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Salivary testosterone is related to both handedness and degree of linguistic lateralization in normal women

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Abstract

The aim of this study was to test the hypothesis that individual differences in testosterone (T) are associated with different patterns of linguistic lateralization and hand preference. Twenty left-handed (LH) and 19 right-handed (RH) women filled in a handedness questionnaire and performed a consonant–vowel dichotic listening test (DL-CV). Salivary T was measured by radioimmunoassay (RIA). LH women showed significantly lower mean salivary T than RH women. T levels were negatively correlated with the absolute value of the DL laterality index. Subjects with right ear advantage (REA) were classified into strongly and weakly lateralized following Wexler et al. method (*Brain Lang*. 13 (1981) 13). When taking into account hand preference, a pattern emerged in that RH-strongly lateralized and LH-weakly lateralized women showed similar T levels. The lowest level appeared for LH-strongly lateralized women and the highest for RH-weakly lateralized women, being significantly different from each other. The results are discussed in terms of several theories that have proposed a link between testosterone and cerebral lateralization.
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Keywords: Testosterone; Handedness; Linguistic lateralization; Dichotic listening

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1. Introduction

The standard pattern of cerebral lateralization is characterized by right-handedness, left-hemisphere lateralization for the control of speech and language, and right-hemisphere superiority for visuoperceptual processes (Bryden, 1982; Hellige, 1993). Level of testosterone (T) exposure in early brain development may be one of the factors that influences the pattern of cortical asymmetry and lateralization in humans and non-human species (for a review see Wisniewski, 1998). A number of recent studies have demonstrated a link between early T exposure and the development of neuroanatomical and functional asymmetries in animals (Stewart and Kolb, 1988; Diamond, 1991; Drea et al., 1995; Westergaard et al., 2000). In humans, there have been formulated at least three different theories hypothesizing a link between early T exposure and the development of language-related asymmetries. The sexual differentiation hypothesis (Hines and Shipley, 1984) is based on data showing neural and behavioral masculinization when exposing animals prenatally to androgens (Goy and McEwen, 1980). The higher rates of left-handedness among men (Annett, 1985), and some evidence that women may be less lateralized for cognitive functions than men (McGlone, 1980), has lead to the suggestion that higher levels of prenatal T could be related to left-handedness and greater cerebral language dominance. For The Geschwind hypothesis (Geschwind and Galaburda, 1985a,b,c) T acts during a critical period of brain development to slow growth of temporoparietal areas of the left-hemisphere and/or enhance growth of the corresponding areas of the right-hemisphere. High levels of prenatal T may cause a shift of left-hemisphere functions, notably handedness and language, to the right-hemisphere, which would predispose an individual to left-handedness or ambidextrality, and reduced cerebral language dominance. On the other hand, The callosal hypothesis (Witelson and Nowakowski, 1991) proposed that cerebral lateralization may result from the pruning of callosal axons during fetal and neonatal periods, which is mediated in part by T. This perspective is based on the finding that, in men, consistent right-handers have a smaller corpus callosum than non-right-handers (Witelson, 1985, 1989; Habib et al., 1991). So, it was suggested that greater axonal pruning leads to greater lateralization of function and that, at least in men, increased levels of prenatal T would be associated with greater cerebral language dominance and a stronger right hand preference.

Evidence in favor of either theoretical approximation is limited, and comes from different approaches. First, handedness and/or cerebral language dominance have been assessed, mainly with handedness questionnaires and the dichotic listening (DL) technique, in subjects with anomalous prenatal endocrine conditions that result in increased virilization during gestation. Such conditions could be found in women exposed in utero to the synthetic estrogen diethylstilbestrol (DES) and women with congenital adrenal hyperplasia (CAH). The results of these studies have been contradictory and few have focused on linguistic lateralization (Helleday et al., 1984; Nass et al., 1987; Schachter, 1994; Scheirs and Vingerhoets, 1995; Kelso et al., 2000; Smith and Hines, 2000). Grimshaw et al. (1995) showed more robust evidence linking prenatal T to functional laterality when using samples of amniotic fluid taken from normal girls at approximately 16 weeks' gestation. They found that girls with higher prenatal testosterone tended, on assessment at age 10, to be more strongly left-hemisphere lateralized for speech and to be more strongly right-handed (RH), arguing in favor of Witelson's proposal. However, a limitation of all these studies is that left-handers could not be specifically recruited, and so the conclusions have been drawn mainly from the degree of right hand preference and not from direction.

