advantage such as a female superiority in location memory since this has no bearing on mating strategies. Hence, it may be asked whether attributing the spatial memory asset in females to natural selection may provide an alternative rationale. As detailed in Section 2, the foraging hypothesis by Silverman and his colleagues (Eals & Silverman, 1994; Silverman & Eals, 1992) submits such an alternative for humans, based on the gathering role these authors deemed to have been mainly assumed by women in ancestral environment. However, as will be shown in Section 5, it seems plausible that females from other species, like chimpanzees, might also exhibit a spatial aptitude that would parallel that in female humans (Geary, 1998). An explanation of such a female advantage must thus be sought outside the strict context of a human sexual division in foraging.

In this section, we attempt to demonstrate that stressing the action, in several mammalian species with polygynous features, of sexual selection in males and of natural selection in females affords the explanatory power required to simultaneously encompass both the male and female sides of spatial cognition. We develop the natural selection component of this twofold process after having summarized the sexual selection component the central portion of which, as it pertains to navigation-related spatial skills, has already been detailed in Section 1.

A Twofold Selection Process

On its male side, the twofold selection process appears to have taken the form of intense male competition for mates (possibly amplified by females choosing to bond first with males who show higher competitive capacities) over the evolution of polygynous species. In order to maximize their reproductive success, males would have benefited from engaging in competition oriented activities that enable encountering mates, through a more extended ranging as highlighted by Gaulin and FitzGerald (1986, 1989), and/or gaining access to them, through male-male physical aggression that includes launching and eluding projectiles (Geary, 1998). Each of these competitive manifestations, variably exemplified depending on species, would have induced a male superiority in distinct sets of spatial abilities: In males from a wide span of species with sex differential ranging, extended navigation would be responsible, as validated in voles by Gaulin and FitzGerald (1986, 1989), for their advantage, in comparison to females, in those spatial abilities that underlie long-range navigation. In species where male competition additionally or alternatively entails agonistic behaviors, such as throwing projectiles at congeners and intercepting the ones they throw, that have been observed in several primate species (e.g., Essock-Vitale & Seyfarth, 1987; Goodall, 1986; Warren, 1976), spatial abilities sustaining these competition patterns would also be superior among males, as will be detailed further on.

While primarily pertinent for humans, work both by Campbell (1999), who does not focus on spatial issues though, and by Sherry and Hampson (1997), who address spatial sex differences, has inspired us to formulate the female side of a twofold selection process. The "staying alive" perspective proposed by Campbell (1999) highlights the critical adaptive value for women of putting a higher premium than men on their own survival. Her hypothesis is based on the observation that, at variance with men, women devote a lot to rearing their children and provisioning them with food through gestation, lactation[7], and solid food suppliance after weaning. As in most mammalian species, this is seen in most contemporary populations (e.g., Eibl-Eibesfeldt, 1989), even if male parental care in humans attains a level unparalleled among primates (Daly & Wilson, 1988). As emphasized by Campbell (1999), the children's survival would then depend more on the mother's than on the father's survival. Thus, because reproductive success (i.e., the capacity to leave fertile descendants) in females is mainly conditional on the possibility that their dependent offspring reach the reproductive period, women should be more concerned with staying alive than men. Data on orphan survivorship in several hunter-gatherer societies support this thesis. As an illustration, in the Aché, K. Hill and Hurtado (1996) have observed that child mortality rate during the dependency period multiplies by five when the mother dies, compared to being increased by a factor of three following the father's death.

On their part, Sherry and Hampson (1997) have suggested that, due to the heavy fertility and mothering constraints placed on women, evolution would have selected for physiological mechanisms that, at critical times during women's reproductive life, would have influenced their spatial cognition and navigation behavior so as to promote

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[7] In foraging societies, lactation usually continues until the child is four years old (Lee, 1979).

reproductive success. In addition to raising predation and accident rates for both mother and infants (Lovejoy, 1981), long-range navigation entails, according to these authors, a costly consumption of calories to the detriment of the energy required for ovulation, pregnancy, and suckling. Their "fertility and mothering" hypothesis offers two refinements in accounting for the difficulties experienced by women in solving spatial problems related to long-range navigation. First, this view highlights the role of fluctuating female sexual hormones as a proximate mechanism that mediates women's spatial cognition and limited mobility and, in so doing, contributes to maximizing their reproductive success. Oestrogen would act, especially during key phases of the female reproduction, primarily by decreasing those spatial abilities that assist long-range nativation, and consequently by curbing females' navigation. To the point, women's performance in spatial tasks in which men generally excel has been reported to be lower when oestrogen levels are the highest during the menstrual cycle (Hampson, 1990; Hampson & Kimura, 1988; Komnenich, Lane, Dickey, & Stone, 1978; Silverman & Phillips, 1993; but see Gordon and Lee, 1993), as well as over pregnancy (Woodfield, 1984). There is also evidence that during pregnancy women have a reduced home range size (English & Hitchcock, 1968). Second, Sherry and Hampson's (1997) view asserts that spatial ability is not so much enhanced in males as reduced in females in critical reproductive periods. As stressed by Sherry (2000), this is not predicted by the sexual selection of better spatial skills in sexually mature males. According to the same author finally, Silverman and Eals' (1992: Eals & Silverman, 1994) foraging hypothesis, which is not concerned with reproductive status, makes no predictions as to age variations in navigation-related spatial skills sustaining sex-linked foraging duties. As a result, it cannot explain the findings that, overall, sex differences in spatial cognition emerge at sexual maturity and that their magnitude increases progressively from late childhood to sexual maturity (Voyer et al., 1995).

Applying the Female Survival Component to Nonhuman Species

The perspective we propose in this paper is basically congruent with those by Campbell (1999) and Sherry and Hampson (1997). We agree with these authors who emphasize the costly female reproductive constraints due to an especially prolonged juvenile dependency in humans (Washburn, 1981). We further argue, however, that, even if to a lesser degree than in humans, parental investment is costly for females in other mammalian species among which the duration of gestation generally increases with body size (Bearder, 1987). Species specific data on interbirth interval provide especially interesting estimates of the amount of maternal investment. In nonhuman primates for instance, females give birth every two years on average in baboons (Collins, Busse, & Goodall, 1984; Dunbar, 1984) as well as in patas monkeys and forest guenons (Cords, 1987), and every two to three years in macaques (Pearl, 1982). In apes, the interbirth intervals appear to be some of the longest among primate species that is, a minimum of 5 years and a 6- to 7-year average in orangutans (Galdikas, 1981); a 3- to 7-year average in bonobos (Nishida & Hiraiwa-Hasegawa, 1987); and a 4- to 8-year average in chimpanzees (Nishida & Hiraiwa-Hasegawa, 1987). Additionally, in monkeys and apes, mothers wean infants after one to five years depending on species (Lancaster, 1985). Overall, these facts imply that, with respect to the longevity of these mammals, the period of offspring dependency lasts long enough to compel females to highly value their own survival and, hence, to adopt spatial and navigational profiles that could parallel the one found in humans.

Invoking the action of natural selection for a strong survival concern may account for a certain female spatial processing profile. Firstly, this potent survival pressure would have selected for proximate mechanisms that might prevent females from engaging in activities that jeopardize their survival, such as extended ranging which, according to Smuts (1987), aggravates risks of predation or body injuries caused by accidents. Secondly, it would have compelled females to pay attention to the spatial features of their immediate environment primarily.

In addition to the proximate role played, at critical reproductive periods, by female sexual hormones in depressing spatial cognition and curbing navigation extent, it is likely that psychological features could have jointly evolved in response to the pressure of maximizing females' chances to survive as well as those of their offspring. During familiarization with the Morris water maze, female Long-Evans rats have been shown to react with more anxiety, fear, and defensive behaviors than their male counterparts

(Perrot-Sinal, Kostenuik, Ossenkopp, & Kavaliers, 1996; but see Johnston & File, 1991, who used a different maze). When facing a new, open field environment during the breeding season, female meadow voles have been observed to display greater stress in that they spent less time than males in the center of the area and demonstrated lower locomotor activity (Perrot-Sinal, Heale, Ossenkopp, & Kavaliers, 1996).

The same kinds of overreactions are seen in humans. More frequently than men, women suffer from space-related panic disorders (i.e., agoraphobia; American Psychiatric Association, 1994); they generally express less self-confidence in virtual navigation situations (Devlin & Bernstein, 1995), and experience more anxiety in either real (Schmitz, 1997) or hypothetical (Lawton, 1994, but see Montello et al., 1999) ones. Such differences in fear and self-confidence are moreover congruent with women being less likely than men to report possessing a good sense of direction (Bryant, 1982) and to believe being apt at remembering directions to go to an unfamiliar place (Crawford, Herrmann, Holdsworth, Randall, & Robbins, 1989). More generally, it should be underscored that the fear of threat to body integrity and of settings involving potential predation or physical harm are more often manifested by women than men (Campbell, 1999). Such defensive features include phobias directed at animals, blood, and injuries (Marks, 1987).

In parallel, a particular spatial cognitive profile would have been shaped by the natural selection of survival concerns. Navigating mostly in small areas is likely to incite paying special attention to the configuration formed by nearby landmarks. This spatial processing may have favored female fitness in a wide range of mammalian species over their respective evolution. It may have allowed females, slowed down by pregnancy or the presence of offspring, to spot the fast retreat paths in case of danger from predators or undesirable encounters. It is equally worth noticing that such detailed attending to short-range spatial configurations appears quite adaptive for species that feed mainly from stationary sources of food like specific plants or fruit. It may enable female individuals to accurately encode places where these foods can be found on a regular basis to meet basic nutritional needs during critical reproduction periods, namely ovulation, conception, and pregnancy, as well as during suckling and when the young are still dependent after weaning.

Data obtained in both humans and nonhuman species support the existence of a female spontaneous spatial awareness as to immediate surroundings. At variance with men, women have been observed to spontaneously focus on neighboring landmarks when performing navigation-related tasks (Choi & Silverman, 1996; Dabbs et al., 1998; Miller & Santoni, 1986; Montello et al., 1999; Ward, Newcombe, & Overton, 1986). The preferential use of spatial cues in close proximity has been found in female rodents learning a maze (Roof & Stein, 1999; Williams, C. L., et al., 1990; Williams, C. L., & Meck. 1991). As will be reviewed later, a female inclination for encoding close spatial referents may also be present in primate species, such as chimpanzees, in which females frequently visit locations associated with stationary food sources, such as ant and termite nests (Boesch & Boesch, 1989; Goodall, 1986; McGrew, 1992).

Overall, the propensity towards small-scale navigation, along with the awareness of short-range space—both mediated by proximate mechanisms—may explain why, in humans, female individuals are better than males at recalling landmarks on a route (e.g., Galea & Kimura, 1993; Kimura, 1992). Whereas encoding the detailed configurations that is, the positions of objects relative to one another, is likely to be unreliable in large-scale ranging (James & Kimura, 1997), it may help women in better remembering the respective locations of items within an array (Barnfield, 1999), as established by Silverman and his collaborators (Eals & Silverman, 1994; Silverman & Eals, 1992). Hence, we surmise that women's memory both for immediate spatial cues during navigation and for object positions in rather small-scale settings is sustained by cognitive processes which are likely to have originated from the selection exerted by a single evolutionary pressure, that of a general concern for survival among females.

IV Competition- and Survival-Related Spatial Abilities

The perspective based on a twofold selection of sex-specific spatial processing profiles appears coherent in both humans and some nonhuman species with regard to the respective adaptive roles that spatial cognition apparently plays in each sex. We now analyze the functional characteristics of the spatial processing that, in several species, allows the solving of sex-specific navigation problems while moving in the field with the objective of maximizing either mating opportunities for males or survival chances for females. We also examine the characteristics of the spatial processing sustaining agonistic interactions in males among primate species including humans. Overall, this permits us to offer an evolutionary rationale for various sex-linked spatial abilities. In humans and in several nonhuman species, most of these abilities are generally evaluated in wayfinding tests; in humans only, they are appraised in either tabletop tasks or realistic settings that may call for either the memorization of absolute versus relative positions, the mastery of geometrical and mechanical principles, or the mental rotation of shapes.

Navigation-Related Spatial Abilities

Depending on species-specific ecological niches and cognitive capacities, evolution could have designed a variety of mechanisms enabling navigation (Heft, 1996). Nonetheless, there is some indication that broad communalities may be found across a number of species as to how they extract and process spatial information for navigation purposes. Indeed, to different extents, both audition and proprioception afford relevant information for principally short-range navigation among humans (e.g., Wierner & Berthoz, 1993) and for both short- and long-range navigation in animal species such as bats and rodents (e.g., Baron, Stephan, & Frahm, 1996; Gallistel, 1990). However in numerous species, including humans, vision generally supplies most of the spatial data, whether two- or three-dimensional, that are needed for short- and long-range navigation. Irrespective of range scale, when a given destination is visible in the field, its mere visual perception is in fact sufficient to guide navigation (Thinus-Blanc & Gaunet, 1997; Wickens, 1999). When the place to reach cannot be directly seen because it is situated too far away though, or, even if close, it is screened from view, then spatial cognition must necessarily be at work.

It involves the processing of spatial information that is essentially drawn from visual referents other than the destination, and/or from more abstract spatial data which are mentally represented. Many researchers (e.g., Wilson, Foreman, Gillett, & Stanton, 1997; O'Keefe & Nadel, 1978; Thinus-Blanc & Gaunet, 1997) have differentiated the spatial data acquired through an egocentric point of view, also labelled body- or self-referencing, from those derived by way of an allocentric perspective, also labelled exo- or world-referencing. For solving navigation problems, one may thus mainly rely on spatial information that is either exclusively self- or world-referenced, or that combines both origins (Wickens, 1999). From the self-referenced point of view, visuo-spatial information is perceived as constantly varying according to the excursions of the individual in the environment since, in terms of angular distances between surrounding elements that are potential referents, the geometry of the environment changes as a function of the individual's travels (Thinus-Blanc & Gaunet, 1997). Also, depending on whether one is going to or coming back from a given location, the relative positions of these referents alternately pass from left to right, from forward to backward, and from near to far. Likewise, as the individual is moving closer to one place, the forward visual perspective switches from a global and large scale to a local and small scale; the reverse applies for the backward field of view. On the other hand, certain kinds of spatial information are world-referenced that is, not strictly obtained through visual perception but grounded in internalized representations of space. Independent of the individual remaining or not at the same location, the sites within an environment can be defined with respect to unchanging, absolute spatial coordinates such as cardinal points. For instance, a certain place is north to a second one and west to a third, and a given salient feature within the environment demarcates the south boundary of the individual's traveling region.

From a functional angle, two main problems are customarily encountered during navigation and, in the case of humans, during navigation unassisted by direction-giving devices. One has to locate oneself in relation to the place where one wants to go, and to decide how to get there (e.g., Howard, 1993). We believe that solving both problems asks for active cognitive processes, namely the mental integration, manipulation, and transformation of spatial information. For instance, in addition to having to build representations of the map of an overall area, and of smaller ones within it, successful navigation requires regularly updating one's position and orientation from encoded spatial information, with regard to a given destination within the environment. Moreover, the trajectory to adopt for reaching such a destination often needs to be readjusted due to detours imposed by the natural or refashioned relief.

As examined in Section 1, there is a good amount of evidence supporting the view that navigation-related spatial systems have been biologically shaped according to the amplitude of sex-specific ranging patterns which were recurrently adaptive (i.e., promoting fitness) during evolution. With regard more particularly to the polygynous and monogamous rodents studied by Gaulin and FitzGerald (1986, 1989), it has been demonstrated that only the reproductive activities of the polygynous species generally entail males covering greater distances than females and, correspondingly, exhibiting better maze learning. Similarly, having elaborated on the implications of sex-linked foraging activities in humans for navigation-related spatial capacities, Silverman et al. (2000) have stressed that such skills are probably exploited to a greater magnitude in the tracking and killing of prey over usually large and novel territories than in the collecting of plants throughout mostly relatively restricted and familiar areas. Considering the habitually goal-oriented nature of navigation, it thus seems likely that when evolution favors ranging activities over territories varying in size in males and females of a given species, selection processes lead accordingly to navigation-related spatial abilities which are in tune with the respective navigation demands placed on each sex. In sum, as navigation seems to be carried out with reproduction or survival purposes in males and females respectively, it should ultimately be the particular cognitive processes sustaining navigation strategies at play in sex-specific problem solving that would have been critical for selection.

It is probable that the more important the distance to cover, the greater the amount of self-referenced spatial data to encode (Gaulin & FitzGerald, 1986, 1989), and the higher the cognitive load with regard to the active processing required for solving the navigation problems encountered. Thus, one may conceive that a small amount of data to encode, due to the relatively short distance between the individual and the destination, poses few problems. In this case, it may be appropriate to count mainly on serial self-referenced data to orient in the field, updating one's position and the trajectory towards the goal. As previously emphasized for females individuals who are likely to have been chiefly concerned with their survival and to have frequently ranged in rather restricted areas, reliance on such a small-scale strategy--equivalent in humans to the route strategy identified by some authors (e.g., O'Keefe & Nadel, 1978; Thinus-Blanc & Gaunet, 1997)--could have been one of the viable options selected over evolution. However, as the distance to destination increases, the amount of self-referenced data to encode increases proportionally. For long-distance travels, as depending only on this serial information may become too costly in terms of memory demands, it is probably an unreliable navigation strategy. Instead, one optimal strategy --equivalent to the survey or map strategy according to O'Keefe and Nadel (1978) as well as Thinus-Blanc and Gaunet (1997), for instance--may consist in minimizing the utilization of self-referenced data by selecting the most salient large-scale features exclusively, while maximizing the use of a few but suitable spatial data whatever the individual's position at a given point in space, that is, world-referenced information. In this context, one may reason that, in species equipped with sensory and cognitive systems able to support the encoding and processing of such information, evolutionary processes could have elicited the spontaneous adoption of this large-scale strategy among individuals who customarily ventured into large and sometimes unfamiliar territories. In species wherein males range more extensively, a trend that is apparent among humans and several other primates, females and males may have thus inherited the respective propensity of primarily drawing on the small- and large-scale navigation mechanisms, as submitted by Geary (1998) and R. R. Baker (1981).

Several findings support such reasoning. For instance, while human participants could employ one or the other of the above-described strategies for learning a route from a map, compared to women, men more often focus on Euclidean, geometrical features (Galea & Kimura, 1993; but see Montello et al., 1999) and memorize a smaller number of landmarks (Galea & Kimura, 1993). When giving directions in relation to a (real or mental) map, men also are generally inclined to provide more cardinal references than women (Dabbs et al., 1998; Montello et al., 1999; Ward et al.,1986; but see Choi & Silverman, 1996). Although female participants do give accurate cardinal directions when prompted (Ward et al., 1986)--and this appears to consolidate the view that adopting such a strategy is not their primary option--, their first answers seem to illustrate, as stressed in Section 1, a preference for supplying more topological cues including landmarks and their configurational relations (Choi & Silverman, 1996; Dabbs et al., 1998; Miller & Santoni, 1986; Montello et al., 1999; Ward et al., 1986). Strengthening the likelihood of evolutionary bases for parallel sex-related navigation strategies in species with far less powerful cognitive capacities than humans, a processing differenciation close to that found in our species has been observed in promiscuous laboratory (Sprague-Dawley) rats: During water maze navigation, males depend almost exclusively on three-dimensional geometrical information, while females additionally utilize landmark referencing, and thus impose greater demands upon their memory (Roof & Stein, 1999; Williams, C. L., et al., 1990; Williams, C. L., & Meck, 1991).

Advocating the twofold evolved nature of spontaneous inclinations for sex-related spatial processes in navigation contexts, at least in mammalian species with polygynous features, thus provides a functional explanation for why, compared to females, male human individuals generally exhibit higher wayfinding abilities or fare better in certain tabletop and realistic spatial tasks.

Wayfinding Abilities. A male advantage in adolescents and young adults has for instance been reported in terms of lower number of errors or shorter time for run completion in full-scale mazes (Schmitz, 1997; but see Overman, Pate, Moore, & Peuster, 1996) and in computer-simulated versions of mazes or of visits through unfamiliar sites (Astur et al., 1998; Devlin & Berstein, 1995; Moffat et al., 1998). Men also make more accurate judgments than women in pointing in the direction of the starting point in virtual mazes (Lawton & Morrin, 1999) and in the direction of target locations situated on a route learned from pictures (Holding & Holding, 1989) or within a mentally pictured, familiar large-scale site (Bryant, 1982).

Absolute Versus Relative Spatial Memory. Men's propensity to rely on world-referenced and geometrical information similarly provides a coherent explanation for the fact that, as indicated in Section 2, they show less difficulty than women at memorizing more absolute positions (Postma et al., 1998, 1999; Vecchi & Girelli, 1998) or at retrieving the position of an object without the assistance of spatial referents (Barnfield, 1999). The same inclination is likely to be responsible for the finding that from childhood to old age, male individuals typically display superior geographical knowledge (e.g., Barrett, R. T., & Farroni, 1996; Beatty, 1989; Dabbs et al., 1998; Montello et al., 1999; Straub & Seaton, 1993; but in children and adolescents see Rutland, 1998). Concerning women, their spontaneously focusing on the relative positioning of environmental features may account for their being more precise about landmark orientation when drawing maps of both unfamiliar (Montello et al., 199; Pearce, 1977) and familiar (McGuinness & Sparks, 1993) areas. Their primary reliance on such a route navigation strategy may rest on a cognitive mechanism which is not separable from that regulating their superior incidental memorization of the global configurations formed by the relative positions of common objects within delimited arrays (Eals & Silverman, 1994; Silverman & Eals, 1992).

