2D:4D digit ratio and religiosity in university student and general population samples

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Abstract

The ratio of index to ring finger length (2D:4D) is used as a proxy for prenatal sex hormone exposure. It has been hypothesised to correlate with religiosity, though no published research has explored this possibility. Here, we initially examined 2D:4D in relation to self-reported religious affiliation and questionnaire measures of general religiosity, spirituality, religious fundamentalism, and religious commitment in male (N = 106) and female (N = 105) university students (Study 1). Although no significant correlations were observed between 2D:4D and the questionnaire measures, females who affiliated with organised religions had higher digit ratios compared to agnostic or atheist females. Study 2 attempted to replicate these findings in an adult general population sample (N = 172 males, N = 257 females), but did not observe significant

effects in either sex. Overall, these findings suggest that high 2D:4D may be relatively-specifically associated with religious affiliation in young, highly-educated, females.

Keywords:

2D:4D; Digit ratio; Oestrogen; Prenatal sex hormones; Religiosity; Testosterone

1. Introduction

Studies in healthy and clinical populations, and animal models, have suggested that a low ratio of index to ring digit length (2D:4D) reflects relatively high exposure to androgens during prenatal life, although the precise meaning of this measure is disputed (Breedlove, 2010; Knickmeyer et al., 2011; Manning et al., 1998, 2014; Richards, 2017a; reply by Manning & Fink, 2017, and response by Richards, 2017b; Richards et al., 2017; Zheng & Cohn, 2011). On average, males exhibit lower 2D:4D ratios than females (Hönekopp & Watson, 2010), with such sexually dimorphic properties emerging at an early stage of gestation (Galis et al., 2009; Malas et al., 2006). Directional asymmetry between the right hand (R2D:4D) and left hand (L2D:4D), calculated as $D_{[R-L]}$, is also sometimes examined, with relatively low R2D:4D (i.e. negative $D_{[R-L]}$) believed to reflect early exposure to high levels of androgens (Manning, 2002; Manning et al., 2014).

Although there are theoretical reasons why 2D:4D may be related to religiosity, no published studies have yet examined this idea. For example, the development of paranormal and superstitious beliefs (that could be said to be related to religiosity), might rely upon a common underlying factor (see Lindeman & Aarnio, 2006), and both have been reported to be associated with high 2D:4D (Rogers, et al., 2017; Voracek, 2009, though see also Richards, 2017c). Voracek (2009) suggested that paranormal and superstitious beliefs may relate to schizotypy, a personality construct that has itself been found to be associated with feminised patterns of digit ratio (see Voracek, 2008 for a review). Although acknowledging that statistically significant relationships with paranormal and superstitious beliefs were only observed in males in his study, and that 2D:4D explained only 1-3% of the variance, Voracek (2009) ultimately concluded that

the findings "suggest biologically-based, prenatally-programmed influences on paranormal and superstitious beliefs." (p.109). Based on these observations, it might be predicted that 2D:4D and religiosity are positively correlated (i.e. high levels of prenatal testosterone exposure would be associated with low levels of subsequent religiosity).

Another reason to suggest that 2D:4D may be related to religiosity is that sex differences in both measures have been consistently observed. 2D:4D is known to be lower in males than in females (e.g. Manning et al., 1998; Hönekopp & Watson, 2010), and sex differences in religiosity have been observed across a range of cultures (Schmitt & Fuller, 2015). Females have been found to display higher attendance and involvement in rituals, praying, and self-reported membership of religious denominations (for a review, see Beit-Hallahmi & Argyle, 1997). Considering the idea that within-sex correlations of 2D:4D and 'female-typical traits' (traits in which females exceed males in scores, propensity, and risk) are expected to be positive in females and less pronounced or nil in males (Austin et al., 2002; Voracek, 2009), these observations suggest that associations between 2D:4D and religiosity will be positive. Furthermore, religiosity has been associated with lower risk-taking behaviour (e.g. Pitel et al., 2012), with Miller and Hoffmann (1995) proposing that sex differences in religiosity reflect female tendency towards risk aversion. Stark (2002) took this further by suggesting that irreligiousness might make up part of a general syndrome of short-sighted risky behaviours that may have a physiological basis. Evidence for biological influences on such processes is provided by the finding that low 2D:4D is associated with high levels of risk-taking behaviour (e.g. Garbarino et al., 2010), although it is noted that some studies have not replicated this effect (see Lima de Miranda et al., 2018).

The above evidence suggests that relationships between 2D:4D and religiosity will be positive, though it is noted that Manning (2002, p.145–146) hypothesised an effect in the opposite direction. This was based on the idea that religion could be akin to lek mating observed in some nonhuman species (i.e. it might enable displaying males to attract large numbers of reproductive females), and that charismatic religious figures may therefore have low 2D:4D ratios. It could be that the effectiveness of male displays in adulthood in lekking species is related to both the organisational effects of prenatal

testosterone exposure, and the activational effects of constitutive testosterone exposure (Alatalo et al., 1996). If high religiosity is similar to lek mating, then religious males may feasibly exhibit physiological markers consistent with high testosterone exposure, i.e. low 2D:4D and high levels of circulating testosterone; to date, there is little evidence of this (Ellis et al., 2016; Halpern et al., 1994).

Here, for the first time, we tested the idea that 2D:4D ratio is associated with religiosity (as indexed by affiliation or lack of affiliation to a religion, and by several questionnaire-based measures) using two moderately-sized samples. Based on the limited and somewhat contradictory literature, it was not possible to predict the magnitude or direction of any expected effects *a priori*, although we suspected that any relationship may be affected by sex. Our data may be relevant for understanding biological factors impacting upon an important human sociocultural behavioural phenomenon.