In fact, if one looks at the predictions derived from the aforementioned hypotheses, it seems that what has been taken into account is the direction (right- vs. left-handedness) and the degree (ambidextrality, greater right hand preference) for handedness, but especially the degree for linguistic lateralization (greater vs. reduced language dominance). Some authors (Colburn, 1978; Eling, 1981) pointed out the theoretical confusion between direction and degree in DL measures, given that they are expressed in a continuous but bimodal way (laterality index, LI). Eling (1981, p. 322) suggested that "It's possible, but not necessary, that both attributes (direction and degree) are coupled to the same underlying mechanism". Moreover, it was put forward recently that the degree refers to the interhemispheric share of information, while the direction reflects intrahemispheric organization of a given function (Zaidel et al., 1995). Many handedness questionnaires suffer from the same problem as the dichotic LI, although handedness measures reflect the feature that a part of the population is ambidextrous, showing a reduced degree for hand preference for other activities different from writing (Peters, 1995). However, what a lesser degree of the dichotic LI represents in terms of neural linguistic representation is more poorly understood. In the search for a cut-off to distinguish between strongly and weakly lateralized people for a given DL LI score, Wexler et al. (1981) proposed a statistical criterion to measure the significance of an individual's ear dominance by using the χ^2-test. The authors found that the scores of strongly lateralized people, either with right ear advantage (REA) or left ear advantage (LEA), fitted best with clinical data about left or right-hemisphere linguistic representation.

Turning to testosterone, the second perspective when investigating the link between T and cerebral dominance consisted of measuring the levels of this hormone in adults with different lateralization patterns. This indirect method limits researchers' inferences about prenatal environment. However, as Moffat and Hampson (2000) argued, it is reasonable to expect adult T levels to be at least moderately representative of individual differences in early-life T secretion, given that studies of monozigotic twins show that genetic factors account for over 80% of the variance in the production rate of baseline T. Researchers have also found a similar genetic influence for other hormones, like baseline cortisol levels (Kirschbaum et al., 1992). On the other hand, the main advantage of measuring T levels in adults is that it provides the means to test cerebral lateralization and hormone levels specifically in left-handers (LH). With respect to direction of hand preference, Tan (1991) found higher T levels, when compared to right-handers, in subjects with 'anomalous dominance', defining this category as left-handers, mixed-handers, and right-handers with familial sinistrality. In studies of adults more carefully separated into right- and left-handers, Moffat and Hampson (1996) found a significantly higher mean in T level for right-handers, although this was not replicated in the Moffat and Hampson (2000) study, in which no differences between groups emerged. With respect to degree of hand preference, Tan (1993) found, in RH women, a positive correlation with T in the moderately RH and a negative correlation with T in the strongly RH.

Finally, the relationship between T and language lateralization as measured with DL has proved to be more complicated than anyone envisioned in the above theories. Moffat and Hampson (1996, 2000) studied the relationship between direction of hand preference (right vs. left hand), direction of ear advantage on DL (REA vs. LEA) and levels of T. The data showed that left-handed (LH) subjects with a left ear advantage (LH-LEA) had higher T levels than LH subjects with a right ear advantage (LH-REA). A tendency for the reversed pattern in RH subjects was also found. This led the authors to propose an association between a higher T level and lateralization of speech and praxic functions in the same hemisphere.

The purpose of the present study was to further examine the relation between T levels, hand preference and DL performance in normal adult women. We explored the possibility of differences in T levels taking into account both the direction and degree of the asymmetry observed for praxic and linguistic functions. In the case of DL, we conducted the analyses both using continuous scores and by applying the Wexler et al. (1981) method to the LI scores. Furthermore, we also measured salivary cortisol (C), a steroid not included in the above-mentioned theoretical approximations to hormones and laterality. C was analyzed as a control hormone with the aim to obtain comparable findings to those of Moffat and Hampson's (1996, 2000), who found their laterality results associated only with T.