Euclidean Spatial Abilities. The action of a twofold selection process on sex-specific navigation strategies could likewise be responsible for the usually higher ability of male humans at understanding Euclidean geometrical principles (Geary, 1996; Hyde, Fennema, & Lamon, 1990). As illustrated in work by Galea and Kimura (1993) as well as by McGuinness and Sparks (1983), when navigating men resort to such principles more correctly than women do. Matthews (1986) has also found that just before puberty (i.e., by the age of 11), boys arrange the elements on the maps they draw in a more integrated and organized fashion than girls and, in so doing, exhibit a more structured understanding of Euclidean space (see also Webley & Whalley, 1987). Therefore, the stronger performances of male individuals in tabletop tasks that, at least in part, involve adeptness at processing Euclidean information, such as the water-level and Rod-and-Frame tests (Linn & Petersen, 1985; Voyer et al., 1995), appear in harmony with the selective action, during hominid evolution, of a male bias towards the survey navigation strategy.

Aggression-Related Abilities: Newtonian Spatial Skills

As previously mentioned, in many polygynous species sexual selection has generally favored male competition for the female sexual resource, and among the various forms of such competition are the males' more extensive ranging in search of mating opportunities and the male-male physically agonistic behaviors to attract females. We argue here that, within the category of agonistic expressions, certain physically aggressive displays in which male hominids and primates may have engaged in their respective evolutionary contexts, probably required spatial skills additional to those strictly related to navigation. This would have been especially true in settings involving projectile weapons, such as stones, given that for efficiently propelling or dodging these it is necessary to grasp mechanical principles, namely those governing movement--which may be conceived as entailing the modification, at distinct points in time, of the relations between an object and its spatial referents. The abilities for understanding and visualizing the kinetic and gravitational components of the behavior of an object flung into the air, like its velocity and travel distance, enable a prediction of its trajectory and, hence, of its impact point in space. These abilities, which we name Newtonian spatial abilities, could thus have been critical for male individuals in agonistic situations over hominid, and to some extent, primate evolution.

The pressure exerted by the tendency of males to engage in such physical competition may have promoted, as suggested by Geary (1998), anticipatory motor, perceptual, and cognitive assets. These assets not only include the already mentioned superior throwing abilities of men (Hall & Kimura, 1995; Thomas & French, 1985; Watson & Kimura, 1991), but also their greater proficiency in estimating when an oncoming object will reach them (Schiff & Oldak, 1990) and in hand-blocking a projectile thrown at them (Watson & Kimura, 1991). In all likelihood, such attack and self-defense advantages are linked to the fact that, in comparison to women, men generally display more advanced knowledge as to the trajectory of moving objects (Kaiser, Jonides, & Alexander, 1986; Kaiser, Proffitt, & Anderson, 1985; Kaiser et al., 1992; Kalichman, 1991; but see Hecht & Bertamini, 2000) and a higher accuracy in judging their relative velocity (Law, Pellegrino, & Hunt, 1993; Poduska & Phillips, 1986).

It is moreover worthwhile noticing that mastering Newtonian spatial abilities, as well as Euclidean skills, requires a certain amount of cognitive processing and spatial knowledge. For instance, correctly apprehending, through visualization, the trajectory of launched objects in three-dimensional Euclidean space in order to predict their impact point is not workable without some understanding of movement principles since the breakdown of such a trajectory into its components cannot be accessed through sensory experience. In order to "see" the trajectory itself, it is necessary to simultaneously take into account the action of something like gravity and some abstract determinants, such as the speed of the moving object. That, in self-evaluations of visual imagery, men report visualizing moving stimuli more vividly than static ones and that their self-declared latency in generating dynamic images is shorter than women's (Paivio & Clark, 1991) thus appears congruent with the sexual selection among male humans of spatial processing mechanisms in tune with male-male competition requirements. The same rationale may apply to the fact that male participants are generally more successful than females in tabletop tasks such as the estimation of the orientation of liquid surfaces in tilted containers (Linn & Petersen, 1985; Voyer et al., 1995) which, in addition to geometric Euclidean principles, call for some understanding of gravitational concepts.

The point here is not that a twofold evolutionary process could have systematically acted against an incorrect understanding of physical properties of the material world, nor that Newtonian spatial abilities would have uniquely evolved from the sexual selection of agonistic patterns among male hominids. Rather, it appears likely that it is because certain false physical principles exerted no deleterious influence at the survival or reproduction level that they were not automatically eliminated during evolution. That humans may entertain erroneous physical beliefs, for instance as to relatively more complex concepts than speed, such as acceleration (e.g., Hecht & Bertamini, 2000), does not therefore invalidate the view that some Newtonian spatial abilities could have preferentially evolved from the selection of male-male aggressive capacities. Male competitive settings, along with childhood activities which are more often practiced by boys, such as ball games (Sandberg & Meyer-Bahlburg, 1994), could have enhanced such skills at sexual maturity by building on elementary physical notions of the material world that seem to be acquired early during ontogenesis by both male and female infants. For example, based on the work of some authors (e.g., Baillargeon, 1995), a rudimentary concept of an object's gravity center would apparently begin to develop before the age of one in both sexes.

Interestingly, Goodall (1986) has observed that in young chimpanzees play may involve throwing. She also noticed that adult males, especially, engage in throwing actions that are only infrequently linked to hunting activities. Warren (1976) has made similar reports in gorillas and orangutans, as well as in monkeys such as baboons, as did Essock-Vitale and Seyfarth (1987) in macaques[8]. Hence, it appears reasonable to infer that the spatial abilities associated with throwing may not be solely developed in humans, and to surmise that they may have been inherited from the agonistic behavior of some primate ancestors. In terms of frequency, among adult chimpanzees, males engage more often than females in throwing stones and pieces of wood at congeners, as well as at baboons and even human intruders (Goodall, 1986). The sex of these targets is not specified though. It is of interest to mention here that, in many primate groups, male agonistic displays are especially connected with establishing and maintaining dominance relationships--which generally confer a prioritary access to sexual resources--, and may often take the indirect form of resource competition (Walters & Seyfarth, 1987).

Mental Rotation

Mental rotation could well be an evolved ability. But is it inherited from the sexual selection of aggression-related spatial skills or from that of the spatial capacities that assist navigation? This issue deserves special attention given that, among human spatial abilities, the mental rotation of three-dimensional stimuli in particular reveals a major (Linn & Petersen, 1985; Voyer et al., 1995) and robust (Masters & Sanders, 1993) male superiority. The answer we propose here discusses several considerations

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[8] In laboratory throwing tasks however, no significant sex difference in accuracy has been reported among capuchin monkeys (Westergaard et al., 2000).

that, globally, point towards mental rotation fitting better navigational, rather than agonistic, constraints involving projectiles.

On the one hand, the possibility that mental rotation ability would have evolved among first humans to support male throwing skills has been the focus of some of the first attempts to provide evolutionary explanations of human spatial sex differences. The overall findings appear equivocal though. Among boys aged 14 to 16, Kolakowsky and Malina (1974) have reported a positive relationship between throwing accuracy and mental rotation proficiency in the PMA Spatial Test. By contrast, using the Cube Comparison Test, Jardine and Martin (1983) have replicated this result in female but not in male twins of similar age. The research conducted by Watson and Kimura (1991) has explored the evolutionary foundations of mental rotation in relation to both throwing and intercepting capabilities. In young adults, these authors have nevertheless failed to find significant correlations[9].

On the other hand, there are two sets of indications in favor of the view that mental rotation ability underlies the solving of navigation problems. First, as already mentioned, navigation, and all the more so when performed over large geographical zones, is likely to call for active processing such as the ability to mentally manipulate spatial information in order to evaluate one's position and orientation within the field or to adjust a trajectory for reaching a given point. Mentally rotating two- and three-dimensional elements could play a part in such processing : During navigation, it would be carried out when the particular configuration of environmental features requires, between two different moments, a shift from a given point of view to another one. Speed in completing mental rotation could provide a time advantage in the processing of navigation-related information. This is suggested by the fact that, in both men and women, the higher the mental rotation achievement under timed conditions, the faster the learning of a route from a map (Galea & Kimura, 1993) as well as the mastery of virtual mazes (Moffat et al., 1998). Men's preferential survey strategy when navigating appears particularly well tuned with the adept rotation of salient, large-scale self-referenced spatial data within a general representation of the configuration of a given

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[9] However, this may have been due to a ceiling effect in men, especially in the intercepting task, as well as to the peculiarities of the mental rotation task used. This task asked for quite subtle judgments as to the exact degree of rotation of the stimuli.

environment that takes into account world-referenced data, as when cognitive maps need to be built. This is supported by the correlation, in men only, between mental rotation scores and accuracy in pointing towards invisible places within visualized large-scale environments (Bryant, 1982). Nonetheless, the route strategy more often favored by women should also profit from mental rotation of short-range self-referenced information. Silverman and his collaborators' (Choi & Silverman, 1996; Silverman et al., 2000) data indicate that landmark referencing in wayfinding tasks is positively, though weakly, correlated with mental rotation proficiency in women only.

Second, because evolution would have led male individuals in polygynous species to navigate over generally larger territories than females, one may presume that their reliance on mental rotation could have been more solicited and, hence, subject to a sexual selection that conferred adaptive benefits on them in a reproductive context. To the point, a significant association between mental rotation scores and navigation achievement in virtual mazes has been found in men only (Moffat et al., 1998).

Consequently, there is strong evidence validating the view that mental rotation, at least in humans, may have evolved to mainly support navigation activities. Further research is nevertheless required to more comprehensively evaluate the tenability of such an evolutionary base as opposed to one stemming from male-male aggression with projectiles. With regard to the latter origin, it should be investigated in humans using an assessment known to yield reliable sex differences, such as the Vandenberg and Kuse (1978) three-dimensional Mental Rotations Test. It would also be interesting to explore it in nonhuman primates.

V Sexual Division of Foraging as a Product of The Twofold Selection Process?

A twofold selection process may have paved the way for the evolution of several forms of sexual division in foraging activities, as exemplified in humans and in certain nonhuman primates. Indeed, among the most striking adaptive benefits that seem to be gained from foraging division is the promotion of reproductive success for both sexes, and this appears to be achieved in a way that looks like what we postulate sexual and natural selection, respectively, may have done in male and female individuals from species with polygynous features. As will be illustrated in the present section, there is some evidence that males engaging in hunting more extensively than females may increase their mating opportunities, and that such a male-linked specialization which involves the mastery of several spatial abilities may be amplified by females choosing to bond primarily with better hunters. Similarly, there are several indications that females' main investment in gathering, drawing on matching spatial expertise, may enhance their probability of survival as well as that of their dependent offspring. Overall, this could have some bearing on how spatial cognition and the sex differences it reveals are studied and interpreted, not only in humans but in some nonhuman species as well.

Sexual Versus Natural Selection of High- Versus Low-Risk Strategies

It was pointed out in Section 2 that one of the core principles of sexual selection is that in numerous polygynous species, and this is relevant for most primates, evolution has generally favored in males phenotypic expressions that are beneficial in competing for female mates. Among the various forms such competition can take are males' more extended ranging in search of mating opportunities and their physically agonistic behavior between themselves to attract females (Smuts, 1987). Like in many mammals, in primates these competition forms are generally associated with risks for individuals, principally in terms of predation while ranging and of bodily injuries while fighting with congeneric opponents (Trivers, 1972). Also, as primate males apparently pay high costs when reproductive benefits are similarly high, the male inclination towards dangerous situations would account for the higher mortality rate among male nonhuman primates in comparison to females (Smuts, 1987). It is important to keep in mind that the same disposition appears to characterize male humans (Daly & Wilson, 1983).

At variance with males, females in most species, and especially among mammals, devote a lot to reproduction itself, through gestation and lactation, as well as to the rearing of young even after weaning. For many of these species, one of the means for maximizing the females' own reproductive success has to do with their mate choice. Females may need to discriminate, among prospective male mates, those who can produce healthy, viable offspring and/or provide resources, such as food, shelter, territory, and protection. In so doing, they ensure their offspring a chance of possessing features that confer adaptive advantages for reproduction or survival, and/or of having access to adequate resources to grow. This implies that sexual selection may have favored in females the expression of psychological mechanisms that orient their choosing of a mate, and such a process may have increased the sexual selection of male-linked competitive features. If such features are related to spatial abilities, then the action of sexual selection on females, while not exerted on their own spatial cognition, may have augmented the effect of sexual selection for spatial abilities in males by compelling females to choose among mates, at least in part, on the basis of their spatial processing profile.

As emphasized in Section 3, a second means through which females may maximize their reproductive success is related to their capacities for staying alive in order to favor, in return, the survival of their offspring (Campbell, 1999). Aside from sexual selection, a strong survival concern is likely to have evolved in female individuals within species characterized by a costly female reproductive cycle, such as one involving an internalized gestation system. Campbell (1999) has posited that the female humans' propensity to attach a high value to protecting their own lives would moreover explain why, in comparison to men, they generally opt for low-risk strategies. Supporting such a reasoning are the near universal findings that from childhood (Rohner, 1976) to adulthood (Brown, D. E., 1991), female individuals participate remarkably less frequently than male ones in situations with a potential for physical aggression. Similarly, among primates like macaques, especially in the contexts of challenges to female dominance hierarchies, the preferred female strategies are those that minimize taking physical risks (see Chapais, 1992). First in humans and then in nonhuman primates, we now briefly illustrate the differential levels of risks habitually faced by each sex while foraging.

Data in Humans

Hunting. A number of authors (e.g., Hayden, 1992; Hurtado et al., 1985; Sassaman, 1992; Torrence, 1983) have noted that hunting, and all the more so if directed at big game, is a meat procurement strategy that is customarily linked to risk taking while venturing into distant, unknown territories. Furthermore, due to fluctuation in game availability over seasons and geographical areas, success in big-game hunting is often unpredictable (Hawkes, 2000). Gaulin (1992) as well as Geary (1998) have suggested that if a between-male variance in meat acquisition existed over evolution, then hunting proficiency could have been one of the modes of intermale competition to attract females. According to Hawkes (1990, 1991), in addition to its capacity to meet some nutritional needs, hunting may have been engaged in chiefly by men in order to trade the meat they acquired against mating advantages. Among numerous present-day cultures that are based on the hunting-gathering subsistence mode, men's competence as providers plays a part in male-male competition and is traditionally used as a criterion in women's choice of mates (Betzig, 1997; Geary, 1998). As also emphasized by Hawkes (1990, 1991, 2000), the case where hunting by men is valued by women not so much for the resulting provisioning of the hunter's family as for the ensuing social status is exemplified among Hadza foragers. Although Hadza men generally hunt to provide no more for their family than for the entire group, women still prefer marrying a superior than an inept hunter, given that, by sharing the obtained meat with other group members, the skilled hunter apparently gains a high status that confers upon him the power to settle social conflicts (Hawkes, 2000). As suitably pointed out by Sherry (2000), with its correlated ranging capacity and spatial skills, hunting amounts to a sexually selected display that partakes less of the competitive ranging behavior of male meadow voles than of the display of male birds of paradise. Overall, because of the potential payoffs such an activity can, directly or indirectly, afford with regard to male reproductive success, the carrying out of hunting mostly in the hands of men may essentially have been sexually selected, and amplified by women's mate choice.

Gathering. The fact that women engage in gathering far more regularly than men is also in agreement with the action of natural selection to primarily value their survival and that of their offspring. Indeed, their predominant foraging activity would constitute a strategy which, at least at two levels, may have raised their reproductive success within the ancestral environments of humans in Africa. First, because finding stationary plant sources is more predictable than attaining moving game, gathering, particularly in tropical zones, is a very efficient way to acquire food throughout the year (Lancaster, 1985; Tanner, N. M., 1987; Tooby & DeVore, 1987; Zihlman, 1989). Hence, females who on a regular basis collect plants and fruit, as well as eggs and insects, not only have good probabilities of satisfying their basic nutritional needs during gestation and lactation but may also support children who, though weaned, are still dependent for several years (Tanner, N. M., 1987).

Second, whereas hunting is usually associated with high risks of predation and bodily injuries, mainly due to its being performed during long-distance travels often into unknown territories, gathering food throughout more restricted and familiar surroundings sets up more secure situations that warrant better chances of survival for both females and offspring. Similarly congruent is the finding that, as indicated in Section 2, women capture small- and medium-sized animals, in addition to gathering, among several traditional societies. Given that they usually catch these prey with static implements, such as traps and nets, rather than with nonstatic ones, like clubs, which involve the true pursuit of animals, their strategy entails little physical risk. That women, in some isolated cases, successfully hunt big game does not deny the presumably more adaptive value of female individuals having primarily favored gathering over hunting during human evolution. Under particular socioecological contexts (e.g., Goodman et al., 1985; Hurtado et al., 1985; Kelly, 1995), only a substantial payoff (e.g., avoiding starvation for women and their offspring) that would compensate for eventual important costs incurred (e.g., serious injuries), would make such a subsistence strategy profitable. This may explain why big-game hunting is not more widespread among female humans in contemporary traditional societies.

Data in Nonhuman Primates

The sexual foraging organization exemplified among some monkeys and apes is far more rudimentary than that witnessed among humans. However, analyzing the benefits, in terms of reproductive success, gained from it by males and females respectively provides additional support for the action of a twofold selection process during primate evolution.

Male baboons for instance engage more actively than females in hunting, and they probably reap reproductive advantages in return as they have been observed to frequently share with estrous females the meat they have acquired (Strum, 1987). A parallel trend is patent in chimpanzees. While the diet of these omnivorous apes is composed of various animal species and plants (Boesch & Boesch, 1989; Goodall, 1986; McGrew, 1992), the degree according to which males and females procure particular food items differs (Tanner, N. M., 1987; Zihlman, 1997). Plants, nuts, and fruit, as well as ants, termites and their grubs, are collected by both males and females, and both sexes hunt small animals that they share with congeners. Yet, males are more frequent and active hunters who tackle a wider range of prey than females (Boesch & Boesch, 1989; Stanford, Wallis, Matama, & Goodall, 1994; Uehara et al., 1992). Furthermore, male chimpanzees share with both sexes the meat they acquire more often than females do (Boesch & Boesch, 1984; Goodall, 1986; Teleki, 1973). It is possible then that, as for human males, sharing meat with both sexes may confer male chimpanzees--directly or indirectly[10] (as a function of their rank within the male dominance hierarchy)—with some mating opportunities. Hunting by males may also have been enhanced by females' mate choice.

While adult female chimpanzees occasionally hunt game, they primarily favor plant and insect picking to meet their nutritional needs. By comparison to males, they spend more time fishing for termites (Boesch & Boesch, 1984; Goodall, 1986), for instance. It is also noticeable that their procurement of these nutrients bears some resemblance with the foraging patterns displayed by human females (Geary, 1998). Indeed, female chimpanzees collect ants and termites in fixed, frequently visited

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[10] As recently shown by Mitani and Watts (2001), male chimpanzees' primary motivation for hunting and sharing meat may also reside in strengthening male social bonding within the group hierarchy.

locations (Boesch & Boesch, 1989; Goodall, 1986; McGrew, 1992). In addition, they share these items along with plant food in greater proportion with their own offspring than with nonrelated individuals (McGrew, 1975; Silk, 1978). According to N. M. Tanner (1987), the strong reliance by females on such foraging activities would be associated with satisfying greater nutritional needs during the critical periods of ovulation, pregnancy, and lactation, as well as with rearing weaned but dependent offspring. However, if female nutritional needs were the sole determinant of such a foraging pattern, it may be asked why then do females not invest more in hunting which, compared to the gathering of plants, fruit, and insects, furnishes a higher energetic resource in terms of proteins and fat especially. To the point, the fact that more than males, females use tools to increase the yield of insect collection--animal protein--(McGrew, 1992) and nut cracking--vegetable fat--(Boesch & Boesch, 1984) attests their marked interest for energetic food. Similarly congruent is the finding that they welcome the meat males have acquired. That female chimpanzees do not engage in hunting more extensively could therefore rest on the same dual rationale that we emphasize in the case of female humans. Considering that acquiring meat is unreliable and potentially dangerous, it may be more advantageous for females to opt for a foraging strategy that fits two requirements: the locating of predictable food sources to supply their nutritional needs on a regular basis, on the one hand, and the minimizing of physical risks by avoiding venturing into unfamiliar regions where game would lead them, on the other hand.

Implications for the Foraging Hypothesis

In sum, a disposition in humans and certain nonhuman primates to favor hunting over gathering among male individuals and the reverse among females, may have resulted from a twofold selection process. Hence, three considerations are in order with regard to the evolutionary origins of sex differences in the spatial realm as conceptualized within the foraging hypothesis. First, adoption of hunting mainly by male individuals is likely to have originated, in part, from the sexual selection, in males, of spatial abilities that support long-range navigation as well as, to various extents depending on species, of those that are useful in aggression contexts. Still, the carrying out of gathering predominantly by female individuals may have been inherited from the natural selection, in females, of a type of spatial memory that assists short-range navigation mostly. With regard to humans more particularly, men's preference for using distant cues as well as geometrical and cardinal referents would meet hunting requirements to track game into new, remote territories and to come back home, as mentioned by R. R. Baker (1981). Additionally, males' proficiency in some aggressive displays drawing on Newtonian spatial skills would enable efficient aiming at and attaining of moving prey. On the other hand, the fact that women are inclined to spontaneously pay attention to landmark configurations within a generally well delimited home range, and, in so doing, to primarily encode the relative positions of items, would allow them to cope with the cognitive demands for picking, within rather familiar areas, from stationary food sources the precise locations of which are memorized.

