Psychoneuroendocrinology (2009) **34**, 1214—1221

available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/psyneuen

Hormone exposure and functional lateralisation: Examining the contributions of prenatal and later life hormonal exposure

Victoria J. Bourne*, **Dawn L. Gray**

School of Psychology, University of Dundee, Park Place, Dundee, DD1 4HN, UK

Received 16 December 2008; received in revised form 12 March 2009; accepted 12 March 2009

KEYWORDS
2D:4D ratio;
Hormone replacement therapy;
Chimeric faces test;
Landmark task

Summary An increasing amount of research has shown a relationship between hormonal exposure and functional lateralisation. In this study different sources of hormonal exposure were examined: prenatal exposure, estimated using the 2D:4D ratio, and later life exposure through examining the effects of hormone replacement therapy. In addition to considering multiple sources of hormonal exposure, three tests of functional lateralisation were used: two versions of the chimeric faces test, one using positive emotion and the other using negative emotion, and the landmark task. The same effects were found across all three measures of lateralisation. Lower 2D:4D ratios, which indicate high levels of prenatal testosterone exposure, were associated with stronger right hemisphere dominance. Later life hormonal exposure was not found to be associated with any of the lateralisation measures. This finding suggests a relationship between prenatal hormonal exposure and brain organisation.

1. Introduction

An increasing amount of research recently has examined a possible relationship between hormone exposure and functional lateralisation. While there is some evidence for such a relationship, the research in this area has typically considered only one source of hormonal exposure or one measure of lateralisation within each study. In this study we consider both prenatal and later life hormonal exposure on three tests of lateralisation in an attempt to further elucidate the relationship between hormones and brain organisation.

Prenatal hormonal exposure has been found to influence patterns of functional lateralisation in later life. For example, Cohen-Bendahan et al. (2004) measured language lateralisation patterns using a dichotic listening task and compared same-sex and opposite-sex twin girls. They found that girls from an opposite sex-twin pair were more strongly lateralised. They suggested that the increased prenatal exposure to testosterone led to more "masculine" patterns of lateralisation (males are typically found to be more strongly lateralised than females; for an example regarding emotion lateralisation see Bourne, 2005).

Other research has examined the role of prenatal testosterone exposure by using the 2D:4D digit ratio. It is now quite well established that the comparative lengths of the second and fourth digits are associated with prenatal hormonal

* Corresponding author.
E-mail address: v.bourne@dundee.ac.uk (V.J. Bourne).

0306-4530/$ — see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.psyneuen.2009.03.010

exposure and that higher levels of prenatal testosterone exposure and lower levels of prenatal oestrogen exposure are associated with lower 2D:4D ratios. This relationship was initially suggested by Manning et al. (1998) and evidence for this has come from a variety of sources. Children with congential adrenal hyperplasia (which is associated with increased prenatal androgens) tend to have lower, or more masculine, 2D:4D ratios (e.g., Brown et al., 2002; Okten et al., 2002). Similarly, women who suffer from polycystic ovary syndrome tend to have increased levels of testosterone and also have lower 2D:4D ratios (Cattrall et al., 2005). A direct link between levels of prenatal testosterone and 2D:4D ratio has been shown by Lutchmaya et al. (2004) who measured levels of testosterone in the amniotic fluid and found an association with 2D:4D. Additionally, work with rats has shown that experimentally increasing levels of prenatal testosterone reduces 2D:4D (Talarovičová et al., 2009) and experimentally reducing levels of prenatal testosterone increases 2D:4D (McMechan et al., 2004). Given the association between prenatal hormonal exposure and 2D:4D, it is not surprising that there is a frequently found sex difference, with males having significantly lower 2D:4D ratios than females (e.g., Putz et al., 2004; Manning et al., 2007).

Very little work has considered whether there may be a relationship between 2D:4D and lateralisation. A magnetic resonance imaging (MRI) study showed a relationship between 2D:4D ratio and hippocampal volume (Kallai et al., 2005). The left side of the posterior section of the hippocampus was found to be significantly smaller in women with low 2D:4D ratios, whereas the left side of the midsection of the hippocampus was found to be smaller in women with high 2D:4D ratios. A number of studies have also considered the relationship between handedness and 2D:4D. Left handers have been found to have lower, or more masculine, 2D:4D ratios (Nicholls et al., 2008). 2D:4D has also been found to be associated with asymmetric hand skill (Manning et al., 2000; Fink et al., 2004; Manning and Peters, in press). Jackson (2008) found that handedness was associated with 2D:4D, but when only considering the interaction between 2D:4D and finger length. On the basis of these studies, it seems that the use of 2D:4D ratio as an estimator of prenatal testosterone and oestrogen exposure may provide some interesting insights into the relationship between hormonal exposure and lateralisation.

While relatively little research has considered the role of prenatal hormonal exposure on lateralisation of cognitive functions, somewhat more has considered how hormonal fluctuations in later life might influence the strength of functional asymmetry. This work has considered two sources of hormonal variability: changes across the menstrual cycle and changes resulting from hormone replacement therapy (HRT).