2. Method

2.1. Subjects

Forty eight neurologically normal undergraduate women were recruited for participation. They were treated in accordance with 'Ethical Principles of Psychologist and Code of Conduct' (American Psychological Association, 1992). The women were contacted from a larger group who had offered themselves as volunteers in response to an advertisement posted around the University of Valencia. A previous by-phone interview allowed us to select the sample adjusted to the variables of interest. We asked about hand used for pencil and paper activities (writing and drawing), menstrual cycle including use of contraceptives, and hearing problems. Half of the women were self-reported right-handers (for writing and drawing) with a mean age of 22.7 years (SD = 2.7), and the other half were self-reported left-handers (for the same activities) with a mean age of 21.6 years (SD = 4.5). The hand preference was outlined with a questionnaire validated in a Spanish population (Castresana et al., 1989). The questionnaire consists of two items asking about which hand is used to write and/or to draw, and 10 items related to a variety of manual activities. Possible answers for the 10 items are right hand, left hand, both hands, which are evaluated giving 0, 2 and 1 point, respectively. The questionnaire classifies as a right-hander that subject who writes and/or draws with her right hand; and obtains a score between 0–6 points on the other 10 items. A left-hander is that subject who writes and/or draws with her left hand; and obtains a score between 7–20 points on the 10 items. The rationale for separating pencil and paper activities from others is in order to detect an 'artificial' hand preference due to social pressure (for instance a subject who writes or draws with the right hand but does all other activities with the left hand). In the 10 items, the mean score for the women who wrote/drew with their right hand was 0.6 (range 0–4), and with their left hand 15.9 (range 8–20). None of the women was taking hormonal contraceptives on testing, due to data concerning abnormal T levels when using these drugs (Bancroft et al., 1980). With regards to menstrual cycle, we selected only women who previously reported they could predict the starting of their menstruation within an interval of 3-4 days, in order to carry out the experiment either before or after menses. This was done for two reasons; first, T has a brief rise at ovulation (Valette et al., 1975; Vermeulen and Verdonk, 1976), although it has been suggested that this variability is small and the individual differences can overwhelm menstrual cycle effects (Dabbs and De La Rue, 1991). Secondly, there are data supporting an influence of the menstrual cycle on DL performance (Altemus et al., 1989; Sanders and Wenmoth, 1998). So, half of the sample (premenstrual group) performed the test 1–10 days before the predicted start of their next menstruation (Mean = 4.6) and the other half (postmenstrual group) 1–7 days following the third day of their menstruation (Mean = 2.8). First day of menses was confirmed by phone after the experiment for the premenstrual group. The menstrual phase at time of testing was counterbalanced equally between RH and LH women. Finally, hearing acuity was determined by a Lafayette 15014 C screening audiometer. Subjects included were those with no imbalance in hearing levels of more than 10 dB (at the frequencies of 500, 1000, 2000, 3000 and 6000 Hz).

2.2. Procedure

We warned the subjects not to eat, drink, smoke or brush their teeth for 1 h prior to testing. On arrival at the laboratory, all subjects were informed that they would be providing saliva for hormonal analyses, and doing some cognitive tasks in a sound-attenuated room in our laboratory. Saliva was directly collected from mouth to tube (Unitek R) 5 min later. One 10-ml sample of saliva was provided. After this they filled in the handedness questionnaire and were tested for hearing acuity. On the basis of the criteria mentioned previously, we rejected five women, and replaced them with an equal number of subjects from the original list to reach a sample of 48 women. Finally, the subjects performed the DL test session and other cognitive tests (not reported here). We carried out all testing between 1600 and 1900 h, in order to minimize the influence of circadian rhythms on T and C secretion (Besch et al., 1984; Hubert et al., 1993). All experiments were carried out in a six month period from October to March. Handedness groups were assigned to be distributed approximately equal across time of day and date of testing.