Second, that adult male chimpanzees perform throwing motions exclusively during agonistic displays, and not when hunting, undermines, as pointed out by Geary (1998), the view that throwing skills may ultimately have originated from male hunting activities. Rather, such a finding directly supports the perspective according to which hunting-related spatial skills may have evolved from competitive pressures exerted on males within hominid socioecological environments. Moreover, although there is an obvious adaptiveness to male human hunters demonstrating better throwing expertise and the associated Newtonian spatial skills, the male dodging aptitudes are uniquely valuable in self-defense situations where the individual attempts to ward off objects propelled by an opponent who is adept at throwing. As our purpose is to identify the evolutionary functions of human sex differences in the spatial domain, the latter point is not trivial: The spatial abilities enabling successful dodging fall outside the narrower scope of the foraging hypothesis that strictly presumes a human male spatial specialization oriented towards hunting, whereas they accord well with a sexual selection of male competition in agonistic displays. Both in humans and nonhuman primates then, the category of spatial skills that are related to sex-linked foraging activities may be subsumed under, or may have developed from, those spatial skills that are related to a twofold selection process. The reverse is not true, however.

Finally, as previously mentioned, given that it does not focus on reproductive benefits, the foraging hypothesis is not in a position to predict nor to account for the finding that, more particularly in humans, the magnitude of spatial sex differences is larger after sexual maturity (Voyer et al., 1995). Contrary to this hypothesis, the perspective based on a twofold selection process emphasizes the evolution of male and female adaptive features that are connected with reproductive success. The sexual selection pressure placed on males in polygynous species would have compelled them to attempt multiplying their mating opportunities; in females, natural selection may have favored engaging in behaviors that would have jeopardized neither survival chances nor, consequently, success in fulfilling maternal obligations. During ontogenesis, both male and female features are expected to be in place before or around puberty, but should culminate at sexual maturity. Furthermore, as stressed by Sherry (2000), the fact that performance in spatial tasks where a male advantage occurs declines in women during pregnancy (Woodfield, 1984) and certain phases of the menstrual cycle (Hampson, 1990; Hampson & Kimura, 1988; Komnenich et al., 1978; Silverman & Phillips, 1993; but see Gordon & Lee, 1993) is congruent with an evolutionary process having naturally selected for reduced mobility, as well as the underlying spatial processing profile, that fits fertility constraints during the critical periods of women's reproductive life. Within a twofold selection framework, spatial skills that usually are superior in females, such as object location memory, should be enhanced in female individuals during such periods.

Overall then, it does not seem very probable that, in humans as in some nonhuman primates, sexual division in foraging activities could have constituted the ultimate evolutionary pressure from which male and female spatial processing profiles originated (Geary, 1998). Indeed, if one conceives that hunting and gathering among these species may have grown from sensory, motor, and cognitive aptitudes that, shaped by a twofold selection process, were respectively suited to male and female navigation as well as to male agonistic behaviors, it follows that such a selective process is likely to have been, on the evolutionary time scale, an earlier source of pressure than that of sexual division in foraging with regard to the occurrence of species-specific spatial sex differences.

This does not mean, however, that sexual foraging division may not have exerted its proper though secondary influence on the evolution of spatial cognition in humans, and even in primates. It appears highly plausible in fact that preexisting but crude sex-specific spatial assets, fashioned by a twofold selection process, may have been progressively sharpened, during the evolution of hominoids (i.e., primates including apes and humans), to cope with the selection of a rudimentary form of sexual division in foraging activities like the one exemplified in chimpanzees, on the one hand, and, of a more extended form in humans, on the other hand. In the latter case, entering the cognitive niches of more sophisticated foraging technologies in order to increase the efficiency of gathering and hunting by women and men respectively over our evolutionary past, may have contributed to enlarging the sex differences in spatial abilities in which female and male advantages are respectively found.

VI Future Directions

By way of conclusion, our twofold selection perspective makes possible the formulation of new propositions as to male and female spatial processing profiles in several species. It includes provisions for both humans and nonhuman species in which sexes differ or not either in their foraging strategies or in their propensity to engage in long-range navigation and/or agonistic displays with projectiles. Therefore, given species-specific modalities as to such behaviors, five general predictions may be derived.

1. Spatial Abilities Which Sustain Long-Range Navigation Should be More Strongly Correlated With the Male Than With the Female Navigation Mode

As we have stressed for polygynous species, following mainly on Gaulin and FitzGerald's (1986, 1989) work, spatial skills supporting long-range navigation would have been sexually selected chiefly in males to promote male competition through extensive ranging drawing on the large-scale navigation strategy. With respect to the female side of the twofold selection view, we have argued that females' primary dependence on the small-scale navigation strategy should match their reduced mobility.

Sex-linked navigation strategies have already been evidenced in humans (Dabbs et al., 1998; Montello et al., 1999; Ward et al., 1986), as well as in promiscuous rats (Roof & Stein, 1999; Williams, C. L., et al., 1990; Williams, C. L., & Meck, 1991). Such processing differentiation is noticeable during navigation with male individuals relying primarily on geometric, Euclidean environmental features, and females focusing on landmarks. Hence, the same differentiation should be found in other species in which ranging extent differs according to sex as, for instance, in rodents, like voles (Ribble & Stanley, 1998) or kangaroo rats (Randall, 1991), in monkeys, like lorisids or tarsiers (Bearder, 1987), and in apes, like orangutans (Galdikas, 1988) or chimpanzees (Greenwood, 1980). Additionally, in male individuals, spatial skills that are deemed to underlie long-range navigation namely, wayfinding capacities in large-scale environments and, to some extent, proficiency in mentally rotating two- or three-dimensional stimuli in the field, in dealing with Euclidean dimensions, and in memorizing the absolute locations of critical elements, should be more convincingly associated with the male than with the female navigation mode, home range size or preferred navigation strategy being valid indicators of navigation mode. In animal studies, mental rotation capacity and the level of understanding reached as to geometrical representations during wayfinding tasks could be evaluated through manipulating, in indoor or outdoor settings, left-right or frontward-backward rotations of significant cues, as well as various combinations of geometrical information supplied by spatial referents.

2. Conversely, Spatial Abilities Which Sustain Short-Range Navigation Should be More Strongly Correlated With the Female Than With the Male Navigation Mode

Based on our twofold selection perspective, a female superiority in retrieving the relative positions of stimuli that have been serially encoded within small-scale areas should be manifest in agreement with the presumed dual action of selection, in female individuals, against extensive ranging and for the reliance on small-scale navigation strategies. In humans, it has been shown that women outscore men in recalling nearby landmarks in navigation-related tasks (Galea & Kimura, 1993). We anticipate the same female asset among those rodent and primate species enumerated in the first prediction. We also expect competence in this type of spatial memory to be more markedly associated with the female than the male navigation mode.

3. Newtonian Spatial Abilities Should be More Strongly Related With Throwing and Intercepting Capacities Than With Navigation Mode

We have hypothesized that agonistic activities involving throwing and, to a certain degree, intercepting projectiles are supported by Newtonian spatial abilities that would have evolved primarily among male individuals in first humans. Such abilities would include the capacity to apprehend gravitational concepts, to gauge the trajectory, relative velocity, and impact point of launched objects, as well as to rapidly process dynamic mental images. Hence, especially in men, these skills should be more closely tied to projectile throwing and intercepting capacities than to navigation factors.

Monkeys, like macaques (Essock-Vitale & Seyfarth, 1987) and baboons, as well as apes, like gorillas (Warren, 1976) and chimpanzees (Goodall, 1986), have been found to hurl various projectiles in aggressive displays. In these species therefore, males should be more adept than females at throwing objects at congeners and, possibly, at intercepting thrown ones within experimentally induced agonistic contexts. Manipulating the distance between thrower and target, as well as the launching speed of the objects to block out or to avoid, would provide good indication of the sex-related Newtonian spatial abilities in primates.

4. The Size of Sex Differences in Spatial Abilities Should Increase According to the Degree to Which, in a Particular Species, These Skills Sustain Sex-Linked Foraging Capacities

As pointed out in Section 4, the perspective based on a twofold selection implies that sex differences in navigation-related spatial abilities preexisted the evolution of a sexual division in foraging patterns in humans and some nonhuman primates. This view does not deny, however, that for a given species wherein sexes differ in foraging mode, such a division may have exerted its proper, additive selective pressure on the spatial cognition of males and females, thus enlarging the sex differences in spatial abilities (Geary, 1998). As the amount of sex-differentiation in foraging activities appears to vary depending on species, it may be conceived that the magnitude of sex differences in the abilities that underlie such activities would likewise vary according to species. For instance, in both humans (e.g., Hawkes, 1996; Isaac & Crader, 1981; Murdock & Provost, 1973; O'Connell et al., 1988) and chimpanzees (e.g., Boesch & Boesch, 1984; Goodall, 1986; Teleki, 1973), hunting—along with its associated larger ranging extent—is favored over gathering—along with its associated smaller ranging extent—among male individuals, while the reverse occurs among females. In baboons though, even if males engage more often in hunting than females (Strum, 1987) and should exhibit superior navigation-related spatial skills, there is no indication that females adopt a gathering pattern paralleling the one observed among humans and chimpanzees. Therefore, in keeping with what is found among humans, a female advantage in remembering the relative locations of stationary objects that occur simultaneously (as opposed to serially) within a small-scale area is anticipated only for nonhuman species wherein females engage in human-like gathering activities, as among chimpanzees; the sex difference as to such spatial memory is expected to be larger in both chimpanzees and humans than in baboons.

Similarly, there is a good probability that as humans make use of projectiles when hunting (big game especially) Newtonian spatial abilities support men's hunting aptitudes. However, the corresponding prediction appears untenable in baboons and chimpanzees among which male hunting has not been observed to draw on throwing capacities. It may thus be predicted that sex differences in Newtonian spatial skills, which seem to assist hunting only in our species, should be larger in humans than in both baboons and chimpanzees.

5 As a Corollary, There Should be no Spatial Sex Differences in Species Wherein Evolution Would not Have Selected for Differential Reliance on Spatial Cognition According to Sex.

In species in which there has been no sex-linked pressure for either extensive ranging, agonistic behaviors with projectiles, or division in foraging activities for instance, there should be no sex differences with respect to spatial skills supporting either navigation, projectile throwing and intercepting, or hunting versus gathering. A possibly adequate primate sample could involve gibbons most species of which are monogamous (Jiang, Wang & Wang, 1999). In general, male and female gibbons are indeed equally committed to caring for the young (Leighton, 1987) and carry out the same foraging activities within similarly extended territories (Gaulin, 1992); they have not been observed to throw objects (Leighton, 1987; Warren, 1976).

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Manuscrit 2 :

Spatial Ability and Home Range Size: Examining the Relationship in Western Men and Women

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Spatial Ability and Home Range Size:
Examining the Relationship in Western Men and Women

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Running head: SPATIAL ABILITY AND HOME RANGE SIZE

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Abstract

Gaulin and FitzGerald's (1986) model attributes the presence of sex differences in spatial abilities to evolved sex differences in navigation extent. Based on this viewpoint, we first evaluated whether in 25- to 45-year-old Western humans (N = 216), living and working in a large urban area, home range size would replicate male individuals' more extended navigation relative to females', as observed in traditional human societies and in many polygynous mammals. In addition, we hypothesized that if, in response to extended navigation, more diversified spatial abilities were selected in ancestral men compared to women, this could still be reflected in men's proficiency being correlated with amount of ranging on a larger number of common spatial tasks than in women. Usual and current home range sizes were assessed as well as performance on a series of spatial tasks most of which usually favor men over women. Men's current home ranges were found to be both larger than women's and, as predicted, more often associated with spatial performance. Indeed, in men current ranging extent was positively correlated with achievement in mental rotation, embedded figures, and surface development tests, as well as in a location memory task; contrastingly, in women, it was linked with embedded figures scores exclusively. These results support the existence of a functional, adaptive linkage between sex-related spatial skills and ranging extent in humans. Ontogenetic implications are also briefly discussed.

Spatial Ability and Home Range Size:
Examining the Relationship in Western Men and Women

A male advantage in several tests of spatial ability[1] has been documented extensively in adult humans from Western countries (see the meta-analyses by Linn & Petersen, 1985; by Masters & Sanders, 1993; and by Voyer, Voyer, & Bryden, 1995) and, to some degree, from nonWestern ones (e.g., Klich, 1988; McShane & Berry, 1988; Mann, Sasanuma, Sakuma, & Masaki, 1990), as well as in sexually mature nonhumans (e.g., Dawson, 1972; Joseph, Hess, & Birecree, 1978; Williams, Barnett, & Meck, 1990). The explanatory framework proposed by Gaulin and FitzGerald (1986, 1989) focuses on the evolutionary bases of the involved sex differences. Successfully tested in rodents, it connects a substantial portion of the variance at stake to the sex-related extent of navigation exemplified among many mammals.

An Evolutionary Model Validated in Nonhuman Species

According to Gaulin and FitzGerald (1989), over the course of evolution spatial ability would have been specifically selected in proportion to "the amount of spatial data an animal must process in its normal movement, and home range size is a useful proxy measure for this amount of data" (p. 323). Home range is the area traveled over by an individual in pursuit of its routine activities and, unlike what is found with the monogamous reproduction system, under both promiscuity and most forms of polygyny males usually compete for mating via more extensive ranging than females (Trivers, 1972). A great many studies conducted in a wide range of polygynous mammals, from rodents to nonhuman primates, have indeed demonstrated the prevalence of males' larger home ranges during the reproductive period (e.g., Avenant & Nel, 1998; Bearder,

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[1] Throughout this article, spatial ability assessment refers to settings that involve spatial information chiefly picked up through vision.

1987; Galdikas, 1988, Norbury, Norbury, & Heyward, 1998; Samson & Raymond, 1998).

Gaulin and FitzGerald (1986, 1989) postulated that, in species where home range size is larger in males, a male superiority should be observed in navigation-linked spatial ability; reciprocally, such ability should be equivalent in males and females in species where home range size is equivalent in both sexes. These authors have validated their dual hypothesis by comparing phylogenetically related vole species in terms of ranging extent in field settings as well as of achievement in a spatial laboratory task. In the polygynous meadow voles (Microtus pennsylvanicus), compared to females males exhibited both larger home ranges and higher proficiency in learning radial mazes during the reproductive season; by contrast, neither ranging nor learning sex differences were detected in monogamous pine (M. pinetorum) and prairie (M. ochrogaster) voles. Data collected in a variety of rodents also strongly support Gaulin and FitzGerald's (1986, 1989) model. Indeed, having experimentally induced breeding and nonbreeding periods in deer mice (Peromyscus maniculatus), a polygynous species exhibiting larger home ranges in males, Galea, Kavaliers, Ossenkopp, Innes, and Hargreaves (1994) established, solely in the breeding group, a male advantage in water maze performance[2]. Furthermore, as to brain and neuron anatomy dimensions [3]that appear to be involved in rodent spatial orientation, a larger hippocampus (Jacobs, Gaulin, Sherry, & Hoffman, 1990) and a higher dendritic density in the parietal and prefrontal cortex (Kavaliers, Ossenkopp, Galea, & Kolb, 1998) have been evidenced in males, in comparison to females, among polygynous meadow voles. Similarly, the hippocampus was found to be larger in males than in females among kangaroo rats (Dipodomys merriami and D. spectabilis; Jacobs & Spencer, 1994) and mongolian gerbils (Meriones unguiculatus; Sherry, Galef, & Clark, 1996), all of which breed polygynously and present larger ranges in males.

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[2] Sawrey, Keith, and Backes (1994) have reported no spatial sex differences in water maze performance among polygynous (M. pennsylvanicus, and M. montanus) as well as monogamous (M. ochrogaster) voles. However, as these authors did not specify the reproductive status of the animals, their negative results may have been obtained outside of the breeding period.

[3] In the following brain studies, data were controlled for sex differences in both brain and body size.

Examining the Relationship in Adult Humans

Two main arguments advocate for jointly examining, in adult humans, sex differences in spatial ability and sex-related ranging activities. First, the existence in our species of a set of anatomical, physiological, and behavioral sex differences--common to polygynous but not to monogamous mammals--is highly supportive of a polygynous tendency in modern humans (Daly & Wilson, 1983; Gaulin, 1992) or, at least, of a polygynous reproduction system in some ancestors of Homo sapiens (Rogers & Mukherjee, 1992). For example, such sex differences pertain to female individuals' earlier sexual maturity and higher degree of parental investment, as well as to male individuals' greater stature, higher mortality rates, and more active courtship behaviors (Gaulin & Boster, 1992).

Second, in human fossils from the middle Paleolithic to the present there are several indications of more extended navigation by male than female individuals (Ruff, 1997). In modern-day adults, though data only come from traditional societies, the sex differential mobility is for instance typical of daily ranging of hunter-gatherer Aka from the Central African Republic (Hewlett, van de Koppel, & Cavalli-Sforza, 1986; MacDonald & Hewlett, 1999). A male trend for larger home ranges is also discernible early during the lifespan since it has been observed both in children from nonWestern countries (e.g., Dasen et al., 1985; Munroe & Munroe, 1971) and in North American children and adolescents (e.g., Hart, 1979, 1981; Herman, Heins, & Cohen, 1987; Wohlwill & Heft, 1987).

Objectives of the Study

The present study has two principal objectives. Firstly, it aims at verifying whether men range further than women in a Western, industrial society even though the legacy of evolutionary pressures for sex-specific extent of navigation may be obscured in such a group due to modern lifestyle resulting in comparable occupations as well as traveling requirements and opportunities in both sexes. Should such ranging data parallel those obtained in sexually mature male and female individuals from more traditional human groups and from nonhuman mammals with polygynous features, they would strengthen the tenability of Gaulin and FitzGerald's (1986, 1989) model that accounts for a male superiority in spatial ability among species where home range size is larger in males. Secondly, in an attempt to clarify the potential role played by extent of navigation in adult human spatial cognition, this study is directed at examining, in each sex, the relationship between ranging degree and proficiency on common laboratory spatial tasks. Whereas in animals the male advantage has been investigated and found mainly in maze settings, in humans its magnitude varies substantially across tasks and a female advantage even occurs in a particular one. Accordingly, an appropriate task selection is crucial in testing human participants.

A Polymorph Spatial Advantage in Men

Having detected heterogeneity in the sex effects entered into their meta-analysis, Linn and Petersen (1985) applied a cognitive and psychometric rationale to partition these data into three task categories that were respectively deemed to call for mental rotation, spatial perception, and spatial visualization processes. They then showed that the male superiority emerging during adolescence held only for the two former categories. Enriched by new data and a more systematic incorporation of the age variable, their classification was later confirmed (Voyer et al., 1995); however, after the age of 18[4] men were found to outscore women in all three categories. More precisely, a large effect was manifest in mental rotation tasks where two- or three-dimensional stimuli must, in imagination, be revolved around their central axes. Moderate sex differences were established in spatial perception tasks in which spatial relations have, in spite of distracting elements, to be determined based on geometrical and/or gravitational information. Finally, a small effect was obtained in tasks of spatial visualization that require multistep manipulations of spatial data such as their disembedment from complex figures. According to Linn and Petersen (1985) as well as Voyer et al. (1995), such a variability strongly suggests that human spatial ability encompasses a broad assemblage of somewhat heterogeneous components.

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[4] There were few participants older than 30.

Women's Superiority in Object Location Memory

Against the spectrum of male spatial assets stands an isolated female advantage in recollecting object locations. The latter sex difference was brought to the fore by Silverman and Eals (1992; Eals & Silverman, 1994) who, based on Tooby and DeVore's (1987) perspective, argued that first men would have chiefly engaged in hunting game over generally large, unknown territories, and first women in gathering plant food within mostly restricted, familiar zones. According to these authors, the current female cognitive profile should still reflect spatial requirements in tune with foraging duties that primarily compelled ancestral women to focus on precise configurations formed by stationary elements in the environment such as plants. Silverman and Eals have indeed shown that, compared to men, women generally better remember the locations occupied by various items within limited areas. In some cases, the drawings of several objects, common (e.g., a teapot, a chair) or uncommon (hard to label), were shown on a sheet of paper; in other cases, real objects (e.g., a stapler, a nutcracker) were dispersed within a small room. In all cases, the objects were simultaneously rather than serially presented. Exact replications have reproduced the female superiority (e.g., Barnfield, 1999; James & Kimura, 1997; Montello, Lovelace, Golledge, & Self, 1999; but see Duff & Hampson, in press); in various settings that departed from the original ones though, women's advantage was not systematic (e.g., Crook, Younghjon, & Larrabee, 1990, but see Janowski, Chavez, Zamboni, & Orwoll, 1998; for a brief review, see Ecuyer-Dab & Robert, 2001). As suggested by Barnfield (1999), Silverman and Eals' tasks (1992; Eals & Silverman, 1994) may, at variance with other spatial memory settings, be solved through encoding the position of an object in relation to that of its neighbors, instead of by its sole, absolute position. When only absolute spatial memory is involved, men excel (Barnfield, 1999; Postma, Izendoorn, & De Haan, 1998; Postma, Winkel, Tuiten, & van Honk, 1999; Vecchi & Girelli, 1998).

Overall, the differential magnitude of men's advantage in mental rotation, spatial perception, and spatial visualization tasks, as well as women's generally better memory for object location attests to the complexity of the issue of spatial sex differences in adult humans and, hence, of that of examining their potential adaptive value from a functional angle coupling them with sex differences in navigation extent.

Designing the Present Study

A possible way for coping with this difficulty lies in attempting to validate an expansion of Gaulin and FitzGerald's (1986) hypothesis. If evolution has shaped men's and women's spatial ability primarily in proportion to the amount of spatial information to process within their respective home ranges, then it could have selected, according to sex, not so much for the capacity to apply the same processing to a larger or smaller amount of spatial data depending on navigation scale, as for the propensity to draw on a wider or narrower collection of distinct spatial processes.