When considering changes in lateralisation (various cognitive functions have been examined) across the menstrual cycle, the rationale is to compare asymmetries during menses, when levels of progesterone and oestrogen are low, with asymmetries after ovulation in the luteal phase, when levels of progesterone and oestrogen are high. It has been suggested that during the luteal phase strength of lateralisation decrease, and this has been found across a number of lateralised tasks. For example, Hausmann and Güntürkün, 2000 found this pattern for both verbal (left hemisphere) and non-verbal (right hemisphere) tasks. They specifically suggested that the hormonal fluctuation influenced the non-dominant hemisphere for that task (i.e., right hemisphere for verbal and left hemisphere for non-verbal), making lateralisation patterns more symmetrical. They also suggested that this may be a result of higher levels of progesterone which lead to a decrease in interhemispheric interaction that consequently causes more symmetrical lateralisation (Hausmann and Güntürkün, 2000; Hausmann et al., 2002; Hausmann, 2005).

The effect of HRT on lateralisation has also been examined. Doty et al. (2008) compared functional asymmetry for an odour memory/discrimination task between women not taking HRT and those taking an oestrogen based HRT. They found that those taking the HRT showed a more strongly lateralised odour memory and discrimination performance bias than those not taking any form of HRT. Another study (Bayer and Erdmann, 2008) compared lateralisation for word (left hemisphere) and face processing (right hemisphere) in three groups of postmenopausal women: women not taking HRT, women taking oestrogen only HRT and women taking oestrogen—progesterone combined HRT. The women not taking HRT and those taking the combined form of HRT showed the expected lateralisation patterns. Those taking the oestrogen only HRT showed enhanced right hemisphere processing on the language task. Unfortunately, in both of these studies, there was no young control group, so it is not possible to determine the exact effect that HRT had on lateralisation. For example, does taking HRT increase lateralisation patterns or protect against age-associated changes in lateralisation?

In this study we consider two possible source of hormonal exposure: prenatal exposure by measuring 2D:4D and later life exposure by considering the effects of HRT on lateralisation for two cognitive functions: emotion processing and visuospatial attention. In terms of the 2D:4D ratio measure, it is predicted that individuals with a low, or masculine, 2D:4D ratios will be more strongly lateralised on both of the lateralised cognitive tasks. Importantly, in addition to testing postmenopausal women, a young control group was also included. This will allow a far greater understanding of the effect of HRT on lateralisation, particularly in terms of distinguishing between changes in lateralisation that may be due to HRT and changes that may be due to ageing. This is particularly important given that a variety of previously lateralised cognitive processes have been found to become more asymmetric with increasing age (see Cabeza, 2001; Dolcos et al., 2002). There are two possible outcomes. First, HRT might protect against age associated changes in lateralisation, in which case patterns of asymmetry in the HRT group would be expected to be similar to the younger control group. Second, HRT may influence lateralisation, in which case the patterns of lateralisation in the HRT group may be different from either of the other groups.

Three different measures of lateralisation will also be used in this study. Two different forms of the chimeric faces test (one positive emotion and one negative emotion) will be used. The chimeric faces test is a frequently used test of lateralisation for processing facial emotion (e.g., Compton et al., 2003; Heath et al., 2005; Bourne, 2005, 2008). Typically this test shows a left visual field, or right hemisphere, bias. However, there is some current controversy regarding the lateralisation of emotion processing. Some suggest and

find that all emotion processing is lateralised to the right hemisphere (e.g., Christman and Hackworth, 1993; Nakamura et al., 1999; Workman et al., 2000; Kucharska-Pietura and David, 2003; Ashwin et al., 2005), whereas others support the valence hypothesis and propose that the processing of positive emotion is lateralised to the left hemisphere and the processing of negative emotion is lateralised to the right hemisphere (e.g., Davidson, 1992; Jansari et al., 2000; Adolphs et al., 2001; Rodway et al., 2003). For this reason two versions of the chimeric faces test were used, one with positive emotion (happiness) and one with negative emotion (anger). The landmark task was also used. This is a test of visuospatial attention that is lateralised to the right hemisphere (Fink et al., 2001). By using multiple tests of lateralisation it will be possible to consider whether the influence of hormones on lateralisation is generalised or more function specific.

2. Methods

2.1. Participants

Seventy-seven Caucasian women participated in this study. There were four groups of women; two younger groups: one not on the contraceptive pill ($N = 22$; mean age = 20, SD = 2.1) and one on the contraceptive pill ($N = 12$; mean age = 21, SD = 1.7); and two older groups: one not taking HRT ($N = 25$; mean age = 57, SD = 5.3) and one taking HRT[1] ($N = 18$; mean age = 55, SD = 7.5). Women in the HRT group had all been on HRT for at least one year (range = 1—21, mean = 8.5, SD = 7.8). Participants were recruited through advertising in the University of Dundee online digest and through adverts in the local newspaper.

Overall there was a significant difference in age across the four groups ($F(3, 73) = 331.2$, $p < .001$). There was no significant difference in age between the two younger groups ($p = 1.0$) or between the two older groups ($p = .827$). Both of the younger groups were significantly younger than both of the older groups (all comparisons $p < .001$). None of the women in the two younger groups had children. Nineteen (76%) of the women in the older non-HRT group had children (range = 1—5). Twelve (67%) of the women in the older HRT group had children (range = 1—5). The women in the two younger groups were all undergraduate students. The older women had an average of 15 years of education (SD = 4.5) suggesting that many were educated to degree level. There was no significant difference in years of education across the four groups ($F(3, 73) = 1.7$, $p = .180$) and did not differ between any of the four groups (all pairwise comparisons $p \geq .171$).