3. Materials

3.1. Dichotic listening test

The dichotic stimuli consisted of the six stop consonants paired with the vowel /a/ to form six consonant–vowel (CV) syllables (ba, da, ga, ka, pa, ta). The syllables were paired with each other in all possible combinations to form 36 different syllable pairs. From these, the homonymic pairs (ba–ba, etc.) were included in the test as a perceptual control, but they were not considered in the statistical analyses. The other 30 syllables were duplicated and recorded randomly, giving 60 test trials, with a maximum correct score of 60. The standard Consonant–Vowel DL test (CV-DL) has been validated both through a comparison with sodium amytal testing (Hugdahl et al., 1997), and through a ^{15}O-PET study on brain activation during CV-DL (Hugdahl et al., 1999). Moreover, the CV test used for this study has achieved a test–retest reliability of 0.86 (for details see Gadea et al., 2000). The DL test was replayed to the subjects from a Sony Walkman WM-EX1HG mini cassette player with plug-in type Sennheiser HD545 headphones. The output from the cassette player was calibrated at a level of 75 dB.

The subjects were informed that different syllables would be presented to each ear simultaneously, and were asked to report only the syllable perceived most clearly. Thus, one response for each trial was emphasized. However, some subjects occasionally gave two responses, and then only the first one was used in the analyses, since the first response is highly correlated to the overall ear advantage (Boles, 1992).

The data were acquired as number of correctly reported items from the left and right ear. An LI score was calculated according to the formula: $\mathrm{LI} = [(\mathrm{RE}-\mathrm{LE})/(\mathrm{RE} + \mathrm{LE})] \times 100$, where: RE=number of correct right ear scores, and LE=number of correct left ear scores. This formula compounds a bimodal distribution ranging from -100 to $+100$. Following the methodology of Wexler et al. (1981), we applied the χ^2-test to determine whether the distribution of correct responses between the right and left ears differed significantly from an even distribution (i.e. significantly different than right equal to left). In this case, for a 60-item test, and given a 90% mean accuracy overall, an LI score between $-100/-25$ or between $+25/+100$ would be significantly different from 0 at the $p < 0.05$ level ($X^2 = 3.63, p < 0.05$).

3.2. Hormonal determinations

At the end of the session, salivary samples were centrifuged and frozen at -20°C until determination. All the samples were run in duplicate in the same assay. Hormonal determinations were performed by an experienced radioimmunoassay (RIA) technician (Central Research Unit, Faculty of Medicine, University of Valencia, Spain) who was unaware of the hypothesis tested.

The salivary T assay required a previous extraction phase due to low levels in saliva. The extraction was carried out by employing 3.5 ml of ether and separating the supernatant by freezing. After evaporation at room temperature, ^{125}I-testosterone tracer was added and decanted into a coated tube with a high specific antibody provided by a commercial kit (ICN Biomedicals, Costa Mesa, CA). Bath incubation was performed at 37 °C for 2 h. After 10 min at room temperature, samples were decanted and counted by gamma counter for 1 min. Duplicate internal and external control tubes were routinely included. T levels were expressed in pmol/l and intra-assay variation coefficient was lower than 5%. Due to the adaptation of the commercial kit to salivary samples, sensitivity was recalculated as the detectable concentration equivalent to twice the standard deviation of the zero-binding value, which was below 6 pmol/l.

Salivary cortisol (C) was determined by a commercial kit adapted to salivary levels after dilution of the standard curve in the buffer, as was recommended in the protocol (Orion Diagnostica, Espoo, Finland). The saliva sample (150 μl) was mixed with ^{125}I-cortisol tracer and the tube coated with high specific antibody. The C antiserum provided in the kit is produced in rabbits by immunizing a BSA conjugate of cortisol-3-carboxy-methoxylamine. The tubes were bath incubated at 37 °C for 30 min. Finally, samples were decanted and counted for 1 min. C levels were expressed in nmol/l and internal and external controls were included in the assays. Good precision was obtained with intra-assay variation coefficients below 5% with a sensitivity of 0.8 nmol/l. C mean values are included in the normal range provided in the hormonal kit.