Spatial Processing in Small- Versus Large-Scale Navigation[5]

As emphasized elsewhere (Ecuyer-Dab & Robert, 2001), chiefly relying on the processing of concrete, untransformed spatial data as, for instance, the locations of environmental elements that mark out a given itinerary, could have only been workable when navigating within restricted home ranges that is, on a rather small scale. In extended home ranges however, exclusive consideration of this profuse serial data is likely to have made navigation unreliable (James & Kimura, 1997), due to the heavy memory load. Instead, navigation on a large scale may have called for the need to efficiently process an abundance of spatial information via the command of several abilities. To enable the regular update of one's changing position while moving throughout a vast territory, the selective extraction of spatial data from the environment and their processing mainly in a rather abstract spatial form, such as that of geometric or symbolic coordinates, probably demands a variety of mental operations. Under the constraints set by their large home ranges, ancestral men could have been driven to more

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[5] Throughout this article, we deem equivalent expressions such as small- and large-scale navigation or short and long ranging to designate traveling performed over smaller and larger areas. However, these expressions are not given any absolute meaning as to the home range size involved.

often exploit spatial processes that, even if solicited to some degree during small-scale navigation, would have been more diversified than those usually employed by women.

Hence, if small-scale navigation was primarily performed by ancestral women, it could have selected in particular for women's capacity to encode, store, and retrieve spatial data virtually under the exact format according to which they are encountered within the environment, one dimension of which is the precise locations of serial elements that serve as landmarks. Many a study has in fact revealed the more pronounced inclination in women, compared to men, for predominantly relying on landmarks in navigation-related tasks (e.g., Choi & Silverman, 1996; Dabbs, Chang, Strong, & Milun, 1998; Galea & Kimura, 1993; Miller & Santoni, 1986; Montello et al., 1999; Ward, Newcombe, & Overton, 1986).

In turn, an evolutionary pressure for large-scale navigation generally exerted on men could have mainly favored their ability not only to selectively attend to some environmental data, such as particularly meaningful highlights including salient landmark locations, but also to mentally transform these data and to integrate the transformations into geometric or symbolic spatial representations. In navigation-related tasks, men have been found, more often than women, to rely both on geometrical information derived from environmental cues, such as crucial angular distances (Galea & Kimura, 1993), and on symbolic references, like cardinal coordinates (Dabbs et al., 1998; Montello et al., 1999; Ward et al., 1986)[6].

Sex-Specific Predictions

It is then a matter of examining whether traces of this sex-specific evolutionary scenario are observable in relationships between present-day navigation extent and a variety of spatial skills such as those at work in mental rotation, spatial perception or spatial visualization tasks, as well as in Silverman and Eals' (1992; Eals & Silverman, 1994) object location memory task. It may be that, in spite of orientation aids such as street or road signaling, the magnitude of navigation activities—as evaluated by home range size—in current men and women from a Western society still rests on a sex-

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[6] Nevertheless, women do indicate accurate cardinal directions when prompted (Ward et al., 1986) or tested in rather small-scale naturalistic contexts (Silverman et al., 2000).

related dominance of particular spatial processes. If our general hypothesis derived from Gaulin and FitzGerald's (1986, 1989) work holds, the association between ranging extent and proficiency in several laboratory tasks should be more convincing in men than in women. Overall, it should also bear out mostly in distinct tasks according to sex, even though some overlap may be presumed in the spatial processes at play during men's and women's navigation.

Mental rotation, spatial perception, and spatial visualization tasks. Specifically, ranging measures should be more systematically and strongly associated with men's than with women's scores in tasks that generally favor men over 18 (Voyer et al., 1995) that is, mental rotation, spatial perception, and spatial visualization tasks. Only in men has rotation skill indeed been found to correlate with correctly pointing towards targets within mentally pictured large-scale areas (Bryant, 1982). However, the correlation may also occur in women as well since it has been shown, in both sexes, that the higher the mental rotation performance, the faster the learning of a route from a map (Galea & Kimura, 1993) and the mastery of a virtual maze (Moffat, Hampson, & Hatzipantelis, 1998).

There is only one indirect analogous indication with regard to each of the spatial perception and spatial visualization task categories. In both sexes, proficiency in the water-level test that is, in a spatial perception task (Linn & Petersen, 1985; Voyer et al., 1995), has been shown to be correlated with the self-reporting of orientation strategies that focus on distances and cardinal points but not on landmarks (Lawton, 1994). Although some equivalence might thus be observed in the correlation patterns established in each sex, we should find stronger connections in men between home range size and achievement in spatial perception tasks involving Euclidean geometric information. A similar prediction is made for spatial visualization tasks that require the application of several mental operations to spatial data, such as the recognition and extraction of target forms from more complex figures, as well as the processing, either parallel or serial, of both two- and three-dimensional spatial information. To the point is the finding that, in men only, competence in a surface development task that is, in a spatial visualization task (Linn & Petersen, 1985; Voyer et al., 1995), was correlated with accuracy in recalling spatial information mentioned in a geographical description even though men and women attained comparable performances in both tasks (Gilmartin, 1986).

Object location memory task. Usually superior in women, the ability to memorize the relative locations of objects probably requires some of the processing responsible for women's better encoding of serial landmark locations (see Ecuyer-Dab & Robert, 2001). Over evolution, such encoding could have been preferentially selected in women on the basis of its reliability for navigating mainly within small areas. Present-day women may thus reveal such a heritage by spontaneously activating this type of spatial memory when traveling through their home ranges. However, one may reasonably presume that even if, like women in traditional societies, Western women range less extensively than men, they are nonetheless likely, due to modern day demands and opportunities, to range further than early women. This broader female navigation may not benefit from a taxing, detailed encoding of object locations relative to one another. Hence, among women proficiency in Silverman and Eals' (1992) task may not covary with home range size. However, considering that in long-range navigation men may encode the sites of particularly salient landmarks in terms of absolute rather than relative positions, their location memory scores, although poorer than women's, could correlate weakly, but positively, with ranging extent.

Method

Study Area

The study took place in Montréal, at that time a city of approximately 1 million residents, situated in the Province of Québec, in Eastern Canada. Located north of the 45th parallel and occupying 36% of the surface of the Island of Montréal which extends 48 km long and 16 km wide, the territory of Montréal then covered 176.73 km^2 (CANSIM, 2000). In terms of population, Montréal and its suburban municipalities represented the largest agglomeration in Québec and the second largest in Canada (Statistics Canada, 1996). From an economic standpoint, the Montréal area forms an industrialized and developed urban center: Among Canadian cities, Montréal ranked second for trade and commerce volume, and third for employment in the manufacturing sector (CANSIM, 2000).

Participants

The important climatic variations between winter and summer that usually prevail in Montréal may affect the ranging patterns of its residents. Indeed, winter frequently constrains traveling, whereas summer is the customary season for vacationing. As a result, the invitation to participate in the study was made in spring (May and June), and then repeated the following fall (October and November). It indicated that Montréalers' traveling habits were to be examined in relation to their thought processes. The invitation was extended in local newspapers (in the classified advertisement section), on an internet site, on a university community radio station, and through leaflets (dropped into the mailboxes of a number of residents from different Montréal neighborhoods, and also distributed by students from the Université de Montréal to their relatives and friends). Over a five-week period at the beginning of both the spring and fall recruitment, a total of 651 prospective participants had left their phone numbers on a voice mail. To enable valid comparisons of home range size between individuals of each sex who were sexually mature while controlling for cultural and geographical homogeneity, selection was restricted to 25- to 45-year-old men and women, who had French as their mother tongue, were born in the Province of Québec from parents also born in Québec, grew up in Québec, and currently both lived and worked in Montréal. Only individuals who were part of the work force were considered[7]. Of the recruited volunteers, 216 (33.2%) met all of these criteria. Confidential screening was performed over the phone by student assistants who were unaware of the research purposes.

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[7] We exclusively recruited employed individuals because ranging variations might be related to differences, which are difficult to assess accurately, in the socio-occupational profiles of persons not gainfully employed (profiles such as being a student, an unemployed person looking for a job more or less actively or not at all, or a full-time caregiver at home).

Consisting of 121 women and 95 men, this unpaid sample participated, during either spring or fall, in the initial session assessing spatial performances and usual home ranges (see definition in the "Home Range Measures" subsection). Table 1 reports relevant demographic information (obtained from answers to a questionnaire) concerning these participants. Using t or chi-square tests, men and women were not found to be significantly different ($p > .05$) on any of the investigated variables except education, χ^2 (4, N = 216) = 13.71, $p < .05$. On average both men and women were 34 years old. The majority of them were single and had an annual income that varied between $10,000 (Canadian dollars) and $44, 000. However, more men (22%) than women (7%) had only a high school diploma, χ^2 (1, N = 216) = 10.99, $p < .05$, whereas more women (50%) than men (36%) had completed a bachelor's degree, χ^2 (1, N = 216) = 4.12, $p < .05$.

One week after the initial (spring or fall) session, a total of 70 women and 58 men of the original sample took part in a complementary (spring or fall) session devoted to the recording of current home ranges (see definition in the "Home Range Measures" subsection). Table 1 shows that, like the participants in the initial session, these women and men were similar on all demographic variables save education, χ^2 (4, N = 128) = 9.63, $p < .05$. On average women were 34 years old, and men 35 years old. A majority of participants were single and their annual income varied between $10,000 and $44,000. More men (22%) than women (6%) had only a high school diploma, χ^2 (4, N = 128) = 7.68, $p < .05$. As the persons who participated in this further session did not differ significantly from those who withdrew after the initial session (N = 88) with respect to age, t (214) = .71, marital status, χ^2 (2, N = 216) = 1.34, education, χ^2 (4, N = 216) = 2.83, and annual income, χ^2 (3, N = 216) = 1.58, there was no evidence of attrition or self-selection effects on these major variables.

Among these 128 participants, the 30 women and 28 men who took part in the complementary fall session additionally recorded their current, personal home ranges (see definition in the "Home Range Measures" subsection). As shown in Table 1, women were equivalent to men on all demographic variables. On average men and women were 36 and 35 years old, respectively. They were primarily celibate with bachelor degrees; annual income varied between $10,000 and $44,000. In terms of age,

$\underline{t}$ (128) = 1.26, marital status, χ^2 (2, $\underline{N}$ = 128) = .40, education, χ^2 (4, $\underline{N}$ = 128) = 5.68, and annual income, χ^2 (3, $\underline{N}$ = 128) = 5.36, the fall participants did not significantly differ from the spring ones.

Table 1
Demographic Data for Men and Women Enrolled in Each Session

Variable		Initial session		Complementary spring and fall sessions combined		Complementary fall session	
		Men	Women	Men	Women	Men	Women
Average age (years)	$\underline{M}$	34.3	34.2	35.2	33.9	35.7	34.8
	$\underline{SD}$	6.2	6.1	6.2	6.3	5.1	5.2
Marital status (%)							
Single		61.5	62.7	62.1	58.6	53.6	60.0
Married		28.4	27.1	27.6	31.4	35.7	30.0
Divorced or widowed		10.1	10.2	10.3	10.0	10.7	10.0
Highest diploma (%)							
Primary school		3.2	0.8	0.0	1.4	0.0	3.3
High school		22.1*	6.6	22.4*	5.7	25.0	10.0
Technical school		24.2	28.1	24.2	33.0	25.0	26.7
Bachelor		35.8*	49.6	36.2	47.1	39.3	53.3
Master		14.7	14.9	17.2	12.8	10.7	6.7
Annual income (%)							
Less than $10,000		16.8	9.8	19.0	8.6	7.1	10.0
$10,000 to $24,000		40.0	44.3	36.2	47.1	32.1	40.0
$25,000 to $44,000		33.7	36.1	36.2	37.1	50.0	36.7
More than 45,000$		9.5	9.8	8.6	7.2	10.8	13.3

* $\underline{p} \leq .05$.

Procedure and Measures

Lasting approximately one hour, the initial session was held at the Université de Montréal, in mixed-sex groups of 3 to 15 persons. The participants completed a series of spatial tasks, answered a questionnaire designed to collect usual home range data, and, finally, filled in another questionnaire on demographic factors as well as mobility indicators complementing ranging information. Before leaving, each individual was invited to participate in the complementary session that involved recording information related to his or her current home range over the following week. The consenting persons were given a diary booklet (in a stamped envelope) to write down these ranging data. They were told that in case they had queries as to how to fill in the booklet, they would receive a telephone call during the coming week. The participants were also informed that the booklet had to be returned to the authors no later than two weeks after recording completion, and that if they did not do so they would receive a reminder call. Scoring of all booklet and questionnaire information as well as spatial performances was conducted by six psychology undergraduates. These scorers were blind to both the participants' sex and the predictions being tested.

Spatial Measures

Mental rotation task. The redrawn version of Vandenberg and Kuse's Mental Rotations Test (Peters et al., 1995) was selected because, among several mental rotation measurements, this test leads to the largest male superiority (Linn & Petersen, 1985; Voyer et al., 1995). For each of the 24 problems, the participants had to find, among a series of four, the two three-dimensional stimuli that were identical, albeit shown in different orientations, to a target stimulus. Six minutes were allowed to complete the problems, and the participants were instructed that they would receive one point per problem if they had both correct answers but would not loose points for incorrect answers or incomplete problems.

Water-level task. Among the tasks calling for spatial perception processes, the water-level task systematically favors men over women (Linn & Petersen, 1985; Voyer et al., 1995). As it can be group administered, it was preferred to the Rod-and-Frame Test. It comprised eight problems presented in a booklet. On the first page, a bottle (rectangular container with lid) was illustrated upright and about half full of water. On the following pages, it was empty and the angles of tilt were sequenced (one per page) as follows: 120°, 150°, 60°, 160°, 135°, 30°, 45°, and 90° (0° corresponded to the horizontal on the right hand side). Unlimited time was allowed to draw a line representing water in the empty bottles (this did not generally exceed 6 minutes). Performance was defined as the mean angle of deviation from the horizontal over all eight problems.

Spatial visualization tasks. Because the tasks subsumed under the category of spatial visualization are quite diversified that is, respectively emphasize mostly distinct mental processes (Linn & Petersen, 1985; Voyer et al., 1995), we opted for including two spatial visualization tasks that respectively solicit recognition and manipulation processes according to Eliot and Smith's (1983) classification. On the one hand, we used the Group Embedded Figures Test (GEFT; Oltman, Raskin, & Witkin, 1971) given our assumption of a male advantage in identifying spatial information inserted in a larger set during navigation-related activities. On the other hand, employing the Surface Development Test (SDT; Ekstrom, French, & Harman, 1976) allowed the verification of whether the capacity to operate imaginary movements on two- and three-dimensional configurations could have been favored among men in relation to their navigating. However, to prevent fatigue from overlong testing, the GEFT and SDT tasks were alternately presented. About half of the men (n = 52) and women (n = 58) performed only the GEFT. After a brief familiarization, they opened a booklet and were requested to find simple shapes hidden within complex figures (two per page). Five minutes were allowed, and the number of correctly identified shapes (out of nine) was recorded. The remaining participants were only presented with the SDT. For each of six problems, 6 minutes were allowed to discover how a series of two-dimensional, unfolded shapes should be folded in order to correspond to three-dimensional target shapes. The total correct score (maximum: 30) was obtained using the criteria defined by the authors of the test.

Location memory task. Silverman and Eals' (1992) recognition task was used to assess location memory. Illustrated on a sheet of paper, a stimulus array of 27 common objects (e.g., umbrella, chair, teapot) was presented to the participants. Incidental learning was involved as the instructions simply asked to examine the objects for one minute. Having turned over the array, the participants were next shown a second, identical array, except that seven objects had exchanged their locations with seven others. One minute was allowed to put a cross through these objects, and to circle those that had not moved with respect to the first array. One point was given for each correct answer.

According to one of 12 random orders, each participant completed four of the five previously described tasks.

Home Range Measures

To provide a comprehensive evaluation of ranging extent according to sex, home ranges were appraised using two kinds of indicators. On the one hand, as they encompassed the bulk of regular navigational activities, the indicators of usual home range were assumed to be representative of the territory typically covered by each participant in the initial session. The involved behaviors were chiefly of a personal nature (e.g., visiting friends and relatives, shopping, or engaging in leisure activities), though traveling to and from the place of work was also included. On the other hand, the data related to current home range among the participants in the complementary sessions allowed a more refined assessment of ranging. Indeed, over a one-week period during either spring or fall, for distinct periods of the week (i.e., from Monday to Friday, or over the weekend), the systematically recorded information indicated all of the participants' travelings as they occurred, irrespective of their professional or personal nature. However, all the comings and goings that were exclusively of a personal nature were additionally examined among the participants enrolled in the fall complementary session. Overall, the ranging data collected across all three sessions were deemed reliable given the low level of inference on the participants' part that results when self-recording deals with everyday behaviors—such as usual or current travelings—as opposed to latent traits or hypothetical constructs (Jackson, 1999).

Usual home ranges. The usual home range measures were based on information drawn from a questionnaire in which the participants had to indicate their customary destinations. Thus, in addition to their residence and work addresses, the participants had to list the places where they habitually went shopping or spent leisure time (i.e., favorite restaurants, public parks, sport and cultural centers, etc.) and the location of the homes of the relatives or friends whom they regularly visited. They were also requested to supply the frequency (i.e., at least once a week, once every two weeks, or once a month) at which they ordinarily visited each place. Only when these places were located in Montréal or its suburban municipalities did the participants have to specify the street and cross street corresponding to each site; otherwise they solely indicated the town or village in which or close to which each destination was located.

Four operations were necessary prior to computing the size of usual home ranges. First, each involved location was codified according to its nature (i.e., participant's home, work place, shopping places, relatives' residences, etc.). The frequencies according to which each place was reported to be visited were also ranked in order to establish the places respectively visited weekly, bimonthly, or monthly. Second, using a detailed map of Montréal and its suburban municipalities (Perly, 1996), the street and the cross street of each location were translated into complete addresses, including door numbers, street names, and directions (i.e., West or East). These addresses, along with the names of the municipalities outside of the Montréal area, were then entered on one of three Excel files according to their associated weekly, bimonthly, or monthly visiting frequencies. Third, each file was fed into the Canada Postal Code Directory (1996) program to form a second file composed of corresponding postal codes. This permitted to geocode the locations to within one postal code either per block in the urban and suburban Montréal area, or per municipality outside of this area. Fourth, these codes were scanned by the MapInfo (1996) cartographic application program that geographically positioned them by attributing longitudinal and latitudinal coordinates from its data bases including all geocoded postal codes in the Province of Québec. The corresponding information for the municipalities located outside of Québec was obtained from topographic maps of regions that are adjacent to Québec in Eastern and Central Canada as well as in Northeastern United States. These coordinates were converted into kilometric coordinates by the MapInfo software using the Universal Transverse Mercator and an ellipsoid axis of reference based on the North American Datum (1927: see MapInfo, 1996).

Based on the weekly geocoded locations, the minimum-convex-polygon algorithm program (McPAAL; Stüwe & Blohowiak, 1985) was used to compute a weekly measure of usual home range size for each participant. Likewise, the bimonthly and monthly data files provided the corresponding home range sizes. The latter two measures were deemed crucial as Gaulin and Fitzgerald (1989) have argued that whereas an individual might range over a small area during any given period of time, the total home range over longer intervals might nonetheless be fairly large in cases where different areas have been visited during each period.

Current home ranges. The current home range measures were computed from the data recorded in the diary booklets (21.5 cm x 28 cm) completed over the week following the initial session, during the spring or fall complementary sessions. On the first page of the diary, instructions asked the participants to specify their home postal code and, as the week went by, to indicate (on following pages) each place they would visit on each day, including the weekend. This meant specifying for each place the complete address (i.e., door number, street name and cardinal direction, and municipality) or, at least, the street and cross street and municipality. To make the recording process easier and more reliable, the participants were supplied with a pocket-sized (7 cm x 10 cm) notebook in which to enter, on the spot, the information corresponding to each of their travels, whether of a personal or a professional nature. Every evening, the participants transcribed in their diaries all they had written in their notebooks during the day.

The last three preliminary operations described above with respect to the geocoding of usual comings and goings were similarly performed to translate the current home range data into complete addresses, postal codes, and longitudinal and latitudinal coordinates. Seven Excel files, one per day of the week, were then prepared. The mean daily range was derived from the seven daily ranges calculated by applying McPAAL to the respective cartographic data for each day of the week. Gaulin and FitzGerald's (1989) reasoning as to total home range was also relevant in defining the weekly current home range size. The Monday-to-Friday and weekend home ranges were additionally selected given that, among the labor force in most Western societies, generally these two periods of the week do not exactly involve similar kinds of activities: From Monday to Friday, professional and personal concerns customarily overlap, whereas the weekend is principally devoted to personal occupations. Thus, the algorithm was applied to the positional data concerning the entire week and, subsequently, to those concerning the five work days and the weekends, respectively[8].

Current personal home ranges. Among the participants in the fall complementary session exclusively, the current personal home range measures were additionally obtained in the just described fashion except for the following changes. A blue and a red ball-point pen were provided with the diary and notebook. The participants were instructed to indicate the places they would visit for personal (e.g., for shopping, or meeting relatives or friends) and professional (i.e., to perform their occupational activities) purposes using the blue and the red pen, respectively. Only the diary entries in blue were used to establish the current personal home range sizes[9]. Since the weekend measure of current home range already focused on a time frame generally devoted to travelings of a personal nature, only the daily and weekly personal current home range sizes were calculated.

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[8] Most participants worked from Monday to Friday. However, for a small number of them (less than 3%), either Saturday or Sunday was a work day, whereas one week day was a day off. In these cases, the instructions to fill in the diary asked to treat the former day as any other work day and the latter as a weekend day.

[9] For these fall participants, information on current home range consisted of all diary entries independent of ink color.