All women were right handed by self-report and this was confirmed using a handedness questionnaire (adapted from Dorthe et al., 1995). None reported having suffered either a head injury or a diagnosis of a psychiatric disorder. The women either received course credit or payment of £8 for participating. This study was given ethical approval by the ethics committee of the School of Psychology, University of Dundee.

2.2. Digit ratio measurement

Finger lengths were measured using digital callipers. 2D:4D ratio was measured for each hand. A low 2D:4D ratio (i.e., <1) indicates high levels of prenatal testosterone exposure and low levels of prenatal oestrogen exposure so a masculine 2D:4D ratio. A high 2D:4D ratio (i.e., ≥ 1) indicates low levels of prenatal testosterone exposure and high levels of prenatal oestrogen exposure so a feminine 2D:4D ratio. Mean 2D:4D, across the entire sample, for the left hand was .99 (SD = .04) and for the right hand was .98 (SD = .03). There was a significant correlation between the left and right hand 2D:4D ratios ($r = .627$, $p < .001$). Analyses for each hand separately showed no difference between the hands, so the mean 2D:4D ratio was calculated and used in all subsequent analyses. The mean 2D:4D in this sample was .986 (SD = .03) which is significantly different from 1 ($t(76) = 3.8$, $p < .001$). This suggests that the sample of women used in this study tended to have higher levels of prenatal testosterone exposure, lower levels of prenatal oestrogen exposure and more masculine 2D:4D ratios.[2]

2.3. Chimeric faces test

Stimuli were those used by Workman et al. (2006) and were made using the Ekman emotional faces. Faces were created using vertically split half faces where one-half is neutral and the other half expresses an emotion, either happiness or anger. Half of the stimuli were formed from a male face and half from a female face. Faces were presented in greyscale on a white background and subtended approximately 4.5° horizontally and 7° vertically at a viewing distance of 52 cm. Participants were instructed to fixate centrally on the screen and a chin rest was used to aid this and to maintain the viewing distance. Faces were presented in pairs with one above the other. One face was expressing emotion in the viewers left visual field and the other was expressing emotion in the viewer's right visual field. Consequently there were four pairs of stimuli for each emotion: male with expression in the left visual field in the top face, male with expression in the left visual field in the bottom face, female with expression in the left visual field in the top face and female with expression in the left visual field in the bottom face. Each stimuli pair was shown six times, making a total of twenty-four trials for each emotion.

The presentation of the faces was randomised and presented in two blocks, one presenting the happy faces and one presenting the angry faces. Order of completing the two emotions was counterbalanced across participants. Face pairs were presented centrally on a computer screen and remained onscreen until participants responded. Participants

[1] Within the HRT group six women were on an oestrogen only type HRT and twelve were on a combined oestrogen and progesterone type HRT. There were no differences between these women on the three lateralisation measures so they were combined for these analyses. The implications of this are considered in the discussion of this paper.

[2] There is no obvious explanation for why the 2D:4D ratios in this sample of women shows a more masculine pattern, however comparable digit ratios in women have been reported in other studies (e.g., Hönekopp et al., 2007; Putz et al., 2004).

Table 1 Descriptive statistics (mean and standard deviation) for the entire sample and each group of women separately for each of the 2D:4D and lateralisation measures.

	N	2D:4D		CFT: Happy		CFT: Angry		Landmark	
		M	SD	M	SD	M	SD	M	SD
All participants	77	.99	.03	.32	.41	.41	.44	.55	.25
Younger: not on contraceptive pill	22	.99	.03	.30	.38	.48	.40	.59	.24
Younger: on contraceptive pill	12	.98	.03	.38	.43	.49	.41	.62	.22
Older: not on HRT	25	.98	.03	.37	.42	.35	.44	.53	.29
Older: on HRT	18	.99	.04	.24	.44	.37	.52	.50	.21

were asked to decide, as quickly but as accurately as possible, which of the two faces was happier or angrier depending on the stimuli being shown. If the top face was deemed to be more expressive participants pressed the left button on a response pad. If the bottom face was deemed to be more expressive participants pressed the right button on a response pad. Participants responded using their right hand. Stimulus presentation and response recordings were achieved using Superlab. Responses were used to calculate a laterality quotient[3] for each emotion that ranged from −1 to +1. Negative scores indicated a left hemisphere (right visual field) bias, whereas positive scores indicated a right hemisphere (left visual field) bias.

2.4. Landmark task

The landmark task comprised horizontal lines, 200 mm in length, with a vertical divider of 10 mm × 0.2 mm. These lines were black and presented on a white background in the centre of a computer screen. Stimulus presentation and response recording was achieved using SuperLab Pro. Eighty trials were completed. In half of the trials the line was bisected at the veridical centre. In the remaining trials, lines were bisected either to the left or right of centre with deviations of 1 mm, 2 mm, 3 mm, 4 mm or 5 mm. Order of presentation was randomised. Participants were asked to decide which side of the line was the longer and to indicate this by pressing either a leftward or rightward button on a response pad. Right responses were always made with the right hand, and left responses were made with the left hand. Participants were instructed to respond as quickly but as accurately as possible. Only responses to the centrally bisected lines were analysed. The number of leftward choices was recorded (maximum of 40) and this was used to calculate the proportion of leftward choices; hence values over .5 indicate a left visual field (right hemisphere) bias.