3.3. Statistical analysis

Hormonal data were unavailable for five subjects due to procedure disruptions during the analyses. Moreover, DL data from another four subjects were dropped from the study due to complications during testing. So the final statistical analyses included data from 39 subjects (19 right-handers and 20 left-handers).

We applied analysis of variance (ANOVA) to the dependent measures. All the analyses were repeated with analysis of covariance (ANCOVA) incorporating three covariate variables: time of day, mean hormonal concentration for each month, and number of days passed before or after menses at the time of testing (entered as negative and positive values, respectively) as an additional way of controlling the variable menstrual cycle). We also performed Pearson correlations between the hand preference questionnaire scores, the LI scores, and the T levels. All statistical analyses were performed on a PC, using the SPSS 7.5 win software. Data are presented in means and standard deviations.

4. Results

4.1. Hormone levels

The mean T level for the sample was 70.18 pmol/l (SD = 35.79), and for cortisol (C) the mean was 5.46 nmol/l (SD = 3.4). These values are within the normal range of salivary T and C in women (Vittek et al., 1985; Kirschbaum and Hellhammer, 1992; Aardal and Holm, 1995).

4.2. Handedness and hormone levels

To investigate the effect of handedness direction (RH vs. LH) on hormone levels, we subjected the data to an ANOVA with T and C concentrations as the dependent variables. There was a significant main effect of handedness $F(1,37) = 4.47, p < 0.04$; in which RH women showed higher T concentrations (Mean = 82.09;SD = 34.95) than LH women (Mean = 58.88;SD = 33.58). Hand preference was not significant for C levels ($p = 0.30$). The additional ANCOVA showed the same results and none of the covariates reached significance. To investigate the effect of degree of handedness we performed Pearson correlations between T levels and the handedness questionnaire scores, separated for the group of RH and LH women. None of the correlations was significant.

4.3. Handedness and dichotic listening

Table 1 shows means and standard deviations for all the DL variables. Menstrual cycle (premenstrual vs. postmenstrual group) did not modify DL scores for RH or LH women. Regarding handedness direction, although LH women showed a lower mean for the right ear scores, a higher mean for the left ear scores, and also a lower mean LI, the ANOVA performed was not significant in any case. The analysis was also repeated with the same covariates listed previously, but all variables were again non-significant. To investigate the effect of handedness degree, we performed Pearson correlations between the handedness questionnaire scores and the LI, separated for RH and LH groups, and including only subjects with a REA ($n = 31$). LEA

Table 1
DL scores for the whole sample and separated for handedness (RH: right-handed; LH: left-handed). The mean and the standard deviation are shown for each ear. For LI the range is also shown. Below are listed the number of subjects (and percentages) with a REA, LEA or No Ear Advantage (LI = 0; NEA)

	Total	RH	LH
Right ear			
Mean (SD)	31.92 (7.94)	33.05 (7.25)	30.85 (8.60)
Left ear			
Mean (SD)	20.28 (7.01)	18.68 (6.49)	21.80 (7.30)
LI			
Mean (SD)	21.89 (27.44)	27.49 (25.31)	16.57 (28.95)
Range	[−42.9/66.7]	[−20/66.7]	[−42.9/63]
REA *n* (%)	31 (79.5%)	17 (89.5%)	14 (70%)
LEA *n* (%)	7 (18%)	2 (10.5%)	5 (25%)
NEA *n* (%)	1 (2.5%)	0	1 (5%)

subjects were excluded to avoid the confusion between degree and direction of lateralization. None of the correlations was significant.

4.4. Handedness, hormone levels and dichotic listening

4.4.1. Direction of DL asymmetry

We applied an ANOVA to test the hypothesis proposed by Moffat and Hampson (1996, 2000) that LH-LEA subjects would have higher T levels than LH-REA subjects. Although the mean T concentration for the LH-LEA women was in fact higher (70.37, SD = 31.93) than for the LH-REA women (57.14, SD = 34.58), the ANOVA was not significative ($F(1,17) = 0.55$). The comparison between RH-REA and RH-LEA subjects was not performed because there were only two RH women with a LEA.