Mobility Indicators

For each sex and session, Table 2 reports the data concerning the various mobility indicators. Chi-square tests were computed to check for sex differences in having a part- or full-time job, as well as in job mobility requirements and in car or public transportation use. Across sessions, between 60% and 72% of men and women were found to be part-time workers. Using the REPERE (1985) system, the participants' occupational activities were classified on a mobility scale ranging from 1 to 3. Score 1 was associated with activities involving no particular mobility, such as clerical occupations, nursing, and retail selling; score 2 concerned low or occasional mobility, as in artistic occupations (e.g., dancing, music playing) and construction jobs (e.g, building, plumbing); and score 3 entailed high mobility, as in the case of transport related activities and commercial traveling. Across sessions, men and women were comparably represented in each of the three occupational categories, most of them with jobs requiring only low mobility or none at all. They were also similar as to their customary use of a car versus public transportation. Among the participants who completed the initial session, 57% reported the use of a car even if only during the weekend, and 46% used public transportation more than three times a week. About the same proportions were found among those who took part in both complementary sessions.

The MapInfo (1996) cartographic application program was used to compute three urban distance indicators (in km), namely the distances between downtown Montréal and each participant's residence and work place, as well as the distance between the latter two locations. Table 2 shows the corresponding average distances according to sex. Based on *t* tests within each session, men and women were found to be similar on each of the three distances.

Finally, because children's and adolescents' ranging patterns may vary as a function of the urban versus rural characteristics of their environment (e.g., Anderson & Tindall, 1972; Berg & Medrich, 1980; Hart, 1979, 1981; Moore & Young, 1978; Poag, Goodnight, & Cohen, 1985), the participants were asked to indicate where they had lived in Québec during their childhood and adolescence. Since the participants' ages

Table 2
Mobility Indicators for Men and Women Enrolled in Each Session

		Initial session		Complementary sessions combined		Complementary fall session	
Variable		Men	Women	Men	Women	Men	Women
Part- or full-time job (%)							
Part-time		71.7	64.9	65.5	62.9	71.4	60.0
Full-time		28.3	35.1	34.5	37.1	28.6	40.0
Job category (%)							
No mobility		45.3	54.9	36.2	54.3	32.2	43.3
Low mobility		40.0	36.9	48.3	34.3	57.1	46.7
High mobility		14.7	8.2	15.5	11.4	10.7	10.0
Use of car (%)							
Each day		27.6	23.7	25.8	18.6	25.0	20.7
Weekend only		31.0	31.6	24.3	34.3	37.5	41.4
Occasional or nil		41.4	44.7	49.9	47.1	37.5	37.9
Weekly frequency of public transportation use (%)							
Less than three times		54.7	54.1	51.7	52.9	46.4	59.8
Three to eight times		21.1	26.7	25.9	32.2	28.6	19.9
More than eight times		24.2	19.2	22.4	14.9	25.0	19.3
Average urban distances (km)							
Residence to downtown	M	6.2	5.4	6.7	5.6	6.7	6.1
	SD	8.6	4.1	10.8	4.8	3.7	3.9
Residence to work	M	5.8	4.0	6.8	4.0	5.7	4.7
	SD	9.7	4.0	9.1	3.9	4.5	5.2
Downtown to work	M	5.0	4.3	5.2	4.2	4.8	4.4
	SD	4.7	3.1	5.4	3.0	3.5	2.1
Early environment type (%)							
Urban		26.3	34.2	29.3	28.6	39.3	40.0
Suburban		34.7	37.5	36.2	40.4	32.1	30.0
Rural		20.0	17.4	22.4	20.0	21.4	23.3
Mixed		19.0	10.9	12.1	11.0	7.2	6.7

ranged between 25 to 45, lists of villages, towns, and cities within the Province of Québec from 1960 to 1986 (Bureau de la statistique du Québec, 1960, 1965, 1970, 1976, 1981, 1986) were used to identify the exact sites and population densities, at those periods corresponding to the participants' childhoods, of all self-declared places. The agglomerations with over 150 000 residents and the surrounding areas were categorized as urban and suburban zones, respectively. The remaining locations which had less than 20 000 residents were considered to be rural areas, whereas those involving between 20 000 and 150 000 were also classified as urban environments. Next, the childhood environments, which generally included more than one location for each participant, were ordered on a scale: 0 = exclusively urban, 1 = urban and suburban, 2 = exclusively suburban, 5 = rural and either urban or suburban, 11 = exclusively rural. This procedure was replicated for the environments related to the participants' adolescence. Finally, the overall environment was obtained for each participant by adding the childhood and adolescence scores; the lower the figure the more urban the environment. Using separate chi-square tests within each session, it appeared that, across sessions, men and women were comparably distributed throughout the various types of early environment. Table 2 shows that most participants had an urban or suburban origin.

Results

For all statistical analyses, the .05 alpha level was adopted.

Preliminary Analyses

Considering that some of the participants' characteristics other than sex might account for part of the variance in the recorded spatial scores and home range sizes, the associations between these characteristics and the dependent variables were first examined. It was found that whereas education level was not significantly associated with any variable, age was inversely related with scores in the location memory, Pearson r (216) = -.14, embedded figures, r (110) = -.17, and surface development, r (106) = -.22, tasks. In addition, whereas, surprisingly, type and amount of occupational activities as well as type of early environment were not significantly related to any variable, marital status was correlated with daily, η (128) = .16, and weekly, η (128) = .21, current home ranges, indicating that single, divorced, or widowed participants of both sexes ranged further than married ones. Expectedly, frequency of car use was positively linked with each of the usual, current, and current personal home range measures, η ranging from .17 to .41. Finally, each of these latter ranging measures was positively associated with each urban distance indicator, r ranging from .20 to .38.

A three-way multivariate analysis of variance (MANOVA) was conducted on each of the usual, current, and current personal home range data sets to detect possible interactions between sex and the two other categorical factors that were related to home range size that is, marital status (married vs. single/divorced or widowed) and car use (each day vs. weekend/occasional or nil). None of the three MANOVAs yielded any interaction involving the sex factor that approached significance. Accordingly, the marital status and car use characteristics were left out of all subsequent analyses.

Spatial Performance

Table 3 presents the means and standard deviations of the scores obtained on each spatial task by men and women[10]. Two one-way analyses of variance (ANOVA) evaluated whether men outscored women in the mental rotation and water-level tests, respectively. The male advantage was found in the mental rotation task, F(1, 214) = 35.67, sex accounting for 14% ($\eta^2 = .14$) of the variance. Similarly, men made smaller errors than women in the water-level task, F(1, 214) = 31.48, with 13% of the variance being accounted for by sex.

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[10] Given that, in keeping with many reports using the water-level test (see Thomas & Lohaus, 1993), scores on this task revealed a marked departure from normality in addition to nonhomogeneous variances across men and women groups, they were transformed using the reciprocal of the square plus 1. However, as the outcomes of the analysis performed on such transformed scores were essentially equivalent to those involving the raw data, only the product of the latter analysis was presented here.

Two separate one-way analyses of covariance (ANCOVAs) verified whether men outperformed women on each of the embedded figures and surface development tasks. Age was used as a covariate due to its being correlated with scores in each task. In both cases, the homogeneity-of-slopes requirement was met since the relationship between age and each dependent variable did not differ significantly as a function of sex. Men surpassed women in each of the embedded figures, F(2, 108) = 4.40, and surface development, F(2, 104) = 4.60, tasks. With age held constant, sex accounted respectively for 4% and 3% of the variance in each task.

Table 3

Mean Scores and Standard Deviations Obtained by Men and Women on Each Spatial Task

	Men		Women	
Task	M	SD	M	SD
Mental rotation	8.53	4.36	5.51	3.05
Water-level	4.10	5.11	14.50	17.47
Embedded figures	5.48	2.53	4.55	2.62
Surface development	14.50	8.62	11.47	8.44
Location memory	16.35	5.19	17.95	5.04

Finally, an ANOVA examined whether women achieved higher scores than men in the location memory task. Because of its correlation with these scores, age was included as a covariate in the ANCOVA. The regression slopes did not significantly differ according to sex. However, given that the only impact of entering the age covariate was to slightly increase the sex effect size, the outcome of the analysis that did not include the age covariate was reported here. Compared to men, women remembered more object locations, F(1, 214) = 5.18, with sex accounting for 2% of the variance.

In sum, as expected we found a male advantage in mental rotation, water-level, embedded figures, and surface development tasks, as well as a female superiority in the memory of object locations.

Home Range Sizes

Table 4 reports the means and standard deviations of the raw sizes of each of the usual, current, and current personal home ranges according to sex. Because in each sex the distribution of these data, along with that of the three urban distance indicators, was positively skewed to a high degree, a log transformation was applied to reduce the occurrence of extreme values and, therefore, to identify true outliers (Marsh, 1988; Stevens, 1996). Inspection of the normalized data revealed that one man and one woman still had extremely large (more than 3 SDs above the mean for their sex) usual home ranges. The same was observed in both the current and current personal ranges of one woman, as well as in one man's and two women's current ranges. Adopting the procedure recommended by several authors (e.g., Allison, Gorman, & Primavera, 1993; Stevens, 1996), these participants' range sizes were removed from the involved data sets to conduct the here presented analyses of variance, but the results obtained in the full samples were also reported (in parentheses).

To test the hypothesis that men would have larger home ranges than women, we carried out three one-way MANOVAs, one per set of data. Because each urban distance indicator was correlated with each ranging measure, we initially included the residence-to-work distance as a covariate. This decision was based on the fact that, in selecting covariates for multivariate analyses, it was important to take into account the degree of intercorrelation between all potential covariates (Stevens, 1996). Accordingly, since both the downtown-to-residence and downtown-to-work distances were associated with the residence-to-work distance, r (214) = .41 and .32, respectively, but, overall, were less strongly connected with each ranging variable than was the residence-to-work variable, only the latter distance was entered as covariate in the three analyses. In each case, no significant Covariate x Sex interaction was found. However, given that the covariate did not substantially alter the results, only the outcomes of the analyses that did not adjust ranging data for the residence-to-work distance were reported.

Table 4

Mean Size (km^2) and Standard Deviations Obtained in Men and Women for Each Type of Home Range Measure

	Men		Women	
Home range measure	M	SD	M	SD
Usual				
Weekly	48.07	119.41	27.68	62.12
Bimonthly	132.36	308.26	72.60	158.95
Monthly	188.64	394.84	113.31	257.84
Current				
Daily	29.03	48.82	18.56	38.83
Monday to Friday	27.18	57.84	16.10	31.69
Weekend	33.69	74.29	24.70	76.29
Weekly	396.20	780.13	339.32	528.28
Current personal				
Daily	31.07	49.57	17.69	49.58
Weekly	390.44	568.47	299.13	476.15

Usual home ranges. The first MANOVA was conducted on the weekly, bimonthly, and monthly indicators of the size of usual home ranges. It was not significant, Wilk's $\Lambda = .98$, F (3, 210) = 1.62, $\eta^2 = .02$ (a similar result followed when the data from two outliers were included, Wilk's $\Lambda = .98$, F [3, 212] = 1.15, $\eta^2 = .02$).

Current home ranges. The second MANOVA was run on the daily, Monday-to-Friday, weekend, and weekly indicators of the size of current home ranges that aggregated professional and personal travelings. Men ranged further than women when the current home range measures were jointly considered, Wilk's $\Lambda = .92$, F (4, 122) = 2.81, with sex accounting for 8% of the overall variance (a nonsignificant conclusion was obtained when the data from one outlier were included, Wilk's $\Lambda = .93$, F [4, 123] = 2.14, $\eta^2 = .07$).

A discriminant function analysis was performed to determine whether the daily, Monday-to-Friday, weekend, and weekly current indicators could reliably differentiate men and women. The discriminant function was calculated, with a significant $\chi^2(4, N = 124) = 10.82$. Table 5 presents the correlations between the four home range indicators and the discriminant function, as well as the standardized discriminant function coefficients and the pooled within-group correlations among the four ranging indicators. These statistics indicate that men's and women's ranging were mainly discriminated from one another by the daily indicator, whereas both the Monday-to-Friday and weekend measures were weak predictors; the weekly measure was no significant predictor. On the discriminant function for each sex, men (M = .33) had higher mean values than women (M = -.28). With a sex classification procedure, 60% of the 127 participants who supplied current measures were classified correctly. This was more likely among women (70% of correct sex predictions) than among men (48%).

Personal current home ranges. Finally, the third MANOVA compared the extent of men's and women's current personal daily and weekly ranging among participants in the fall session. Overall, men had larger personal home ranges than women, Wilk's $\Lambda = .89$, F (2, 51) = 3.15, with 11% of the variance accounted for by sex (a nonsignificant conclusion was obtained though when the data from four outliers were included, Wilk's $\Lambda = .95$, F [2, 55] = 1.26, $\eta^2 = .04$).

A discriminant function analysis was conducted using the daily and weekly current personal indicators as predictors of sex membership. The discriminant function was calculated, with a $\chi^2(2, N = 57) = 5.94$. Table 6 reports the correlations between the two home range indicators and the discriminant function and the standardized discriminant function coefficients. The pooled within-group correlation among the two ranging indicators was .77. These statistics indicate that, again, daily ranging reliably predicted sex membership whereas weekly ranging did not. On the discriminant function for

Table 5

Discriminant Function Analysis of Current Home Range (HR) Variables

				Pooled within-group correlations among HR variables		
HR variable	Correlations between HR variables and the discriminant function	Standardized coefficients for the discriminant function	Univariate F(1, 125)	Monday-to-Friday	Weekend	Weekly
Daily	.54	1.14	3.27 (ns)	.85	.72	.86
Monday-to-Friday	.44	.46	2.25 (ns)		.36	.73
Weekend	.50	.56	2.83 (ns)			.65
Weekly	.05	-1.62	0.03 (ns)			
Canonical R	.29					
Eigenvalue	.09					

each sex men (M = .34) had higher mean values than women (M = -.36). Using a sex classification function, 67% of the 54 participants who provided current personal measures were correctly classified. This was more likely in men (82%) than in women (50%).

Table 6

Discriminant Function Analysis of Current Personal Home Range (HR) Variables

HR variable	Correlations between HR variables and the discriminant function	Standardized coefficients for the discriminant function	Univariate F (1, 52)
Daily	.60	1.57	2.34 (ns)
Weekly	-.04	-1.25	0.01 (ns)
Canonical R	.33		
Eigenvalue	.12		

In short, the prediction that men's overall ranging would be larger than women's received substantial support. This sex difference was demonstrated for both the current and current personal home ranges, though it was not significant in the case of usual ranging.

Complementary check. Approximately 70% of our sample was composed of single, divorced, or widowed persons. Probably because, compared to married participants, these persons were less tied down with family commitments, both sexes displayed more current mobility in terms of daily and weekly ranging. In addition, for men and women, between 60% and 71% of the participants who supplied the current data were part-time workers, with therefore more time between Monday to Friday, than individuals with a full-time job, to engage in personal activities requiring some mobility.

These two sample traits raised the question of whether, irrespective of sex, the present current ranging measures may have predominantly reflected the mobility of unmarried and part-time employed participants. To answer this question, we performed two separate 2 (marital status) x 2 (job-time requirements) MANCOVAs on current and current personal ranging indicators, using the residence-to-work distance as covariate. There was no significant interaction (with and without outliers) between the two factors for either current, Wilk's $\Lambda = .98$, $\underline{F}$ $(4, 120) = .44$, $\eta^2 = .02$, or current personal, Wilk's $\Lambda = .99$, $\underline{F}$ $(2, 52) = .51$, $\eta^2 = .03$, ranging. Moreover, unmarried participants did not range significantly further than married ones in terms of either the global current, Wilk's $\Lambda = .93$, $\underline{F}$ $(4, 120) = 2.05$, $\eta^2 = .07$, or current personal, Wilk's $\Lambda = .94$, $\underline{F}$ $(2, 52) = 2.80$, $\eta^2 = .11$, indicators. Finally, part- and full-time workers did not significantly differ in their current, Wilk's $\Lambda = .93$, $\underline{F}$ $(4, 120) = 2.06$, $\eta^2 = .07$, and current personal, Wilk's $\Lambda = .99$, $\underline{F}$ $(2, 52) = .22$, $\eta^2 = .01$, home ranges. These data attest that our ranging findings truly characterized our whole sample.

Home Range Size and Spatial Performance

We predicted different patterns of associations between ranging extent and spatial performance as a function of sex. First, the relationships should involve a broader variety of tasks in men than in women that is, there should be a greater number of significant relationships in men. Second, there should be little overlap between the relationships obtained in each sex that is, distinct tasks should be involved in men and in women, respectively. To test these predictions we computed, within each sex, Pearson correlations between each indicator of the usual, current, and current personal home ranges and the scores recorded in each spatial task. Because the residence-to-work distance might have affected the magnitude of the associations, all ranging measures were controlled for this factor. Likewise, the location memory scores, as well as the embedded figures and surface development ones, were adjusted for age.

For women and men respectively, Tables 7 and 8 report the zero-order and partial correlations between home range sizes and spatial scores, including outlier values. Although the two types of coefficients showed fairly similar patterns, partialing out residence-to-work distance and age generally increased the magnitude of the significant associations. Therefore, focus was placed on the partial correlations.

Ranging and mental rotation, spatial perception, and spatial visualization. Home range measures were found to be positively related to mental rotation scores exclusively in men. These relationships involved all indicators of their usual ranging, along with their daily ranging according to both current indicators and their Monday-to-Friday current ranging. However, none of the ranging indicators was significantly associated with performance in the water-level task in either sex. Also at variance with our predictions, proficiency in disembedding figures was positively connected, in men, with only two ranging measures that is, the bimonthly and monthly usual home ranges, whereas, in women, the relations involved all current ranging measures irrespective of time frame, as well as weekly current personal ranging. Finally, only in men was achievement in the surface development task positively tied with ranging, save for the usual monthly and current weekend and weekly measures; the link with personal home ranges emerged particularly strongly.

Ranging and location memory. Only in men was home range size significantly related with location memory. The positive correlations involved all current ranging indicators, save the weekend one.

Overall, the patterns of within-sex correlations between spatial scores and the three sets of home range measures were generally consistent with predictions. As expected, men (19) totaled nearly four times as many significant correlations as women (5). Additionally, in men the correlations spanned four of the five tasks that is, all but the water-level task, whereas in women all correlations concerned the sole embedded figures task.

Table 7

Zero Order and Partial Correlations Between Performance on Each Spatial Task and Home Range (HR) Measures in Women

		Usual HR			Current HR				Current personal HR	
Spatial task	Type of Correlation	Weekly	Bimonthly	Monthly	Daily	Monday To Friday	Weekend	Weekly	Daily	Weekly
			(n = 120)			(n = 69)			(n = 27)	
Mental rotation	Zero order	.02	.01	-.05	.00	.05	-.12	-.09	-.13	-.02
	Partial	.03	.00	-.07	.01	.06	-.10	-.07	-.15	.02
Water-level	Zero order	.04	.08	.05	.17	.10	.19	.19	.07	.12
	Partial	.07	.11	.07	.18	.13	.18	.19	.01	.12
Location memory	Zero order	.13	.06	.05	-.04	-.03	-.08	-.05	-.20	-.12
	Partial	.08	.02	.01	-.04	-.03	-.07	-.04	-.14	-.12
			(n = 57)			(n = 38)			(n = 13)	
Embedded figures	Zero order	.22*	.26*	.16	.42*	.39*	.24	.38*	.39	.56*
	Partial	.18	.20	.09	.47*	.41*	.35*	.40*	.39	.56*
			(n = 63)			(n = 31)			(n = 14)	
Surface development	Zero order	.10	.02	-.04	-.11	-.21	-.04	-.22	-.28	-.05
	Partial	.10	.02	-.03	-.12	-.22	-.05	-.22	-.27	-.04

* $p \leq .05$.

Table 8

Zero Order and Partial Correlations Between Performance on Each Spatial Task and Home Range (HR) Measures in Men

		Usual HR			Current HR				Current personal HR	
Spatial task	Type of Correlation	Weekly	Bimonthly	Monthly	Daily	Monday to Friday	Weekend	Weekly	Daily	Weekly
			(n = 94)			(n = 58)			(n = 27)	
Mental rotation	Zero order	.18*	.21*	.17*	.19	.18	.11	.17	.36*	.26
	Partial	.22*	.25*	.19*	.21*	.21*	.12	.19	.34*	.25
Water-level	Zero order	-.10	-.02	-.03	.04	.07	-.10	.00	.09	-.04
	Partial	-.09	.00	-.01	.00	.02	-.10	-.03	.07	-.06
Location memory	Zero order	.10	-.02	.06	.21*	.17	.08	.26*	.39*	.48*
	Partial	.13	-.00	.08	.25*	.24*	.08	.31*	.38*	.48*
			(n = 52)			(n = 33)			(n = 14)	
Embedded figures	Zero order	.21	.27*	.26*	.10	.20	-.16	.11	-.06	-.14
	Partial	.18	.24*	.23*	.15	.27	-.11	.15	.06	-.15
			(n = 42)			(n = 25)			(n = 13)	
Surface development	Zero order	.26*	.21	.17	.39*	.45*	.17	.30*	.76*	.61*
	Partial	.28*	.26*	.21	.36*	.41*	.22	.26	.80*	.68*

* p ≤ .05.

Discussion

Our results clearly demonstrate a relationship between a collection of spatial abilities and sex-linked ranging extent in Western adults. Prior to discussing them however, we think it pertinent to explain our approach in measuring home range size.