2.5. Statistical analyses

Two sets of analyses were conducted. The first set examined whether the expected lateralisation biases were found for the three lateralisation tasks. This was achieved by using one-sample *t* tests to compare the laterality scores (laterality quotient for the two chimeric faces tests and proportion of leftward choices for the landmark task) to reference values which represent no lateralised biases in responding. For the chimeric faces test, possible scores range from −1 (left hemisphere bias) to +1 (right visual field bias), with 0 representing no lateralised bias. Therefore, for the chimeric faces test analyses the comparison value is 0 and scores significantly larger (i.e., positive) would indicate right hemisphere dominance. For the landmark task, the scores range from 0 (all rightward decisions) to 1 (all leftward decisions) with .5 representing no bias towards either leftward or rightward decision. Therefore, for the landmark task analysis the comparison value is .5 and scores significantly larger than .5 would indicate right hemisphere dominance.

The second set of analyses examined whether hormonal exposure was predictive of lateralisation. Separate analyses were conducted for each lateralisation measure, hence three analyses were conducted. In order to analyse the differences between the four groups of women in a regression model, it was necessary to treat the groups as dummy variables as each group represented a discreet category and there was no linear continuum across the groups. Three dummy variables were calculated. As the younger group who were not on the pill was not of primary interest in these analyses, this group was not used as a dummy variable. Therefore each of the remaining three groups was each treated as separate dummy variables in the analyses. These dummy variables represent the difference between that participant group and the other three groups in combination. For each of the regression analyses four predictor variables were entered into the model: the dummy variable representing the younger group on the contraceptive pill, the dummy variable representing the older group not on HRT, the dummy variable representing the older group on HRT and the 2D:4D ratio. All four variables were simultaneously entered into the model.

3. Results

Laterality quotients were significantly above 0 (see Table 1), indicating right hemisphere dominance (happy: $t(76) = 6.9$, $p < .001$; angry: $t(76) = 8.2$, $p < .001$). For the landmark task the proportion of leftward choices was significantly above chance ($t(76) = 1.8$, $p = .039$) indicating right hemisphere dominance. These analyses suggest that all three tests of lateralisation showed right hemisphere dominance. For the landmark task this shows the predicted lateralised bias. For the chimeric faces tests, both the positive and negative emotions showed a significant right hemisphere bias, which is consistent with the predictions of the right hemisphere hypothesis. One-way independent ANOVAs comparing laterality scores across the four groups of women showed no significant differences (happy CFT: $F(3, 73) = .5$, $p = .708$;

[3] Laterality quotient = (Number of LVF choices − (24 − Number of LVF choices))/24.

Table 2 Summary of regression analyses with 2D:4D and each of the dummy variables predicting lateralisation across the three different measures (see Section 2 for a full description of how the analyses were conducted).

	CFT: Happy			CFT: Angry			Landmark		
	β	t	p	β	t	p	β	t	p
2D:4D	*−3.1*	*−2.2*	*.032*	*−3.4*	*−2.3*	*.026*	*−2.5*	*−3.0*	*.003*
Younger: on contraceptive pill	.1	.5	.615	.1	.1	.990	.1	.3	.771
Older: not on HRT	.1	.6	.563	−.1	−1.1	.274	−.1	−.9	.357
Older: on HRT	−.1	−.3	.769	−.1	−.7	.517	−.1	−.9	.346

Significant results are italicised.

angry CFT: $F(3, 73) = .5$, $p = .654$; landmark: $F(3, 73) = .8$, $p = .502$).

For the happy chimeric faces test, the overall model was not significant ($F(4, 72) = 1.6$, $p = .193$) only explaining 2.9% of the variance in strength of lateralisation. Looking at the individual predictors (see Table 2), only 2D:4D ratio was a significant predictor of lateralisation for processing positive emotion. The same pattern was found for the angry chimeric faces. The overall model was not significant ($F(4, 72) = 1.7$, $p = .156$) only explaining 3.6% of the variance in strength of lateralisation. Looking at the individual predictors (see Table 2), only 2D:4D ratio was a significant predictor of lateralisation for processing negative emotion. A similar pattern was found for the landmark task, although the overall model was significant ($F(4, 72) = 3.0$, $p = .025$) explaining 9.4% of the variance in strength of lateralisation. Again, 2D:4D was the only significant predictor of landmark bias (see Table 2).

The same pattern of results was found across all three of the lateralisation tests: a relationship with 2D:4D ratio, but not with later life hormonal exposure. For all tests a negative relationship was found, showing that participants with lower 2D:4D ratios tend to be more strongly lateralised. It is interesting to consider the extent to which the relationship may differ across the three tests. In order to do this we ran zero-order correlations between 2D:4D ratio and each of the laterality measures and then statistically compared them (see Table 3). None of the correlations differed significantly (all p's $\geq .579$) suggesting that the relationship between 2D:4D ratio and lateralisation is the same across different behavioural tests of lateralisation.