4.4.2. Degree of DL asymmetry

We performed Pearson correlations between T levels and the LI score of the REA subjects. A highly significant negative correlation was found ($r(31) = -0.54, p < 0.002$), which was also significant for RH ($r(17) = -0.50, p < 0.04$) and for LH subjects ($r(14) = -0.69, p < 0.006$). Moreover, with the aim of including LEA individuals in the analysis, we applied Pearson correlations between T levels and the absolute value of the LI. The correlations were again significant and negative, both for the whole sample ($r(39) = -0.43, p < 0.005$) and for subgroups of RH ($r(19) = -0.51, p < 0.02$) and LH women ($r(20) = -0.48, p < 0.03$).

Additionally, and following Wexler's method, we applied the +25 cut-off point to the LI scores of the REA subjects, classifying them into strongly (S) (LI higher than 25, $n = 18$) and weakly (W) lateralized (LI lower than 25, $n = 13$). An ANOVA with the factor strength of REA (S vs. W) was performed on the dependent hormonal measures (T and C). The ANOVA was significant for T levels ($F(1,29) = 7.6, p < 0.01$), but not for C levels ($p = 0.11$). The additional ANCOVA performed showed the same results. Thus, for the REA women, the S lateralized showed lower levels of T (Mean = 55.80,SD = 25.02)) than the W lateralized (Mean = 87.82,SD = 39.54)), independent of their hand preference. We could not apply the same analysis to the LEA subjects (with the −25 cut-off point) because there were only two S and five W lateralized LEA women.

Finally, we classified the REA subjects on the basis of the variables hand preference (RH/LH) and strength of REA (S/W). The sample was divided into four groups: RH-S ($n = 10$), RH-W ($n = 7$), LH-S ($n = 8$), and LH-W ($n = 6$). An ANOVA was performed with the factor group (four levels) on the dependent variables T and C concentrations, which proved to be significant for T ($F(3,27) = 4.13, p < 0.01$), but not for C ($p = 0.23$). Post hoc Tukey HSD test revealed that T levels were significantly higher for the RH-W women than for the LH-S women ($p < 0.009$). None of the other comparisons reached statistical significance. Fig. 1 shows mean T levels with respect to direction of handedness and degree of the dichotic LI.

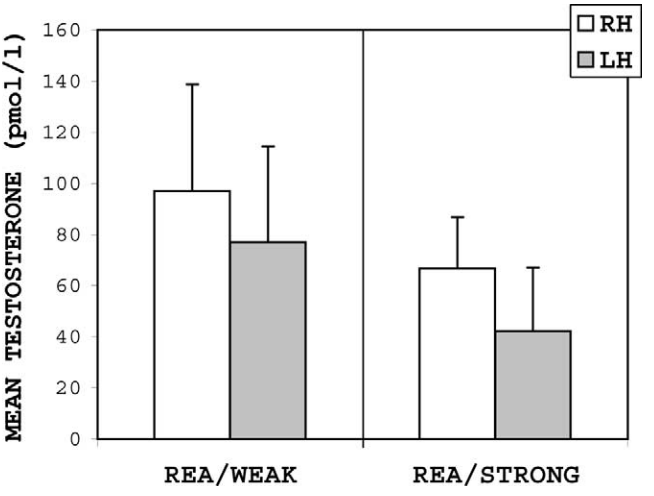

Fig. 1. Mean testosterone concentration (pmol/l) as a function of handedness (RH: right-handed; LH: left-handed) and degree (weak vs. strong) of the LI score for the women who obtained a REA. Small bars: standard deviation.

5. Discussion

The aim of this study was to test the hypothesis that individual differences in T are associated with different patterns in linguistic lateralization as measured with DL, and with praxic lateralization reflected in hand preference. There were various interesting findings. First, and replicating Moffat and Hampson (1996) finding, the higher T levels were associated with right-handedness. Secondly, T levels were negatively correlated with the absolute value of the LI for the whole sample. Moreover, and from a dichotomic point of view, the higher T levels were also associated with a weak LI when considering only REA subjects, and independent of the subject's hand preference. Thirdly, the combination of the variables handedness (RH/LH) and a strong (S) or weak (W) LI for REA subjects revealed a pattern of results in which the groups RH-S and LH-W showed a similar level of T. These groups were in an intermediate point between the group LH-S (the lowest T levels), and the group RH-W (the highest T levels), these extremes being significantly different from each other. These effects were found in healthy women with salivary T levels that fell within the normal range. We carefully controlled diurnal and circannual rhythms in T secretion, through counterbalancing and additional analyses of covariance. Moreover, we controlled the menstrual cycle with both methods, in an attempt to exclude the potential influence of hormones other than T on DL performance. The results did not extend to C levels, which were measured as a control hormone that is not supposed to be related to lateralization.