Appraising Home Range Size in Western Men and Women

Most human ranging studies have been conducted in child samples. Estimating usual ranging has chiefly consisted of boys and girls drawing a map illustrating the territory they habitually cover in their everyday activities (e.g., Anderson & Tindall, 1972; Hart, 1979, 1981). Assessing current home ranges has generally involved observers recording how frequently distinct locations, distributed within and around a given study area, were visited by each child over given periods of time (e.g., Dasen et al., 1985; Mishra, 1996; Munroe & Munroe, 1971). Because children's daily travelings generally take place within relatively small geographical zones (e.g., a set of street blocks, or a village), these two techniques are likely to yield a reliable appraisal of children's ranging. However, neither of them would have been appropriate to establish the extent of mobility that characterizes Western adults. As men's and women's travelings may indeed spread over dozens of kilometers, drawing the large involved areas would have been subject to considerable error. Also, since travelings may be carried out using a profusion of transportation modes, particularly in urban environments, it is virtually impossible for observers to follow all of an adult sample's comings and goings.

In animal studies on the other hand, radiotracking each individual to acquire objective estimates of its current ranging in natural habitat is customary (e.g, Alterio, 1998; Mizutani & Jewell, 1998; Newell, 1999; Randall, 1991). This technique would have also been problematic with sexually mature human participants who have professional activities in industrial societies. While telemetric data would have provided valid current positioning coordinates according to various time frames (e.g., weekend vs. weekdays), they would have been uninstructive as to whether the travelings met strictly personal objectives or a combination of personal and professional goals. Collecting this contextual information permitted us to establish that the same sex difference held in both cases, as will be further discussed. Suited to literate populations, our procedure was advantageous overall for evaluating home range size in Western working adults. Still, there were some differences between the diverse types of ranging indicators that we used.

Usual versus current home ranges. To obtain an overview of ranging extent we worked from usual, current, and current personal indicators with respect to various time frames. The latter two measures were nearly perfectly correlated for the daily (r = .96) and weekly (r = .95) time frames which they had in common. But considering the only frame common to all three sets of measures, the weekly indicator of usual ranging was not strongly associated with that of either the current (r =.28) or current personal (r = .22) ranging. It is also striking that the weekly usual home range was about eight times smaller than both weekly current ranges. These contrastive findings suggest that our usual ranging questionnaire tapped somewhat different inputs from those collected with both current recordings that requested each participant to indicate all of his or her travelings as they occurred over one week. In the usual ranging questionnaire on the other hand, participants were asked about a series of places they customarily visited mainly in relation to shopping, entertainment, friends, and family. However, that no open-ended questions were included could have prevented the reporting of other sorts of usual destinations, such as places to attend religious services, or evening courses, or to engage in voluntary work. Additionally, given that, compared to the recording of travel in progress, usual ranging retrieval may, to some degree, have required the participants to mentally represent the destinations that were habitual for them in order to indicate their geographic positions, the ensuing measures may have been more or less accurate. These two characteristics of usual home range estimates could explain that, although the sex difference was as expected in all three sets of measures, only the one in the usual, or noncurrent, set failed to reach significance.

Ranging in Western men and women. In keeping with studies conducted in polygynous mammals (e.g., Avenant & Nel, 1998; Bearder, 1987; Galdikas, 1988; Norbury et al., 1998; Samson & Raymond, 1998) as well as in human traditional societies (e.g., Hewlett et al., 1986; MacDonald & Hewlett, 1999), we found that, in Western humans, adult males have larger current home ranges than females. Our ranging results thus complement other findings which, in terms of traits as diversified as height, sexual maturity, or courtship style (see Daly & Wilson, 1983), have documented the existence, in humans, of a set of sex differences that characterize most polygynous mammalian species and are deemed to derive from the action of sexual selection. In addition, our results provide substantial support for Gaulin and FitzGerald's (1986, 1989) model according to which a sex difference in spatial ability should be manifest in species where males and females differ in navigation extent.

Two ranging features potentially proper to humans, particularly from an industrial society, also emerge from the present data. Firstly, in both current measures, size of daily home range was the main predictor of the overall ranging sex difference, whereas that of the ranging indicator for the longest time period that is, the week, was no significant predictor. Still, the global sex difference stemmed from the joint consideration of small differences over distinct time periods, with only the daily differences approaching significance (see univariate F values in Tables 5 and 6). This departs from the sex differences established among adult rodents in which males range further than females both daily and over several days (Gaulin & FitzGerald, 1986, 1989). Our findings may be explained in reference to a cultural factor involving how far apart the geographical areas covered from Monday to Friday were compared to those during the weekend. As both areas were encompassed in the weekly measure, when they did not overlap and were distant from each other, this resulted in a larger weekly home range than when they overlapped, or were in close proximity.

Secondly, men had larger current home ranges regardless of whether the involved travel was of a strictly personal nature or not. Within the current data aggregating personal and professional travel on the one hand, it was shown that while the weekend and Monday-to-Friday periods ordinarily differ in terms of proportions of personal and both personal and professional activities, each of these time frames discriminated fairly similarly between men's and women's ranging. On the other hand, the sex difference in the current personal measures appeared to account for only a slightly higher portion of variance compared to that accounted for by current measures. Overall, it thus seems as if, in each sex, professional activities contributed equally to global mobility. Such likelihood is strengthened by the observation that no within-sex relationship occurred between home range size and work-related variables such as job mobility or job-time requirements. Obviously, these results have to do with the present men and women holding, in equal proportions, jobs that required either little or no mobility. However, precisely because of the comparable professional mobility between men and women, the present ranging data clearly bear witness to men's inclination to navigate further than women, even in a Western context. This contrasts with sex differentiated ranging in traditional societies wherein navigation extent closely matches occupational travel owing to men hunting and women gathering within large and limited territories, respectively (e.g., Hewlett et al., 1986; Gaulin & Hoffman, 1988; MacDonald & Hewlett, 1999).

In sum, the hypothesis that, like in numerous mammals, sexually mature male humans would have larger home ranges than females appears validated in Western men and women who were highly similar in terms of mobility and demographic traits, except for the fact that women were on average slightly more educated than men. In neither sex, however, was education significantly related with any study variable. Still, such a tight equivalence across sexes also led to ranging sex differences that were fairly modest, and even unstable given that they only held after the extreme ranging values had been discarded from analysis. Nevertheless, the substantial sex comparability did not prevent stable sex differences, and in several cases some relatively strong ones, from occurring in both spatial skills and their relationships with ranging extent.

Spatial Achievement and its Relationships With Home Range According to Sex

Our spatial performance results corroborate the meta-analytic reports of a clear male superiority in both mental rotation and water-level tasks (Linn & Petersen, 1985;

Masters & Sanders, 1993; Voyer et al., 1995), as well as that of a smaller one in embedded figures and surface development tasks (Voyer et al., 1995). As also expected, our results replicated women's better memory for object locations (e.g., Eals & Silverman, 1994; James & Kimura, 1997; Montello et al., 1999; Silverman & Eals, 1992)[11].

One of our main purposes was to evaluate the tenability that several spatial abilities evolved respectively in men and women to support their main respective navigation modes within ancestral environments, and are still manifest in modern humans. In harmony with this perspective, the present study shows that the scope of tasks for which spatial performance covaried with home range size was about four times larger in men than women, with only minimal overlap between the tasks involved for each sex. Overall, these results support the idea that processing spatial data via the command of diversified spatial abilities would be more typical of men's than of women's navigation mode. Such processing would have been preferentially selected in men in response to the need, during evolution, to more often travel over extended territories than women.

Ranging extent and proficiency in mental rotation, location memory, and surface development tasks. Only among men was home range size associated with competence in mental rotation, location memory, and surface development tasks. The relations involving the first two tasks appear congruent with the hypothesis that the ability to carry out mental rotations on spatial data, along with the capacity to remember, even approximately, the configurations formed by stationary elements, continues to contribute to navigation in present-day Western men more than it does in women. Our argument was that, in ancestral men, frequently dealing with the profuse spatial information to be processed in long-range navigation would have favored mastering the ability to encode the locations of only certain salient stimuli in the field, and of mentally manipulating

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[11] It should furthermore be noted that, at variance with the first two tasks, scores in the last three were negatively correlated with age. In the two spatial visualization tasks, significant sex differences were only obtained when the adverse effect of aging was controlled and, in the location memory task, such control slightly increased the sex effect size. Overall, this suggests that between the ages of 25 to 45, compared to those involved in mental rotation and spatial perception tasks, some of the processes involved in disembedding figures, developing surfaces, and memorizing object locations both deteriorate faster and are less dissimilar across sexes.

these spatial data, as well as others such as the aptitude to rotate them in all three Euclidean directions. It may be argued that such abilities are useful when, upon the return trip, the memorized environmental features or the configuration they form must be shifted from left to right, from front to back, or from far to near, and vice versa. Moreover, that only men's object location memory scores correlated with their home range sizes may be viewed as in agreement with Barnfield's (1999) position that, instead of recording object positions relative to one another, men would encode object location chiefly with respect to absolute position that is, a memory task in which they excel (Postma et al., 1998, 1999; Vecchi & Girelli, 1998). The reverse would occur in women among whom the failure to find significant correlations between ranging measures and object location memory proficiency is compatible with the perspective that as, for them, to rely on such an ability, although it is slightly more developed than in men, does not substantially assist navigation, it is not linked to home range size. Similarly, when traveling women would rarely make use of the kind of mental rotation process involved in Vandenberg and Kuse's (1978) test. This view appears pertinent even though ranging extent in present-day Western women somewhat overlaps with that in men and is probably greater than that in early women because of contemporary traveling demands and opportunities.

In like manner, that somewhat strong correlations were obtained between surface development scores and ranging measures strictly in men supports the idea that the mental processes used for solving the task at stake would assist navigation in present-day Western men but not in women. Proficiency in developing surfaces calls for the ability to rotate spatial data (Eliot & Smith, 1983), as well as the capacity, which may not be strictly spatial (Eliot & Smith, 1983; Linn & Petersen, 1985), to conduct, simultaneously or in succession, several mental operations on the to-be-processed information. The latter dimension could besides explain why sex differences in solving this spatial visualization task are usually small (Linn & Petersen, 1985; Voyer et al., 1995): Conceivably, both sexes are comparably able to execute a series of mental operations. Thus, it appears probable, based on our correlations involving men's ranging exclusively, that when navigating men are prone to perform a number of mental operations on spatial data—including their rotation—, whereas in the case of women, conducting these multitype operations would not particularly influence the navigational mode. It may also be that the rotation component required to solve the surface development task is less complex than the one central to success in Vandenberg and Kuse's test. Mentally rotating two-dimensional stimuli in order to transform them into three-dimensional ones or the reverse, as is the case in surface development tasks, could be cognitively less demanding than rotating three-dimensional stimuli in all three Euclidean directions. This lesser complexity would similarly account for the small sex differences generally found in surface development tasks, compared to the large sex effect manifest in Vandenberg and Kuse's test (Linn & Petersen, 1985; Voyer et al., 1995). Moreover, if the rotation component in surface development is easier to execute, this could explain that, in navigational contexts, men more often activate the simpler rotation process than the more difficult one. Finally, in first women who, in comparison to men, may have traveled over smaller territories wherein focus is on the immediate surroundings, the capacity to alternately shift from a three-dimensional perspective to a two-dimensional one that also applies to salient topographic elements on the horizon line, may have been less particularly selected.

Ranging extent and proficiency in water-level and embedded figures tasks. In two aspects within-sex relationships were at variance with expectations. We had reasoned that since perceiving environmental characteristics of a geometrical nature, as well as extracting particular spatial information from a complex set, could have been more critical to male than to female ancestral navigation, these two skills should be associated with modern ranging more convincingly in men than in women. However, in neither sex were ranging measures significantly correlated with performance in the water-level task that is, a spatial perception task according to Linn and Petersen's (1985) classification. In addition, ranging measures and embedded figures scores were less often correlated in men than in women.

As it deals with the competent analysis of Euclidean coordinates regardless of distracting information, the water-level test is a spatial perception task (Linn & Petersen, 1985). Nevertheless, it also involves knowing about the invariant orientation of liquid surfaces due to gravity (Liben, 1991). The latter physical dimension may have prevented significant relations, between the processing of geometrical features and ranging extent, from emerging. Using tasks strictly focusing on spatial perception would more directly ascertain whether traces of an evolutionary legacy as to geometrical processing in navigation contexts may be observed in present-day humans. Such tasks may consist in positioning a rod vertically (Rod-and-Frame Test; Witkin, Dyk, Faterson, Goodenough, & Karp, 1962) or in drawing horizontal lines (Liben & Golbeck, 1986) within tilted frames.

Scores in the embedded figures task, which requires the discernment of a mentally represented shape within an intricate arrangement, were associated with usual home ranges in men but with current ones in women. However, attempting to account for usual ranging being correlated with achievement in men only appears pointless. Our usual ranging indicators may have lacked validity as suspected earlier, and this possibility may have affected men and women differently, as suggested by our correlation pattern. Consequently, the validity of the concerned correlations with spatial performance could have been compromised as well. As to the associations between women's embedded figures scores and current ranging, they reveal women's reliance on extracting simple spatial data from the overall environment to guide their navigation, in harmony with their propensity, while navigating, to focus on particular environmental elements such as landmarks (e.g., Galea & Kimura, 1993) that need no be highly salient. In parallel however, that in women the correlations involve embedded figures but not object location memory scores weakens the view that women's navigational mode is primarily connected with memorizing some spatial data such as landmarks or the configuration they form. Instead, these findings concur with the view that an advantage in memorizing object locations would not have evolved in women chiefly to assist female navigation but rather, as hypothesized by Silverman and Eals' (1992), to support ancestral women's gathering duties which require the recollection, within familiar areas, of the precise location occupied, season after season, by edible plants.

That a significant association between current ranging and disembedding figures did not occur in men, though, contradicts our prediction of a significant involvement of the disembedding process in male ancestral navigation. In other words, while a substantial part of our results is fairly consistent with the position that sex differences in several spatial tasks would be adaptive responses to sex-differential navigation-related pressures, it appears that extent of navigation does not account for men's slight advantage in solving the embedded figures task, just as it did not previously explain why, generally, men outscore women in the water-level task. As emphasized by Sherry (2000), it may be that some spatial tests assess skills that, to various degrees, are independent of the capacities required for orienting throughout a home range. In that vein, men's superiority in the water-level task and, to a lesser extent, in the embedded figures one, could rather be related to a nonnavigational evolutionary factor. As advocated elsewhere (Ecuyer-Dab & Robert, 2001), in a few primate species, including humans, male agonistic settings may include throwing and intercepting objects that is, behaviors that serve no navigational purposes, yet call for a number of spatial capacities. It is conceivable that a rudimentary understanding of some physical concepts, such as the gravitational force, involved in throwing or intercepting may have been extended to matter in general, whatever its solid or liquid consistence. Likewise, the skill to isolate certain spatial features inherent to the behavior of moving objects, such as the mass and the altitude of a projectile, in order to predict its trajectory might be part of an overall spatial disembedding ability. Although in this case such ability may be more cognitive than perceptual, the reverse occurring in the embedded figures task, both skills incorporate an extraction process. Future research should gain from exploring the potential complementarity of distinct selective pressures with respect to the occurrence of sex differences in human spatial abilities.

Conclusion

The present results show that in a Western, industrial context men globally range further than women. They also support the view that, in humans, a substantial part of sex differences in spatial ability may be due to men having inherited more diversified spatial processing advantages, compared to women, in response to a stronger pressure for large-scale navigation in ancestral environments. The latter interpretation could appear, however, to be challenged by the claim that because they range more extensively than women, and as boys have done so earlier relative to girls (e.g., Hart, 1979, 1981; Herman et al., 1987; Wohwill & Heft, 1987), present-day men have acquired more experience in the processing of a wider scope of spatial data and, therefore, display a superior mastery in several spatial skills. As argued by Gaulin (1992) though, a Darwinian standpoint does not rule out the contribution of proximate developmental pressures to the existence of spatial sex differences. It may even conjecture on how, in a variety of species, selection is likely to have favored sex-linked spatial abilities, for instance, via certain ontogenetic processes that are sex related. These processes may themselves be construed as evolved developmental programs that is, programs that serve adaptation.

Perhaps sex-differential spatial learning, even in response to comparable spatial input for both sexes, constitutes one of the proximate mechanisms that cause spatial cognition to differ from men to women. Abundant human data argue against such a proposition however: For example, Baenninger and Newcombe (1989, 1995) have concluded from their reviews that spatial experience impacts similarly on the learning level reached by each sex. But our within-sex correlations between current home range size and spatial performance seem to undermine the idea that, irrespective of sex, spatial performance is mainly a matter of spatial experience through navigation for instance. To make our reasoning clear, a reminder of some procedural and statistical fac tors is needed. First, our current ranging data (including the current personal) may be deemed to reflect fairly stable navigation patterns even though they covered only one week; we thus attach little importance to the fact that such navigation followed rather than preceded spatial testing. Second, the inclusion of extreme ranging values canceled the significant sex difference in current home range size, whereas the within-sex correlations between ranging and achievement measures were not affected by including outliers on either measure. Hence, even though the amount of current navigation appears to have been comparable across sexes, our findings suggest that, to some extent, its relation to spatial performance differed according to sex. Of course an accurate interpretation of both the present data and those reviewed by Baenninger and Newcombe (1989, 1995) would require a comprehensive testing of an experiential hypothesis necessitating an exhaustive assessment of experiential input from early life onward. But this is, at the moment, impracticable in humans[12].

Overall, it would be productive to attempt a deeper understanding of the developmental mechanisms that are likely to mediate evolutionary ones in the genesis of spatial sex differences. Among the most plausible mediators are the sex-specific organizational (e.g., Williams et al., 1990, in rodents) and activational (e.g., Hampson & Kimura, 1988, in humans) effects of sex hormones on spatial cognition (and its neurological substrates). At the organizational level for instance, it is possible that factors such as early sex-differential hormonal impregnation produce sex differences in how spatial experience is assimilated, and in resulting spatial abilities. As emphasized by several authors (e.g., Gaulin & FitzGerald, 1986; Gray & Buffery, 1971; Kimura, 1999), opposing phylogenetic and ontogenetic models simply introduces a false dichotomy between the respective actions of ultimate and proximate mechanisms given that such models offer an explanation of spatial sex differences through levels of analysis that are not necessarily incompatible.

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[12] However, the systematic longitudinal recording of amount of traveling could become possible using promising geographical positioning techniques from satellites.

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Discussion générale

L'examen des fondements théoriques et empiriques propres au modèle de la sélection sexuelle de Gaulin et FitzGerald et à celui de la division sexuelle du travail de Eals et Silverman a conduit, dans le premier manuscrit, à envisager l'évolution d'un ensemble d'habiletés spatiales en réponse à l'action de pressions évolutives distinctes selon le sexe des individus. Chez les mâles des espèces présentant des caractères associés à la polygynie, la sélection sexuelle aurait opéré sur les traits comportementaux et cognitifs avantageux en regard de la compétition qu'ils se livrent généralement pour maximiser leurs opportunités de reproduction : (a) la compétition axée sur la mobilité aurait généré une supériorité masculine dans les épreuves spatiales associées à la navigation ; (b) quant à la compétition qui s'exprime dans les comportements agonistiques où interviennent le lancer et l'interception de projectiles, elle pourrait avoir engendré un avantage masculin dans la maîtrise des principes mécaniques et cinétiques sous-jacents à la résolution de certaines épreuves spatiales.

Dans les espèces où la gestation, l'alimentation (même après la période de sevrage) et la protection des petits imposent aux femelles des coûts élevés sur les plans énergétique et temporel, la sélection naturelle semble susceptible d'avoir agi sur les patrons cognitifs et comportementaux qui favorisent la survie des femelles elles-mêmes, comme celle de leur progéniture : la propension féminine à limiter les déplacements dans le but de minimiser les prises de risques physiques permettrait de rendre compte, à la fois, d'un profil cognitif orienté vers les indices visuels situés à proximité dans l'environnement et d'une plus grande facilité à mémoriser l'emplacement de divers objets.

De nombreuses données cognitives et comportementales suggérant l'existence de ces différentes pressions évolutives chez plusieurs espèces de mammifères y compris les humains, il était justifié d'examiner la validité d'une série d'hypothèses portant sur la valeur adaptative de plusieurs différences intersexes dans les habiletés spatiales. Ainsi, alors qu'une relation de type fonctionnel entre l'avantage masculin dans les épreuves spatiales liées à la navigation et celui qui s'observe dans l'étendue des déplacements a été clairement mise en évidence chez plusieurs espèces de rongeurs, une démonstration équivalente était à entreprendre chez l'humain.

L'étude décrite dans le second manuscrit visait principalement ce dernier objectif. Nous avons d'abord tenté de vérifier auprès d'un échantillon de Montréalais francophones si, en dépit d'un mode de vie moderne où hommes et femmes seraient relativement similaires quant aux occupations qu'ils exercent et aux modes de transport qu'ils utilisent, on pouvait observer une propension des hommes à se déplacer davantage que les femmes. La procédure exploitée s'appuyait essentiellement sur un découpage des périodes de déplacements éprouvé chez l'animal, que nous avons cependant adapté à l'humain pour tenir compte des contextes de mobilité personnelle et professionnelle. Il en résulte deux ensembles de mesures des domaines vitaux dont au moins un témoigne de différences intersexes.

D'une part, il est apparu que les superficies des domaines vitaux habituels des hommes et femmes ne se distinguent pas. Ce résultat semble néanmoins partiellement tributaire de la technique d'obtention des données se rapportant aux lieux ordinairement visités. Notamment parce que cette technique n'a vraisemblablement donné accès qu'à une portion de l'information concernée et, possiblement, dans des proportions variant d'un sexe à l'autre, elle ne rendrait pas adéquatement compte des déplacements habituels propres à chaque sexe, portant ainsi à l'abandonner à l'avenir.