Zero-order correlations were also run examining the relationship between each of the lateralisation measures and 2D:4D ratio for the left and right hands separately and the difference between the left and right hands (see Table 3). These were conducted as previous work had shown that the right hand 2D:4D ratio and the difference in 2D:4D ratio between the hands are the 2D:4D measures that are most strongly correlated with hand preference (Manning et al., 2000). The correlations show that, for all three of the lateralisation measures, the relationship between 2D:4D ratio and strength of lateralisation is larger for the right hand 2D:4D than for the left hand 2D:4D. The difference between the hands was not correlated with any of the lateralisation measures.

4. Discussion

The main finding of this paper was a relationship between 2D:4D ratio and strength of lateralisation for both emotion processing and visuospatial attention. Across three tests of lateralisation the same pattern was found: participants with lower 2D:4D ratios, which indicates high levels of prenatal testosterone exposure and low levels of oestrogen exposure, were more strongly lateralised.

This finding fits well with the existing literature on sex differences in lateralisation which has frequently shown that males are more strongly lateralised than females on a variety of cognitive tasks, including emotion and language processing (e.g., Kansaku et al., 2000; Baxter et al., 2003; Bourne, 2005, 2008; Proverbio et al., 2006). This lends support to the argument that sex differences in lateralisation, possibly for any cognitive task, may be explained in terms of hormonal exposure (e.g., Putz et al., 2004; Hausmann, 2005). According to this explanation it is the increased levels of testosterone and lower levels of oestrogen in males which influences strength of cerebral lateralisation. The findings presented in this paper support this view as women with 2D:4D ratios indicating high levels of prenatal testosterone exposure and

Table 3 Zero order correlations between the three lateralisation measures and 2D:4D ratio for each hand separately, the mean 2D:4D ratio across both hands (the primary measure used in the regression analyses) and the difference in 2D:4D ratio between the hands.

	CFT: Happy		CFT: Angry		Landmark	
	r	p	r	p	r	p
Mean 2D:4D ratio	*−.260*	*.022*	*−.259*	*.023*	*−.342*	*.002*
Left hand 2D:4D ratio	−.204	.075	−.212	.064	*−.288*	*.011*
Right hand 2D:4D ratio	*−.271*	*.017*	*−.258*	*.023*	*−.334*	*.003*
2D:4D ratio difference (R−L)	−.031	.792	−.008	.947	.006	.956

Significant correlations are italicised.

low levels of oestrogen exposure (i.e., more masculine hormonal exposure) were more strongly lateralised for processing facial emotion and visuospatial attention.

While our findings suggest that hormonal exposure may explain strength of lateralisation for the two right hemisphere tasks examined, it is not clear from this study whether hormone exposure might provide a complete explanation. There are two possible ways in which hormone exposure might be implicated in accounting for the sex difference in lateralisation of cognitive functions. First, it might be that hormonal exposure provides a complete account of lateralisation strength. Second, it might be that hormonal exposure explains some of the variability of lateralisation within each sex. It is not possible to distinguish between these possibilities with the data presented here as only females were tested. However, a replication examining the relationship between 2D:4D and lateralisation across a variety of cognitive tasks in both males and females would help to clarify this issue. If hormone exposure completely explains the sex difference in lateralisation, then this should not be evident when controlling for 2D:4D ratio.

Although this study provides strong support for the role of hormones in explaining sex differences in lateralisation of emotion processing and visuospatial attention, this does not necessarily mean that hormonal exposure is the only possible account of the reported sex differences. Two alternative accounts have been suggested. One explanation is that sex differences in strength of lateralisation may in fact be explained in terms of sex differences in interhemispheric transfer (e.g., Nowicka and Fersten, 2001). This explanation is not necessarily incompatible with a hormonal explanation as a relationship has also been reported between hormonal exposure and interhemispheric transfer (e.g., Hausmann and Güntürkün, 2000; Bayer et al., 2008). This explanation is not necessarily incompatible with the data presented in this paper and further research is necessary to examine a possible interaction between hormonal exposure, strength of lateralisation and speed of interhemispheric transfer.

A second explanation is that sex differences in lateralisation may be explained in terms of men and women using different strategies for completing lateralised tasks (Welsh and Elliott, 2001). This possibility may be explained in terms of hormonal exposure. Typically men perform at a higher level on visuospatial cognitive tasks, whereas women tend to perform at a higher level on verbal cognitive tasks (Halpern, 2000). Performance on "male" cognitive tasks and "female" cognitive tasks has been found to vary systematically according to oestrogen exposure (see Sherwin, 2003) and testosterone exposure (e.g., Schattmann and Sherwin, 2007). It is therefore possible that the relationship between hormone exposure and lateralisation occurs as a result of differences in cognitive ability and strategies for completing cognitive tasks. Again, this possibility requires further examination.