Our results did not fit exactly with any of the theoretical perspectives proposed about the association between T and functional asymmetries. With respect to manual preference, both the sexual differentiation and the Geschwind and Galaburda hypothesis suggested that high levels of T would be associated with left-handedness or ambidextrality, while the callosal hypothesis proposed that high levels of T would be related to right-handedness. With respect to linguistic lateralization, the sexual differentiation and the callosal hypothesis would predict a higher lateralization index related to higher T levels, while Geschwind and Galaburda hypothesized an opposite pattern.

In this study we found higher levels of T associated with right-handedness, and also with a lesser degree of linguistic lateralization independent of the subject's hand preference. It seems to be that, while our data regarding hand preference were more congruent with the callosal approximation, the data regarding linguistic lateralization were more in consonance with the hypothesis of Geschwind and Galaburda. Our position here is one that points out the confusion in the laterality literature on the interpretation/difference between degree and direction (of hand preference, or LI in DL) (Colburn, 1978). Given that point, it could be that the association between T and cerebral dominance is different for degree than for direction of lateralization. For example, the available data about hand preference and T in adults show higher T levels for right-handers than for left-handers (Moffat and Hampson, 1996) but opposite patterns of correlations with T when exploring, for only right-handers, their strong or weak right hand preference (Tan, 1993).

On the other hand, our data regarding T and direction of LI for LH subjects do not disagree completely with those of Moffat and Hampson (1996, 2000), because LH-LEA subjects had in fact a higher mean than LH-REA subjects. This difference was not significant, but this could be due to the small sample of LH-LEA subjects (5), which makes it more difficult to detect any disparity.

Another point of interest was that the groups RH-S and LH-W lateralized showed equal T levels. It is known that, in general, left-handers show a lower mean in laterality scores than right-handers, although the difference is not always—as in this study—significant, presumably due to a greater variance for left-handers' scores (Bryden, 1988; Kim, 1994). Assuming this, we could suggest (given the present data, and within a normal range of T levels) that the 'typical' patterns of relationship between hand preference and degree of linguistic lateralization (RH-S and LH-W) are both associated with a given level of T, at least in women. Deviations from this level could also be associated with a disruption in that relationship, with patterns like LH-S or RH-W emerging. We think it could be worth examining this suggestion with larger samples of both sexes.

To conclude, we think that an integrated theory about lateralization and testosterone should take into account two points: First, asymmetry for praxic function could be relatively independent of asymmetry for linguistic function; second, the relationship of T with asymmetry for praxis and language could be different if we consider the direction *or* the magnitude of that asymmetry. In this sense, and following the proposal of Zaidel et al. (1995) about direction vs. degree of laterality, our data suggest that the higher levels of T are associated with a praxic intrahemispheric organization located at the left-hemisphere, and, on the other hand, with a higher degree of interhemispheric share of linguistic information. Moreover, when combining praxic and linguistic functions, subjects with left intrahemispheric praxis and low interhemispheric linguistic share showed similar T levels than subjects with right intrahemispheric praxis and high interhemispheric linguistic share. Given that both organizations can be considered typical (although with a different incidence in the population), this suggests the presence of a third latent factor (probably genetic) which would operate to define a concrete organization in an individual brain. We also suggest that, once this hypothetic factor exerts its influence, deviations of T levels could modify the association between praxis and language. Thus, the higher T levels would promote left intrahemispheric praxis with high interhemispheric linguistic share, and the lower T levels would promote right intrahemispheric praxis with low interhemispheric linguistic share.

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