D'autre part, l'analyse des déplacements actuels a montré qu'examinés sur différentes périodes entre le lundi et le dimanche, les domaines vitaux sont assez similaires d'un sexe à l'autre, mais que considérés dans leur ensemble, ils se révèlent plus vastes chez les hommes. En outre, cette différence se manifeste peu importe la nature strictement personnelle ou non des déplacements effectués au cours de la semaine de l'étude. Globalement, ces résultats confortent, à deux niveaux, la validé de l'hypothèse voulant que la tendance des individus de sexe masculin à se déplacer davantage que ceux de sexe féminin soit le produit d'une sélection darwinienne. Premièrement, ces différences intersexes convergent avec celles mises en évidence chez de nombreuses espèces polygynes non humaines pour lesquelles il y a lieu de présumer une action prépondérante de la sélection sexuelle. Deuxièmement, à la différence des données humaines analogues qui, recueillies exclusivement dans les sociétés traditionnelles, demeurent dans une certaine mesure imputables aux écarts de superficie entre les territoires respectivement exploités par les hommes chasseurs et les femmes cueilleuses, les présents résultats ne peuvent se confondre avec les patrons de mobilité professionnelle. Dans des proportions en effet très semblables d'un sexe à l'autre, les présents participants exerçaient des emplois requérant beaucoup ou peu de déplacements ou n'en requérant pas. Les différences intersexes ici obtenues ne sont d'ailleurs pas davantage attribuables à des disparités entre hommes et femmes sur le plan de facteurs pouvant affecter la mobilité générale tels le temps consacré au travail, les moyens de transport utilisés, la distance entre les lieux de résidence et de travail et la provenance rurale ou urbaine des participants. Les participants des deux sexes étaient également comparables quant à l'âge, l'état civil et le niveau de revenu. La seule distinction significative entre hommes et femmes concernait le niveau d'éducation, mais cette variable ne s'est montrée associée ni aux mesures de déplacement ni à celles de la performance spatiale. Dans leur ensemble, les comparaisons effectuées entre domaines vitaux masculins et féminins autorisent donc clairement à conclure à l'inclination des hommes, au sein d'une société moderne, à parcourir des territoires globalement plus vastes que ceux des femmes.

Ces mesures de déplacement ont permis de vérifier une série d'hypothèses proposées pour expliquer, d'une part, la supériorité des hommes ici retrouvée dans diverses épreuves spatiales et, de l'autre, la supériorité des femmes également reproduite dans une forme de mémoire spatiale. Sur leur versant masculin, ces hypothèses voulaient qu'un plus large éventail d'habiletés spatiales ait été sélectionné chez les hommes en réponse aux exigences de navigation à large échelle dans les environnements ancestraux. Sur leur versant féminin, elles proposaient que la capacité des femmes à mémoriser l'emplacement d'objets ait principalement évolué dans un contexte de mobilité à l'intérieur de domaines vitaux de taille plus modeste. Les prédictions prévoyaient des corrélations plus accentuées chez les hommes que chez les femmes entre superficie des domaines vitaux et performance dans des tâches spatiales généralement à l'avantage des individus de sexe masculin. De plus, elles postulaient une absence de relation entre la capacité à mémoriser l'emplacement d'objets et la taille des domaines vitaux féminins que l'on pouvait supposer plus importante à l'intérieur d'une société industrialisée que dans l'environnement ancestral. En revanche, il était envisageable que cette aptitude donne lieu à des corrélations positives avec la taille des domaines vitaux masculins.

Conformément à ces prédictions, les relations positives dégagées sont quatre fois plus nombreuses chez les hommes que chez les femmes. De surcroît, les patrons masculin et féminin de corrélations mettant en jeu mobilité et réussite spatiale ne se chevauchent pratiquement pas. On trouve ainsi, chez les hommes, que l'amplitude des déplacements est associée à la performance dans les tâches de rotation mentale --où la supériorité masculine est la plus marquée--, de figures intriquées et de développement de surfaces --où l'avantage masculin est assez faible dans les deux cas--, de même que dans la mémoire de la localisation --où la supériorité féminine est aussi assez faible. Chez les femmes, le seul lien significatif avec la taille des domaines vitaux concerne le rendement dans l'épreuve des figures intriquées. Finalement, ces relations ont toutes été dégagées alors que des facteurs comme l'âge —réduisant la performance spatiale-- et la distance domicile-travail --affectant la superficie des domaines vitaux-- avaient été neutralisés.

Ces résultats s'inscrivent dans le sens de l'hypothèse générale voulant qu'un lien de type fonctionnel existe entre les différences intersexes dans les habiletés spatiales et celles qui portent sur l'étendue de la navigation. Plus spécifiquement, ils corroborent assez bien la position selon laquelle une plus large gamme des aptitudes spatiales dans lesquelles les hommes s'illustrent mieux que les femmes ait évolué en réponse à la nécessité de s'orienter et de se déplacer à l'intérieur de plus vastes territoires ancestraux que dans le cas de leurs consoeurs. Chez les femmes, l'absence de lien entre mémoire des localisations et amplitude des déplacements serait compatible avec l'idée que, parce que, durant l'évolution humaine, ce processus cognitif aurait surtout été sélectionné chez elles pour permettre l'encodage et la récupération de l'emplacement occupé par divers objets au sein d'une aire familière et relativement limitée dans l'espace, il n'assisterait actuellement pas plus la navigation qu'effectuent les femmes sur de vastes domaines vitaux que celle qu'elles mènent sur des domaines plus restreints. Les femmes pourraient donc continuer à ne pas solliciter davantage cette forme de mémoire spatiale dans un contexte de navigation actuelle plus étendue que celle de leurs ancêtres. Par contre, chez elles, l'aptitude à identifier des formes simples à l'intérieur d'un ensemble plus complexe semble mise en jeu directement en proportion de l'amplitude des déplacements accomplis. Ces données paraissent ainsi en harmonie avec celles qui témoignent d'une propension féminine à se centrer sur des repères topologiques lors des épreuves de navigation. Cependant, elles tempèrent aussi l'hypothèse voulant que l'attention portée à ces repères et la mémorisation de leurs emplacements nécessitent dans une large mesure des processus cognitifs communs. Des études ultérieures sont donc nécessaires pour mieux départager, selon le sexe, les processus sous-tendant l'attention aux repères topologiques de ceux sous-jacents à la mémoire de leurs emplacements.

Par ailleurs, il importe de souligner qu'en comparaison de la taille des domaines vitaux masculins actuels combinant déplacements personnels et professionnels, celle des domaines vitaux strictement personnels est généralement plus fortement reliée au degré de réussite dans les épreuves de rotation mentale, de mémoire de localisation et, particulièrement, de développement de surface. Ce dernier type d'association fait alors ressortir que ce ne serait pas tant la meilleure aptitude des hommes à effectuer, en pensée, des rotations d'objets tridimensionnels qui les assisterait dans leurs déplacements que celle qui consiste soit à mener--de front ou successivement--plusieurs types de manipulations mentales (incluant la rotation de données spatiales), soit à effectuer des opérations de rotation mentale qui seraient moins complexes que dans le premier cas parce que portant sur des objets bi- et tridimensionnels relativement simples. En outre, en regard de l'aptitude à effectuer des rotations de stimuli tridimensionnels, la capacité à mémoriser —même assez sommairement chez les hommes-- l'emplacement occupé par divers objets semble davantage inhérente aux comportements masculins de navigation, alors que les hommes affichent une moindre performance que les femmes sur ce chapitre. Ceci renforce ainsi l'idée selon laquelle le mode de navigation des hommes repose de façon assez substantielle sur les référents spatiaux topologiques, tout comme on pouvait le présumer aussi en ce qui concerne les femmes. Mais la mobilité est pourtant plus fortement corrélée à la performance dans l'épreuve des figures intriquées chez les femmes que chez les hommes. Or la perspective de l'implication d'une pression évolutive liée à une navigation ancestrale plus importante chez les hommes vise à rendre compte de l'avantage masculin actuel, même léger, dans les tâches de visualisation spatiale comme celle des figures intriquées.

Globalement donc, ces indications portent à penser que si, au cours de l'évolution de notre espèce, la navigation pratiquée par les hommes sur une large échelle semble bien avoir nécessité le concours de plusieurs habiletés spatiales, ce type de pression sélective ne contribuerait que partiellement à expliquer la supériorité masculine observée de nos jours dans un ensemble d'épreuves spatiales. La meilleure capacité des hommes à manipuler mentalement des données bi- et tridimensionnelles paraît trouver ici une réponse satisfaisante quant à son origine adaptative. Cependant, dans la genèse de certaines habiletés spatiales, également à l'avantage des individus de sexe masculin, l'influence potentielle de sources de pression évolutive non liées à la navigation semble aussi suggérée par le profil des présents résultats. Il convient en effet de noter que la seule tâche spatiale qui se révèle sans relation avec la superficie des domaines vitaux est l'épreuve d'horizontalité des liquides où la supériorité des hommes demeure néanmoins assez nette. La résolution de cette tâche fait toutefois intervenir la connaissance du principe de l'invariance de l'horizontalité des surfaces liquides. Tel qu'indiqué dans le premier manuscrit, la meilleure compréhension masculine des principes physiques, incluant celui de la gravité, pourrait elle-même avoir été plus particulièrement héritée d'une forme de compétition intermâles mettant en jeu le lancer et l'interception de projectiles. Des travaux s'avèrent donc nécessaires pour vérifier l'existence d'une relation fonctionnelle, plus accentuée chez les individus de sexe masculin, entre la maîtrise de concepts mécaniques et cinétiques, sous-jacents à la solution de certaines tâches spatiales, et l'habileté à manipuler des projectiles.

Conclusion générale

La présente recherche a permis de conforter l'idée selon laquelle, chez les mammifères présentant des caractères polygynes, la sélection sexuelle pourrait être le mécanisme le plus à même d'avoir favorisé, chez les mâles, tant une expansion de la navigation et/ou une inclination à interagir de façon agonistique au moyen de projectiles, que les aptitudes spatiales qui sous-tendent ces deux types de patrons comportementaux. En revanche, la sélection naturelle paraît apte à avoir mis en place, chez les femelles, un système de limitation de la navigation, ainsi qu'un profil cognitif essentiellement centré sur l'encodage et la rétention des informations spatiales situées dans l'environnement immédiat. Dans son ensemble, cette analyse suggère que les différences intersexes dans les habiletés spatiales animales autant qu'humaines auraient ultimement une valeur adaptative en regard des contraintes de reproduction et de survie qui, dans l'environnement ancestral de plusieurs espèces, se seraient exercées de manière différentielle selon le sexe des individus. Il est donc particulièrement intéressant de signaler ici que si, comme le portent à penser de nombreux éléments empiriques, la sélection naturelle a surtout opéré sur la capacité spatiale des femelles et que ces dernières ont pu renforcer l'action de la sélection sexuelle sur les aptitudes cognitives des mâles -- en choisissant leurs partenaires masculins prioritairement parmi ceux présentant les aptitudes spatiales les plus adaptatives --, alors cela signifie que les individus de sexe féminin auraient joué un rôle prépondérant au cours de la phylogenèse de la cognition spatiale.

La présente étude menée au sein d'une société occidentale a aussi révélé que lorsque les paramètres culturels, démographiques, sociogéographiques et professionnels sont contrôlés, les hommes exploitent des domaines vitaux actuels globalement plus vastes que ceux des femmes et que leur degré de réussite dans plusieurs épreuves spatiales est plus souvent associé à l'amplitude de leurs déplacements que dans le cas des femmes. Ces résultats sont en adéquation avec l'hypothèse de la genèse d'une portion des habiletés spatiales en réponse à des patrons de navigation masculin et féminin hérités de nos ancêtres. Cependant, il convient de souligner la nature corrélationnelle des données recueillies; celle-ci ne peuvent donc, en aucune façon, démontrer ou prouver le bien fondé d'une relation de causalité entre l'action présumée des facteurs évolutifs ici invoqués et les schèmes comportementaux et cognitifs observés en relation avec l'espace. En effet, tout au plus ces données permettent-elles de renforcer la plausibilité de l'hypothèse darwinienne énoncée précédemment puisque, n'ayant pas infirmé sa validité, elles témoignent du potentiel explicatif et prédictif d'un tel paradigme en regard des différences intersexes dans les habiletés spatiales de plusieurs espèces, incluant la nôtre. De plus, il est important de rappeler que ce témoignage, tout comme les principes conceptuels avec lesquels il se confond, n'écarte pas l'influence exercée sur la cognition spatiale par des facteurs ontogénétiques, comme l'apprentissage. Loin de s'opposer à ces derniers, les approches darwiniennes cherchent généralement à les intégrer, les concevant comme des médiateurs de l'évolution, la capacité à effectuer des apprentissages, aussi sophistiqués puissent-ils être et aussi fonctionnels que soient leurs produits, étant elle-même très probablement le fruit d'un processus de sélection.

Appendice A

Questionnaire portant sur les informations générales et sur celles liées aux déplacements habituels des participants et participantes

Renseignements généraux

Le questionnaire suivant vise à recueillir certains renseignements personnels en relation avec vos habitudes de déplacement de manière générale. Les informations que vous allez inscrire ici sont essentielles à la bonne marche de cette enquête scientifique et elles s'avèrent complémentaires aux informations relatives au formulaire que vous remplissez à la maison.

Veuillez lire attentivement chaque question et pour chacune d'elles, répondez en lettres MAJUSCULES **moulées** ou encerclez le nombre correspondant à la réponse qui vous paraît la plus adaptée à votre cas personnel. Chaque personne est différente, de sorte qu'il n'y a pas de bonnes ou de mauvaises réponses. Nous tenons à vous assurer que tout ce que vous allez écrire restera **strictement confidentiel et ne sera utilisé qu'à des fins de recherche**.

SI CERTAINES QUESTIONS NE S'APPLIQUENT PAS À VOUS (par exemple, si vous n'avez pas d'enfant, ou n'avez plus de parents), PASSEZ AUX QUESTIONS SUIVANTES.

1. **Où êtes-vous né(e)?**

Dans la municipalité de --

Province ou État de------------------------ Pays-------------------------------

2. **Où est né votre premier enfant?**

Dans la municipalité de --

Province ou État de------------------------ Pays-------------------------------

3. **Où est née votre mère?**

Dans la municipalité de --

Province ou État de------------------------ Pays-------------------------------

4. **Où est né votre père?**

Dans la municipalité de --

Province ou État de------------------------- Pays-------------------------------

5. **Si vous avez vécu <u>toute la période de votre petite enfance et adolescence</u>** (entre l'âge de 2 ans et 15 ans) **dans <u>un même endroit</u>, indiquez-le maintenant et passez ensuite à la question 7. (Sinon, allez directement à la question 6).**

Dans la municipalité de --

Province ou État de------------------------- Pays-------------------------------

6. **Si vous avez déménagé <u>au moins une fois</u> durant la période de votre enfance et de votre adolescence** (entre l'âge de 2 ans et 15 ans), **indiquez les endroits successifs et les différents âges que vous aviez alors.**

1. Dans la municipalité de --de à ans

Province ou État de------------------------- Pays-------------------------------

2. Dans la municipalité de --de à ans

Province ou État de------------------------- Pays-------------------------------

3. Dans la municipalité de --de à ans

Province ou État de------------------------- Pays-------------------------------

4. Dans la municipalité de --de à ans

Province ou État de------------------------- Pays-------------------------------

5. Dans la municipalité de --de à ans

Province ou État de------------------------- Pays-------------------------------

6. Dans la municipalité de --de à ans

Province ou État de------------------------- Pays-------------------------------

PLUSIEURS DES QUESTIONS SUIVANTES DEMANDENT PARFOIS UN EFFORT DE MÉMOIRE. MERCI D'ESSAYER D'ÊTRE LE PLUS PRÉCIS POSSIBLE DANS VOS RÉPONSES ET D'ÉCRIRE EN LETTRES MAJUSCULES MOULÉES CHAQUE FOIS QUE C'EST NÉCESSAIRE.

7. **Indiquez le CODE POSTAL de votre domicile actuel.**

___ ___

8. **Quelle est la rue et le coin de rue le plus proche de votre lieu de travail actuel.**

Sur la rue ----------------------------------, au coin de la rue --------------------------

dans la municipalité de ------------------------

9. **Indiquez la rue et le coin de rue le plus proche de l'école de votre enfant ou de chacun de vos enfants.**

1. Sur la rue ----------------------------------, au coin de la rue ------------------------

dans la municipalité de ------------------------

2. Sur la rue ----------------------------------, au coin de la rue ------------------------

dans la municipalité de ------------------------

3. Sur la rue ----------------------------------, au coin de la rue ------------------------

dans la municipalité de ------------------------

10. **Indiquez la rue et le coin de rue le plus proche de la garderie de votre enfant ou de chacun de vos enfants.**

1. Sur la rue ----------------------------------, au coin de la rue ------------------------

dans la municipalité de ------------------------

2. Sur la rue ----------------------------------, au coin de la rue ------------------------

dans la municipalité de ------------------------

11. **Si votre ou vos enfants n'habitent pas avec vous, indiquez la rue et le coin de rue le plus proche de leur domicile. S'ils ne vivent pas tous ensemble, répondez en fonction de l'un deux.**

Sur la rue ----------------------------------, au coin de la rue --------------------------

dans la municipalité de ------------------------

12. **Si vos enfants ne vivent pas ensemble, indiquez la rue et le coin de rue le plus proche du domicile d'un deuxième enfant.**

Sur la rue ---------------------------------------, au coin de la rue ------------------------------

dans la municipalité de -------------------------

13. **Indiquez la rue et le coin de rue le plus proche du domicile d'un troisième enfant.**

Sur la rue ---------------------------------------, au coin de la rue ------------------------------

dans la municipalité de -------------------------

14. **Indiquez la rue et le coin de rue le plus proche du domicile de vos parents. Si vos parents ne vivent pas ensemble, répondez en fonction de l'un de vos deux parents.**

Leur domicile est situé sur la rue ----------------------- au coin de la rue ----------------------

dans la municipalité de ------------------------------ Province ou État de--------------------

Pays---

15. **Si vos parents ne vivent pas ensemble, indiquez la rue et le coin de rue le plus proche du domicile de l'autre de vos deux parents.**

Le domicile est situé sur la rue ----------------------- au coin de la rue ----------------------

dans la municipalité de ------------------------------ Province ou État de--------------------

Pays---

16. **En dehors des lieux où se situent votre famille (parents ou enfants), ou votre travail, PENSEZ au <u>lieu où vous vous rendez le plus souvent</u>** (ex; la piscine ou un terrain de sport, un parc pour faire de la marche, un club de rencontre, la bibliothèque ou ailleurs...). **Indiquez la rue et le coin de rue le plus proche de <u>ce lieu où vous vous rendez le plus souvent</u>.**

Sur la rue ---------------------------------------, au coin de la rue ------------------------------

dans la municipalité de -------------------------

17. **Si il existe un deuxième lieu où vous rendez aussi très souvent** (ex; la piscine ou un terrain de sport, un parc pour faire de la marche, un club de rencontre, la bibliothèque ou ailleurs...). **Indiquez la rue et le coin de rue le plus proche de <u>ce lieu où vous vous rendez très souvent</u>.**

Sur la rue ---------------------------------------, au coin de la rue ------------------------------

dans la municipalité de -------------------------

18. **En dehors des lieux où se situent votre famille (parents ou enfants), ou votre travail, PENSEZ à la** **<u>personne que vous visitez actuellement le plus souvent</u>** (ex; un(e) ami(e), votre partenaire amoureux, un thérapeute, un conseiller ou quelqu'un d'autre...) **Indiquez la rue et le coin de rue le plus proche du <u>lieu où habite la personne que vous visitez actuellement le plus souvent</u>.**

Sur la rue ----------------------------------, au coin de la rue --------------------------

dans la municipalité de ------------------------

19. **S'il existe une deuxième personne que vous visitez aussi très souvent,** (ex; un(e) ami(e), votre partenaire amoureux, un thérapeute, un conseiller ou quelqu'un d'autre...), **indiquez la rue et le coin de rue le plus proche du <u>lieu où habite cette personne que vous visitez actuellement très souvent</u>.**

Sur la rue ----------------------------------, au coin de la rue --------------------------

dans la municipalité de ------------------------

20. **S'il existe une troisième personne que vous visitez aussi très souvent,** (ex; un(e) ami(e), votre partenaire amoureux, un thérapeute, un conseiller ou quelqu'un d'autre...), **indiquez la rue et le coin de rue le plus proche du <u>lieu où habite cette personne que vous visitez actuellement très souvent</u>.**

Sur la rue ----------------------------------, au coin de la rue --------------------------

dans la municipalité de ------------------------

21. **Quelle est la rue et le coin de rue le plus proche de l'endroit où vous faites habituellement <u>votre marché</u> (pour votre alimentation)?**

Sur la rue ----------------------------------, au coin de la rue --------------------------

dans la municipalité de ------------------------

22. **Si vous avez l'habitude de faire votre marché dans <u>plus d'un</u> magasin ou centre d'achat, indiquez la rue et le coin de rue le plus proche de l'endroit où vous faites habituellement <u>votre marché</u> (pour votre alimentation)?**

Sur la rue ----------------------------------, au coin de la rue --------------------------

dans la municipalité de ------------------------

23. **Si vous avez l'habitude de faire votre marché dans <u>plus d'un</u> magasin ou centre d'achat, indiquez la rue et le coin de rue le plus proche de l'endroit où vous faites habituellement <u>votre marché</u> (pour votre alimentation)?**

Sur la rue ----------------------------------, au coin de la rue --------------------------

dans la municipalité de ------------------------

24. Indiquez la rue et le coin de rue le plus proches de l'endroit où vous faites habituellement du magasinage pour des vêtements ou pour vos loisirs.