The relationship between prenatal hormonal exposure and strength of lateralisation was found across three different tests of lateralisation: processing positive facial emotion, processing negative facial emotion and visuospatial attention. This suggests that the influence of hormones is not specific to a particular lateralised cognitive ability, but that hormones have more general effect on the cognitive processing mechanisms that are lateralised to the right hemisphere. However, all three measures were tests of right hemisphere cognitive functions and indeed all showed significant right hemisphere biases. It is not clear from this study how hormonal exposure might influence strength of lateralisation for left hemisphere tasks. It would be interesting to replicate this study with additional lateralisation measures of left hemisphere functions.

The possibility of hormones having different effects on the left and right hemispheres is particularly relevant given that some have argued for a hemisphere specific effect of hormones. For example, some have suggested that hormonal exposure has a greater effect on the left hemisphere (Bibawi et al., 1995) while others have suggested that hormonal exposure has a greater effect on the right hemisphere (Sanders and Wenmoth, 1998). Alternatively it has been suggested that the effect of hormones on lateralisation is due to fluctuations in interhemispheric transfer (Hausmann, 2005). Our data suggests that hormonal exposure does influence right hemisphere lateralisation, however the exact nature of this is unclear. For example, it may be that the differences found in strength of lateralisation across different cognitive tasks actually reflect differences in speed of interhemispheric transfer.

In this study we did not find an effect of HRT use on any of the lateralisation measures. This is somewhat unexpected given that previous work has shown stronger patterns of lateralisation for women on HRT for language lateralisation (Bayer and Erdmann, 2008) and odour memory and discrimination (Doty et al., 2008). Bayer and Erdmann (2008) compared the effects of oestrogen only HRT and combined oestrogen and progesterone HRT and only found stronger patterns of language lateralisation in the oestrogen only group. This suggests that different effects may be found for different types of HRT. Our sample included women on oestrogen only HRT ($N = 6$) and women on combined oestrogen and progesterone HRT ($N = 12$). On the basis of the findings of Bayer and Erdmann (2008), it may be predicted that the effects differ between these two groups and that combining them may have caused possible findings to be reduced. A comparison of the laterality scores according to the type of HRT being taken reveals no significant differences (happy CFT: $t(18) = 1.0$, $p = .354$; angry CFT: $t(18) = .8$, $p = .453$; landmark task: $t(18) = .1$, $p = .936$). This suggests that the type of HRT being taken was not associated with strength of lateralisation for either emotion processing or visuospatial attention; however the relatively small sample sizes, particularly in the oestrogen only HRT group, means that this possibility cannot be discounted. It is also possible that the effects of HRT on strength of lateralisation may only be apparent after a long period of time. The duration of having taken HRT was wide ranging, from one year through to twenty-one years. It may be that the effects were only apparent in those who had taken HRT for a long period of time. Within our data set this seems unlikely as duration was not correlated with any of the lateralisation measures (happy CFT: $r = .28$, $p = .269$; angry CFT: $r = .15$, $p = .558$; landmark task: $r = -.1$, $p = .948$).

It is interesting to consider the extent to which the association between hormone exposure and strength of lateralisation for emotion processing and visuospatial attention might vary according to the type of hormonal exposure. 2D:4D provides a combined estimator of prenatal testosterone and oestrogen exposure; therefore it is not possible to distinguish between these in terms of whether one particular

hormone, or even both, might be influencing strength of lateralisation for the two tasks. Within the HRT group we can only consider the possible effects of oestrogen and progesterone on lateralisation for emotion processing and visuospatial attention. Although we failed to find a relationship, other studies have (Bayer and Erdmann, 2008; Doty et al., 2008), therefore it seems hasty to suggest that there is no relationship. It would, however, be interesting to try to distinguish more specifically between the effect of oestrogen and testosterone on strength of lateralisation across a number of tasks. One possible way this could be achieved would be to compare lateralisation patterns on a variety of cognitive tasks in women taking HRT, who have increased levels of oestrogen, with women who are suffering from polycystic ovary syndrome, who have been found to have increased levels of testosterone. No work has yet considered patterns of lateralisation for any cognitive function in women with polycystic ovary syndrome, but it has been shown that these women tend to perform less well on cognitive tasks that typically show a female advantage (Schattmann and Sherwin, 2007). It may therefore be predicted that women suffering from polycystic ovary syndrome may show stronger (more masculine) patterns of lateralisation.

This study has found a relationship between 2D:4D ratio and strength of cerebral lateralisation across three different right hemisphere tasks. This finding suggests that women with lower levels of prenatal oestrogen exposure and higher levels of prenatal testosterone exposure have stronger patterns of lateralisation for emotion processing and visuospatial attention. Given that men have been shown to be more strongly lateralised than females (across a variety of cognitive tasks), this finding lends support to the suggestion that hormonal exposure influences functional lateralisation, and may account for the reported sex difference. The exact nature of this relationship, whether this relationship may be found in both hemispheres and whether the relationship between hormonal exposure and lateralisation is a direct one is still unclear; however this study provides good evidence which furthers our understanding of why the brains of men and women may differ.

Role of funding source

This work was supported by a grant from the British Academy (SG-48294). The funding body had no further role in any stage of this research.

Conflict of interest

None declared.

Acknowledgement

This work was supported by a grant from the British Academy (SG-48294).

References

Adolphs, R., Jansari, A., Tranel, D., 2001. Hemispheric perception of emotional valence from facial expressions. Neuropsychology 15, 516—524.

Ashwin, C., Wheelwright, S., Baron-Cohen, S., 2005. Laterality biases to chimeric faces in Asperger syndrome: what is 'Right' about face-processing? J. Autism Dev. Disord. 35, 183—196.

Baxter, L.C., Saykin, A.J., Flashman, L.A., Johnson, S.C., Guerin, S.J., Babcock, D.R., Wishart, H.A., 2003. Sex differences in semantic language processing: a functional MRI study. Brain Lang. 84, 264—272.

Bayer, U., Erdmann, G., 2008. The influence of sex hormones on functional cerebral asymmetries in postmenopausal women. Brain Cogn. 67, 140—149.

Bayer, U., Kessler, N., Gunturkun, O., Hausmann, M., 2008. Interhemispheric interaction during the menstrual cycle. Neuropsychologia 46, 2415—2422.

Bibawi, D., Cherry, B., Hellige, J.B., 1995. Fluctuations of perceptual asymmetry across time in women and men—effects related to the menstrual-cycle. Neuropsychologia 33, 131—138.

Bourne, V.J., 2005. Lateralised processing of positive facial emotion: sex differences in strength of hemispheric dominance. Neuropsychologia 43, 953—956.

Bourne, V.J., 2008. Examining the relationship between degree of handedness and degree of cerebral lateralization for processing facial emotion. Neuropsychology 22, 350—356.

Brown, W.M., Hines, M., Fane, B.A., Breedlove, S.M., 2002. Masculinized finger length patterns in human males and females with congenital adrenal hyperplasia. Horm. Behav. 42, 380—386.

Cabeza, R., 2001. Cognitive neuroscience of aging: Contributions of functional neuroimaging. Scand. J. Psychol. 42, 277—286.

Cattrall, F.R., Vollenhoven, B.J., Weston, G.C., 2005. Anatomical evidence for in utero androgen exposure in women with polycystic ovary syndrome. Fertil. Steril. 84, 1689—1692.

Christman, S.D., Hackworth, M.D., 1993. Equivalent perceptual asymmetries for free viewing of positive and negative emotional expressions in chimeric faces. Neuropsychologia 31, 621—624.

Cohen-Bendahan, C.C.C., Buitelaar, J.K., van Goozen, S.M.H., Cohen-Kettenis, P.T., 2004. Prenatal exposure to testosterone and functional cerebral lateralization: a study in same-sex and opposite-sex twin girls. Psychoneuroendocrinology 29, 911—916.

Compton, R.J., Fisher, L.R., Koenig, L.M., McKeown, R., Munoz, K., 2003. Relationship between coping styles and perceptual asymmetry. Pers. Soc. Psychol. Rev. 84, 1069—1078.

Davidson, R.J., 1992. Emotion and affective style—hemispheric substrates. Psychol. Sci. 3, 39—43.

Dolcos, F., Rice, H.J., Cabeza, R., 2002. Hemispheric asymmetry and aging: right hemisphere decline or asymmetry reduction. Neurosci. Biobehav. Rev. 26, 819—825.

Dorthe, N.J., Blumenthal, T.D., Jason, D.R., Lantz, P.E., 1995. The use of next-of-kin in assessing handedness. Percept. Mot. Skills 81, 203—208.

Doty, R.L., Kisat, M., Tourbier, I., 2008. Estrogen replacement therapy induces functional asymmetry on an odor memory/discrimination test. Brain Res. 1214, 35—39.

Fink, B., Manning, J.T., Neave, N., Tan, U., 2004. Second to fourth digit ratio and hand skill in Austrian children. Biol. Psychol. 67, 375—384.

Fink, G.R., Marshall, J.C., Weiss, P.H., Zilles, K., 2001. The neural basis of vertical and horizontal line bisection judgments: an fMRI study of normal volunteers. NeuroImage 14, 59—67.

Halpern, D.F., 2000. Sex Differences in Cognitive Abilities, 3rd ed. Lawrence Earlbaum Associates.

Hausmann, M., 2005. Hemispheric asymmetry in spatial attention across the menstrual cycle. Neuropsychologia 43, 1559—1567.

Hausmann, M., Güntürkün, O., 2000. Steroid fluctuations modify functional cerebral asymmetries: the hypothesis of progesterone-mediated interhemispheric decoupling. Neuropsychologia 38, 1362—1374.

Hausmann, M., Becker, C., Gather, U., Gunturkun, O., 2002. Functional cerebral asymmetries during the menstrual cycle: a cross-sectional and longitudinal analysis. Neuropsychologia 40, 808—816.

Heath, R.L., Rouhana, A., Ghanem, D.A., 2005. Asymmetric bias in perception of facial affect among Roman and Arabic script readers. Laterality 10, 51—64.

Hönekopp, J., Bartholdt, L., Beier, L., Liebert, A., 2007. Second to fourth digit length ratio (2D: 4D) and adult sex hormone levels: new data and a meta-analytic review. Psychoneuroendocrinology 32, 313—321.

Jackson, C., 2008. Prediction of hemispheric asymmetry as measured by handedness from digit length and 2D:4D digit ratio. Laterality 13, 34—50.