Sur la rue -----------------------------------, au coin de la rue --------------------------

dans la municipalité de ------------------------

25. Si vous avez l'habitude de faire du magasinage dans <u>plus d'un</u> magasin ou centre d'achat, indiquez la rue et le coin de rue le plus proches de l'endroit où vous faites habituellement du magasinage pour des vêtements ou pour vos loisirs.

Sur la rue -----------------------------------, au coin de la rue --------------------------

dans la municipalité de ------------------------

26. Quelle est la rue et le coin de rue le plus proche du restaurant ou du café-bar où vous aimez aller le plus souvent, seul(e) ou avec des ami(e)s.

Sur la rue -----------------------------------, au coin de la rue --------------------------

dans la municipalité de ------------------------

27. Combien de fois, en moyenne, allez-vous dans ce restaurant ou café-bar?

1- Plus de deux fois par semaine.
2- Une ou deux fois par semaine.
3- Deux fois par mois.
4- Une fois par mois.
5- Une ou deux fois par deux mois.
6- Une ou deux fois par an.

28. Vous arrive-t-il de conduire ou d'aller chercher votre enfant ou vos enfants <u>à l'école</u>?

1- Non, presque jamais.
2- Oui, une fois sur deux environ.
3- Oui, presque toujours.

29. Vous arrive-t-il de conduire ou d'aller chercher votre enfant ou vos enfants <u>à la garderie</u>?

1- Non, presque jamais.
2- Oui, une fois sur deux environ.
3- Oui, presque toujours.

30. Si vous avez des enfants et que certains ne vivent pas avec vous, combien de fois en moyenne, les visitez-vous?

1- Une fois par jour
2- Une ou deux fois par semaine
3- Deux fois par mois
4- Une fois par mois
5- Une ou deux fois par an
6- Je ne les visite pas ou presque jamais

31. **Combien de fois en moyenne, visitez-vous vos parents?**

1- Une fois par jour.
2- Une ou deux fois par semaine.
3- Deux fois par mois.
4- Une fois par mois.
5- Quelques fois par an.
6- Je ne les visite pas ou presque jamais.

32. **Combien de fois, en moyenne, allez-vous au cinéma, au théâtre ou au concert?**

1- Plus de deux fois par semaine.
2- Une ou deux fois par semaine.
3- Deux fois par mois.
4- Une fois par mois.
5- Une ou deux fois par deux mois.
6- Une ou deux fois par an.

33. **En rapport avec ce que vous avez répondu à la question 29, à quel endroit avez-vous l'habitude d'aller le plus souvent?** (n'encerclez que la réponse la plus proche de la réalité)

1- Dans le quartier où j'habite.
2- Dans le quartier où je travaille.
3- Dans le centre ville de Montréal.
4- Dans un quartier différent de ceux énumérés en 1-, 2-, 3-. Quel est ce quartier?

----

34. **Choisissez parmi les réponses suivantes, celle qui correspond le mieux à la distance que vous souhaiteriez idéalement avoir à faire, pour vous rendre de votre domicile à votre lieu de travail (imaginez que c'est possible)**

1- J'aimerais travailler dans l' immeuble ou la maison où j'habite.
2- J'aimerais travailler à moins de deux milles (trois kilomètres) de l'immeuble ou de la maison où j'habite.
3- J'aimerais travailler à plus de deux milles (trois kilomètres) de l'immeuble ou de la maison où j'habite.
4- Cette question ne s'applique pas à moi, car j'aimerais exercer une activité où j'aurais constamment à me déplacer.

35. **Imaginez maintenant que vous disposez de deux jours de temps libre sans contraintes par rapport à votre famille, votre couple ou votre travail et que vous avez le goût de vous rendre à la campagne ou dans une autre ville. Quelle serait alors LA DURÉE MAXIMALE EN AUTO que vous seriez prêt à consacrer à ce trajet, depuis votre domicile jusqu'à l'endroit que vous avez choisi, sachant que vous devez être de retour pour la veille au soir de la reprise du travail?**
(considérez seulement le trajet aller- simple)

Environ --------- minutes OU Environ ---------- heure(s)

d'ordinaire, quelle est LA VITESSE MOYENNE à laquelle vous roulez sur l'autoroute?

Environ ---------- milles/heure OU Environ ---------- kilomètres/heure

36. **Durant vos temps libres, vous arrive-t-il de quitter la ville où vous habitez pour aller passer une partie de la journée à la campagne ou dans une autre ville?**

1- Non, presque jamais. 2- Oui, environ une fois par deux mois.

3- Oui, au moins une fois par mois. 4- Oui, presqu'à chaque fin de semaine.

37. **En rapport avec ce que vous avez répondu à la question 36, à quelle DISTANCE de votre lieu de résidence vous rendez-vous alors en moyenne** (considérez seulement le trajet aller- simple)

Environ ---------- mille(s) OU Environ ---------- kilomètre(s)

38. **En rapport avec ce que vous avez répondu à la question 37, quelle est LA DURÉE EN AUTO qui vous est nécessaire pour faire ce trajet** (considérez seulement le trajet aller- simple)

Environ ---------- minutes(s) OU Environ ---------- heure(s)

39. **Il y a cinq ans, résidiez-vous à Montréal?**

1- Oui 2- Non, je résidais dans la municipalité --

Province ou État- ---

40. **Utilisez-vous votre voiture?** (n'encerclez que la réponse la plus proche de la réalité pour vous)

1- Tous les jours

2- Je la prend les fins de semaine surtout, ou durant mes moments de temps libre.

3- Je loue une voiture quelquefois durant l'année.

4- Je ne conduis jamais de voiture.

41. **Durant la dernière semaine, combien de fois approximativement, avez-vous utilisé**

l'autobus ou le métro?

zéro fois 1 à 2 fois 3 à 5 fois 6 à 8 fois 9 à 14 fois 15 fois et plus

le vélo ou la moto?

zéro fois 1 à 2 fois 3 à 5 fois 6 à 8 fois 9 à 14 fois 15 fois et plus

la voiture en tant que conducteur(rice)?

zéro fois 1 à 2 fois 3 à 5 fois 6 à 8 fois 9 à 14 fois 15 fois et plus

la voiture en tant que passager(e)?

zéro fois 1 à 2 fois 3 à 5 fois 6 à 8 fois 9 à 14 fois 15 fois et plus

42. **Pour les différents moyens de transport qui suivent, encerclez <u>pour chacun d'eux</u> le chiffre qui correspond le mieux à la <u>fréquence générale</u> selon laquelle vous l'utilisez durant vos déplacements ordinaires <u>de plus</u> de 1 mille (1,5 kms).**

<u>l'autobus ou le métro:</u>

1- JAMAIS 2- TRÈS RAREMENT 3- QUELQUEFOIS 4- SOUVENT 5- TRÈS SOUVENT

<u>À pied</u>

1- JAMAIS 2- TRÈS RAREMENT 3- QUELQUEFOIS 4- SOUVENT 5- TRÈS SOUVENT

<u>le vélo ou la moto</u>

1- JAMAIS 2- TRÈS RAREMENT 3- QUELQUEFOIS 4- SOUVENT 5- TRÈS SOUVENT

<u>la voiture en tant que conducteur(trice)</u>

1- JAMAIS 2- TRÈS RAREMENT 3- QUELQUEFOIS 4- SOUVENT 5- TRÈS SOUVENT

<u>la voiture en tant que passager(e)</u>

1- JAMAIS 2- TRÈS RAREMENT 3- QUELQUEFOIS 4- SOUVENT 5- TRÈS SOUVENT

43. **Quelle est la DISTANCE moyenne que vous estimez <u>parcourir par jour</u>, à pieds, en véhicule à deux roues et/ou comme chauffeur et/ou passager d'une automobile ou d'un transport collectif (essayez d'additionner tous vos déplacements ordinaires dans une journée normale de semaine)**

Environ ---------- mille(s) <u>OU</u> Environ ---------- kilomètre(s)

<u>ou</u> environ ---------- pieds <u>ou</u> environ ------------ mètres

44. **Quand vous aviez entre 7 et 10 ans, vous arrivait-il de jouer régulièrement seul(e) ou avec d'autres enfants, à l'<u>extérieur</u> de votre maison?**

1- Non, je jouais presque toujours à la maison ou dans la cour.

2- Oui, je jouais régulièrement à l'extérieur, en général à une distance <u>de moins</u> de trois coins de rue de chez moi.

3- Oui, je jouais régulièrement à l'extérieur , en général à une distance pouvant être <u>de plus</u> de trois coins de rue de chez moi.

POUR LES RENSEIGNEMENTS QUI SUIVENT, VEUILLEZ COMPLETER OU ENCERCLER LA RÉPONSE APPROPRIÉE À VOTRE CAS. MÊME SI CERTAINES QUESTIONS VOUS SEMBLENT TRÈS INTIMES ET PERSONNELLES, SOUVENEZ-VOUS QUE TOUT CE QUE VOUS ÉCRIVEZ RESTERA STRICTEMENT CONFIDENTIEL.

45. Quel âge avez-vous? ------- ans

46. Quel est votre sexe?

1- masculin

2- féminin

47. Votre orientation sexuelle concerne

1- les personnes du sexe opposé au vôtre

2- les personnes des deux sexes

3- les personnes du même sexe que vous

48. Quel est votre état civil?

1- célibataire

2- en union libre

3- marié(e)

4- séparé(e), divorcé(e) ou veuf(ve)

49. Quelle est la langue maternelle de votre mère?

1- français

2- anglais

50. Quelle est la langue maternelle de votre père?

1- français

2- anglais

51. Vous travaillez

1- à temps partiel

2- à temps plein

52. Quel emploi occupez-vous? --

53. Quel est votre revenu brut individuel approximatif? (au cours de la dernière année)

1- moins de 10 000 $

2- de 10 000 à 15 000 $

3- de 16 000 à 20 000 $

4- de 21 000 à 25 000$

5- de 26 000 à 30 000$

6- de 31 000 à 35 000 $

7- de 36 000 à 40 000 $

8- de 41 000 à 50 000$

9- de 51 000 à 60 000 $

10- de 61 000 à 70 000 $

11- de 71 000 à 80 000 $

12- de 81 000 à 100 000 $

13- plus de 100 000 $

54. Indiquez le niveau de scolarité le plus élevé que vous avez complété

1- 0 - 4 ème année

2- 5 - 8 ème année

3- un peu d'école secondaire

4- Diplôme d'école secondaire

5- Diplôme d'une école d'administration ou de métiers

6- Diplôme collégial

7- Diplôme universitaire de 1 er cycle

8- Diplôme universitaire de 2 ème ou 3 ème cycle

VEUILLEZ VOUS ASSURER QUE VOUS AVEZ REPONDU À TOUTES LES QUESTIONS QUI S'APPLIQUENT À VOTRE SITUATION.

Fermez cette chemise et placez-la à votre gauche.

Appendice B

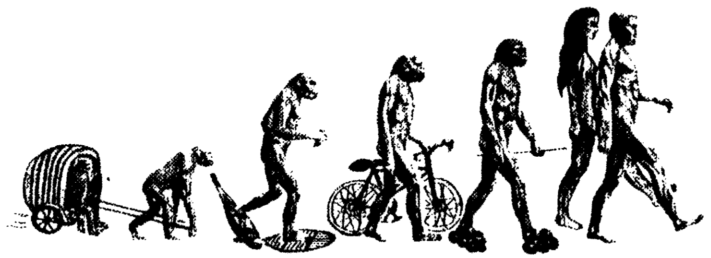
Questionnaire portant sur les informations liées aux déplacements actuels des participants et participantes

321

Université
de Montréal

Enquête Scientifique:

“VOTRE FAÇON DE VOUS DÉPLACER
Nous intéresse...”



Phase 2

Formulaire à remplir
à
domicile

Suivez ces indications pour remplir le formulaire:

- Inscrivez le <u>code postal</u> correspondant à votre <u>domicile</u> dans le cadre supérieur droit des pages # 1 et 2. Ainsi, il ne vous sera **plus nécessaire de répéter votre adresse personnelle** dans les colonnes du formulaire correspondant aux différents jours de la semaine, **<u>même si dans une seule journée</u>,** vous repassez à votre domicile plusieurs fois.

- Notez <u>le jour</u> et <u>le mois</u> en haut de **<u>chaque</u>** colonne correspondant aux jours de la semaine où vous participez à l'enquête.

- Utilisez les codes chiffrés suivant, représentant les différents moyens de transport que vous pouvez utiliser au cours de vos déplacements :

1:	**Auto** (conducteur)	**5:**	**Moto**
2:	**Métro**	**6:**	**Vélo**
3:	**Autobus**	**7:**	**À pieds**
4:	**Auto** (passager)	**8:**	**Autre**

En face de chacun des déplacements que vous effectuez, vous **pouvez inscrire,** dans la colonne T (transport), jusqu'à **<u>trois</u>** moyens de locomotion différents pour un même déplacement.

Ex:

T
2
3
7

(Ceci représente un déplacement effectué d'abord en métro, puis en autobus et, enfin, à pieds.)

- Chaque soir, prenez quelques instants pour transcrire vos **notes de brouillon** de la journée dans la colonne appropriée.

Ex: ***<u>Madame X a transcrit ses notes de brouillon du lundi 15 avril comme suit:</u>***

LUNDI (JOUR) 15 (MOIS) 04	T	
No 4450 Rue DE MAISONNEUVE O Ville MONTREAL	1	(Le matin, elle s'est sans doute rendue en **auto (1)** à son lieu de travail.)
No 1500 Rue STE CATHERINE O Ville MONTREAL	3	(À la pause de midi, elle a peut-être décidé de prendre **l'autobus (3)** pour se rendre au centre ville y déguster son lunch et faire un peu de magasinage.)
No 4450 Rue DE MAISONNEUVE O Ville MONTREAL	2 7	(Puis elle a regagné son lieu de travail pour l'après-midi en **métro (2)**, et **à pieds (7)** pour le reste du chemin)
No 4120 Rue CHAMBORD Ville MONTREAL	1	(En fin d'après-midi, elle est passée en **auto (1)** prendre ses enfants à l'école de son quartier.) (Puis **Madame X est rentrée chez elle,** mais **<u>ne l'inscrit pas</u>** car **elle a déjà indiqué** son code postal.)
No 3200 Rue ST MARTIN E Ville LAVAL	4	(En soirée, le conjoint de Madame X l'a accompagnée **en auto (4)** pour souper chez son père qui réside à Laval.) **(Quand elle a regagné son domicile, elle <u>ne le note pas</u>** car **elle a déjà indiqué** son code postal.)

IMPORTANT:

ECRIVEZ avec un stylo bille ou encre

en lettres MAJUSCULES moulées

Codes chiffrés des moyens de transport utilisés:

1: Auto (conducteur)
2: Métro
3: Autobus
4: Auto (passager)
5: Moto
6: Vélo
7: À pieds
8: Autre

Inscrivez ici
le CODE POSTAL de votre domicile:

— — — - — — —

LUNDI (JOUR) — — (MOIS) — —	T	MARDI (JOUR) — — (MOIS) — —	T	MERCREDI (JOUR) — — (MOIS) — —	T
No ________	—	No ________	—	No ________	—
Rue ______________________	—	Rue ______________________	—	Rue ______________________	—
Ville ______________________	—	Ville ______________________	—	Ville ______________________	—
No ________	—	No ________	—	No ________	—
Rue ______________________	—	Rue ______________________	—	Rue ______________________	—
Ville ______________________	—	Ville ______________________	—	Ville ______________________	—
No ________	—	No ________	—	No ________	—
Rue ______________________	—	Rue ______________________	—	Rue ______________________	—
Ville ______________________	—	Ville ______________________	—	Ville ______________________	—
No ________	—	No ________	—	No ________	—
Rue ______________________	—	Rue ______________________	—	Rue ______________________	—
Ville ______________________	—	Ville ______________________	—	Ville ______________________	—
No ________	—	No ________	—	No ________	—
Rue ______________________	—	Rue ______________________	—	Rue ______________________	—
Ville ______________________	—	Ville ______________________	—	Ville ______________________	—
No ________	—	No ________	—	No ________	—
Rue ______________________	—	Rue ______________________	—	Rue ______________________	—
Ville ______________________	—	Ville ______________________	—	Ville ______________________	—

IMPORTANT:

ECRIVEZ avec un stylo bille ou encre

en lettres MAJUSCULES moulées

Codes chiffrés
des moyens de transport utilisés:

1: Auto (conducteur)	5: Moto
2: Métro	6: Vélo
3: Autobus	7: À pieds
4: Auto (passager)	8: Autre

<u>Inscrivez</u> à nouveau ici
le CODE POSTAL de votre domicile:

___ ___ ___ - ___ ___ ___

LUNDI (suite)	T	MARDI (suite)	T	MERCREDI (suite)	T
No ________	___	No ________	___	No ________	___
Rue ________________________	___	Rue ________________________	___	Rue ________________________	___
Ville ________________________	___	Ville ________________________	___	Ville ________________________	___
No ________	___	No ________	___	No ________	___
Rue ________________________	___	Rue ________________________	___	Rue ________________________	___
Ville ________________________	___	Ville ________________________	___	Ville ________________________	___
No ________	___	No ________	___	No ________	___
Rue ________________________	___	Rue ________________________	___	Rue ________________________	___
Ville ________________________	___	Ville ________________________	___	Ville ________________________	___
No ________	___	No ________	___	No ________	___
Rue ________________________	___	Rue ________________________	___	Rue ________________________	___
Ville ________________________	___	Ville ________________________	___	Ville ________________________	___
No ________	___	No ________	___	No ________	___
Rue ________________________	___	Rue ________________________	___	Rue ________________________	___
Ville ________________________	___	Ville ________________________	___	Ville ________________________	___
No ________	___	No ________	___	No ________	___
Rue ________________________	___	Rue ________________________	___	Rue ________________________	___
Ville ________________________	___	Ville ________________________	___	Ville ________________________	___

JEUDI (JOUR) —— (MOIS) ——	T	VENDREDI (JOUR) —— (MOIS) ——	T	SAMEDI (JOUR) —— (MOIS) ——	T
No ———	—	No ———	—	No ———	—
Rue ———	—	Rue ———	—	Rue ———	—
Ville ———	—	Ville ———	—	Ville ———	—
No ———	—	No ———	—	No ———	—
Rue ———	—	Rue ———	—	Rue ———	—
Ville ———	—	Ville ———	—	Ville ———	—
No ———	—	No ———	—	No ———	—
Rue ———	—	Rue ———	—	Rue ———	—
Ville ———	—	Ville ———	—	Ville ———	—
No ———	—	No ———	—	No ———	—
Rue ———	—	Rue ———	—	Rue ———	—
Ville ———	—	Ville ———	—	Ville ———	—
No ———	—	No ———	—	No ———	—
Rue ———	—	Rue ———	—	Rue ———	—
Ville ———	—	Ville ———	—	Ville ———	—
No ———	—	No ———	—	No ———	—
Rue ———	—	Rue ———	—	Rue ———	—
Ville ———	—	Ville ———	—	Ville ———	—

DIMANCHE (JOUR) —— (MOIS) ——	T		T		T
		No ———	—	No ———	—
		Rue ———	—	Rue ———	—
		Ville ———	—	Ville ———	—
No ———	—	No ———	—	No ———	—
Rue ———	—	Rue ———	—	Rue ———	—
Ville ———	—	Ville ———	—	Ville ———	—

UTILISEZ LA DEUXIÈME PAGE POUR LA SUITE (*PLUS DE 6 DÉPLACEMENTS DANS LA JOURNÉE*)

JEUDI (suite)	T	VENDREDI (suite)	T	SAMEDI (suite)	T
No	—	No	—	No	—
Rue	—	Rue	—	Rue	—
Ville	—	Ville	—	Ville	—
No	—	No	—	No	—
Rue	—	Rue	—	Rue	—
Ville	—	Ville	—	Ville	—
No	—	No	—	No	—
Rue	—	Rue	—	Rue	—
Ville	—	Ville	—	Ville	—
No	—	No	—	No	—
Rue	—	Rue	—	Rue	—
Ville	—	Ville	—	Ville	—
No	—	No	—	No	—
Rue	—	Rue	—	Rue	—
Ville	—	Ville	—	Ville	—
No	—	No	—	No	—
Rue	—	Rue	—	Rue	—
Ville	—	Ville	—	Ville	—

DIMANCHE (suite et fin)	T		T		T
		No	—	No	—
		Rue	—	Rue	—
		Ville	—	Ville	—
No	—	No	—	No	—
Rue	—	Rue	—	Rue	—
Ville	—	Ville	—	Ville	—

Pour toutes informations supplémentaires,
n'hésitez pas à appeler au:

990-1849

Un membre de l'équipe de recherche
vous retournera votre appel.

Votre collaboration nous est très précieuse.
Nous tenons à vous en remercier chaleureusement!

Appendice C

Accord des coauteurs

Accord des coauteurs

1) Identification de l'étudiante et du programme (option s'il y a lieu)

Isabelle Ecuyer-Dab, Ph.D. Psychologie « Sciences cognitives »

2) Liste des auteurs, titre de l'article, revue visée si article en fin de préparation

Ecuyer-Dab, I., Robert, M., Have sex differences in spatial ability evolved from a male competition for mating and a female concern for survival. Cognition.

3) Déclaration du coauteur :

A titre de coauteure de l'article identifié ci-dessus, je suis d'accord pour que Isabelle Ecuyer-Dab inclue cet article dans sa thèse de doctorat qui a pour titre : Analyse évolutionniste des différences intersexes dans les habiletés spatiales.

Nom du coauteur : Michèle ROBERT

Signature : [redacted]

Date : Le 11 décembre 2001

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