Jansari, A., Tranel, D., Adolphs, R., 2000. A valence-specific lateral bias for discriminating emotional facial expressions in free field. Cogn. Emot. 14, 341—353.

Kallai, J., Csatho, A., Kover, F., Makany, T., Nemes, J., Horvath, K., Kovacs, N., Manning, J.T., Nadel, L., Nagy, F., 2005. MRI-assessed volume of left and right hippocampi in females correlates with the relative length of the second and fourth fingers (the 2D:4D ratio). Psychiatry Res. Neuroimag. 140, 199—210.

Kansaku, K., Yamaura, A., Kitazawa, S., 2000. Sex differences in lateralization revealed in the posterior language areas. Cereb. Cortex 10, 866—872.

Kucharska-Pietura, K., David, A.S., 2003. The perception of emotional chimeric faces in patients with depression, mania and unilateral brain damage. Psychol. Med. 33, 739—745.

Lutchmaya, S., Baron-Cohen, S., Raggatt, P., Knickmeyer, R., Manning, J.T., 2004. 2nd to 4th digit ratios, fetal testosterone and estradiol. Early Hum. Dev. 77, 23—28.

Manning, J.T., Peters, M., in press. Digit ratio (2D:4D) and hand preference for writing in the BBC Internet Study. Laterality DOI:10.1080/13576500802637872.

Manning, J.T., Churchill, A.J.G., Peters, M., 2007. The effects of sex, ethnicity, and sexual orientation on self-measured digit ratio (2D:4D). Arch. Sex. Behav. 36, 223—233.

Manning, J.T., Scutt, D., Wilson, J., Lewis-Jones, D.I., 1998. The ratio of 2nd to 4th digit length: a predictor of sperm numbers and concentrations of testosterone, luteinizing hormone and oestrogen. Hum. Reprod. 13, 3000—3004.

Manning, J.T., Trivers, R.L., Thornhill, R., Singh, D., 2000. The 2nd: 4th digit ratio and asymmetry of hand performance in Jamaican children. Laterality 5, 121—132.

McMechan, A.P., O'Leary-Moore, S.K., Morrison, S.D., Hannigan, J.H., 2004. Effects of prenatal alcohol exposure on forepaw digit length and digit ratios in rats. Dev. Psychobiol. 45, 251—258.

Nakamura, K., Kawashima, R., Ito, K., Sugiura, M., Kato, T., Nakamura, A., Hatano, K., Nagumo, S., Kubota, K., Fukuda, H., Kojima, S., 1999. Activation of the right inferior frontal cortex during assessment of facial emotion. J. Neurophysiol. 82, 1610—1614.

Nicholls, M.E.R., Orr, C.A., Yates, M.J., Loftus, A.M., 2008. A new means of measuring index/ring finger (2D:4D) ratio and its association with gender and hand preference. Laterality 13, 71—91.

Nowicka, A., Fersten, E., 2001. Sex-related differences in interhemispheric transmission time in the human brain. Neuroreport 12, 4171—4175.

Okten, A., Kalyoncu, M., Yaris, N., 2002. The ratio of second- and fourth-digit lengths and congenital adrenal hyperplasia due to 21-hydroxylase deficiency. Early Hum. Dev. 70, 47—54.

Proverbio, A.M., Brignone, V., Matarazzo, S., Del Zotto, M., Zani, A., 2006. Gender differences in hemispheric asymmetry for face processing. Bmc Neurosci. 7 .

Putz, D.A., Gaulin, S.J.C., Sporter, R.J., McBurney, D.H., 2004. Sex hormones and finger length—what does 2D:4D indicate? Evol. Hum. Behav. 25, 182—199.

Rodway, P., Wright, L., Hardie, S., 2003. The valence-specific laterality effect in free viewing conditions: the influence of sex, handedness, and response bias. Brain Cogn. 53, 452—463.

Sanders, G., Wenmoth, D., 1998. Verbal and music dichotic listening tasks reveal variations in functional cerebral asymmetry across the menstrual cycle that are phase and task dependent. Neuropsychologia 36, 869—874.

Schattmann, L., Sherwin, B.B., 2007. Testosterone levels and cognitive functioning in women with polycystic ovary syndrome and in healthy young women (vol. 51, p. 587, 2007). Horm. Behav. 52, 280—1280.

Sherwin, B.B., 2003. Estrogen and cognitive functioning in women. Endocr. Rev. 24, 133—151.

Talarovičová, A., Krskova, L., Blazekova, J., 2009. Testosterone enhancement during pregnancy influences the 2D:4D ratio and open field motor activity of rat siblings in adulthood. Horm. Behav. 55, 235—239.

Welsh, T.N., Elliott, D., 2001. Gender differences in a dichotic listening and movement task: lateralization or strategy? Neuropsychologia 39, 25—35.

Workman, L., Chilvers, L., Yeomans, H., Taylor, S., 2006. Development of cerebral lateralisation for recognition of emotions in chimeric faces in children aged 5 to 11. Laterality 11, 493—507.

Workman, L., Peters, S., Taylor, S., 2000. Lateralisation of perceptual processing of pro- and anti-social emotions displayed in chimeric faces. Laterality 5, 237—249.