Study 1

2. Materials and Methods

2.1 Participants

Two hundred and eleven (106 male, 105 female) Caucasian student (predominantly undergraduate) volunteers aged 18-35 years (*median* = 20.00, *interquartile range [IQR]* = 1.00) were recruited through opportunity sampling at Swansea University, UK. Participants were informed that the study intended to examine relationships between the 2D:4D ratio and attitudes and beliefs about religion, that they would be required to complete a series of questionnaires, and that their second and fourth fingers on each hand would be measured using Vernier callipers.

The study was completed with the understanding and written informed consent of each participant, and data were anonymised so that individual responses could not be identified. The research was conducted under the approval of Swansea University's Department of Psychology Ethics Committee, and in compliance with the Declaration of Helsinki.

2.2 Apparatus/Materials

Religious affiliation was recorded with a single item. Participants were asked to state their religion, and were further instructed "if not a follower of an organised religion, please give details, e.g. agnostic or atheist".

The General Religiosity and Spirituality Measure (Saroglou & Galand, 2004; Saroglou & Muñoz-García, 2008) was employed to give an indication of intrinsic (or general) religiosity. The questions "God is important in my life" and "Religion is important in my life" were based on a seven-point scale ranging from "Not important at all" (1) to "Very important" (7). The question "Do you pray" was also scored on a seven-point scale, though differed from the other two questions in that the following responses were assigned: 1 = never, 2 = rarely (e.g. at exceptional moments in my life), 3 = occasionally (3-4 times a year), 4 = several times a year, 5 = quite often (several times a month), 6 = often (several times a week), 7 = a lot (nearly every day). The sum of the scores for these three questions was then used to give an indication of general religiosity that ranged from 3 (least religious) to 21 (most religious). For these three items, Cronbach's α for the current sample was .888. The General Religiosity and Spirituality scale also included a single item to measure spirituality ("Spirituality is important in my life"). Responses to this item were registered on a seven-point scale (1 = Not important at all, 7 = Very important).

The Revised Religious Fundamentalism Scale (Altemeyer & Hunsberger, 2004) is used to measure basic, fundamental beliefs about the nature and importance of religion. It consists of 12 items (six are reverse scored) for which participants respond how strongly they agree or disagree on a nine-point scale (-4 = very strongly disagree, 4 = very strongly agree). Possible scores range from -48 (least religious fundamentalism) to 48 (most religious fundamentalism). Cronbach's α for the whole scale was .822.

The Religious Commitment Inventory-10 (Worthington et al., 2003) was employed to give an indication of participants' levels of commitment to religion. This scale is based on Worthington's (1988) definition that religious commitment relates to the degree to which a person adheres to his or her religious values, beliefs, and practices, and uses them in daily living. Following on from this, it is presumed that highly religious people are likely to evaluate the world through religious schemas, thus integrating religion into

much of their lives. The RCI-10 lists 10 statements which the respondent is required to relate to themselves on a five-point scale (1 = not at all true of me, 2 = somewhat true of me, 3 = moderately true of me, 4 = mostly true of me, 5 = totally true of me), giving a possible range of 10 (least religious commitment) to 50 (most religious commitment). Cronbach's α for the whole scale was .920.

2.3 Design & Procedure

Direct measures of the second and fourth digits on each hand were taken twice using Vernier callipers (measuring to 0.1mm) by a single experimenter. To reduce error, participants were asked to keep their fingers straight at the time of measuring. The 2D:4D ratio was then calculated for each hand by dividing the length of the index finger by that of the ring finger; directional asymmetry was calculated as $D_{[R-L]}$ = R2D:4D – L2D:4D. Using two-way mixed, single measures intra-class correlation coefficients (*ICC*) with absolute agreement definition, it was determined that the repeatability was high for both R2D:4D, $ICC = .916$, $F = 23.083$, $p < .001$, and L2D:4D, $ICC = .889$, $F = 17.289$, $p < .001$. Each set of measurements was averaged to create the R2D:4D and L2D:4D variables that were used in all subsequent analyses.

2.4 Statistical analysis

Data are presented as mean and standard deviation for normally distributed variables, and as median and interquartile range for non-normally distributed variables. R2D:4D, L2D:4D, and $D_{[R-L]}$ were all normally distributed, as indexed by Shapiro-Wilk test. Sex differences were therefore examined using between-subjects t-tests. A dichotomous variable for religious affiliation was derived by creating two groups, one for participants who reported affiliation to an organised religion, and one for participants who reported being agnostic or atheist. The other outcome variables for religiosity (general religiosity, spirituality, religious fundamentalism, and religious commitment) were all continuous, not normally distributed, and could not be normalised by logarithmic transformation. Age was also non-normally distributed. Non-parametric tests were employed: Mann Whitney *U* tests were used for the dichotomous variable 'religious affiliation', and Spearman's tests were used for the continuous variables. Differences in slopes observed for males and females were tested with Fisher's *r*-to-*z* tests. Statistically significant effects were considered to occur at α of $p < .05$, and

Bonferroni correction was used to control for multiple testing. Note that the *Ns* for individual statistical tests differ from those of the overall sample due to missing values (i.e. in rare cases participants did not complete all questions/measures).

3. Results

3.1 Associations between 2D:4D and sex

R2D:4D was significantly lower in males (M = .970, SD = .033) than in females (M = .980, SD = .032), t (206) = -2.084, p = .038, and the same direction of effect was seen for L2D:4D (male M = .975, SD = .033; female M = .983, SD = .031), although this effect was non-significant, t (207) = -1.869, p = .063. $D_{[R-L]}$ did not differ between males (M = -.006, SD = .021) and females (M = -.003, SD = .024), t (205) = -.886, p = .377.

3.2 Associations between religiosity and sex

In general, the sample reported relatively low levels of religiosity on the questionnaire measures (**Table 1**) (note that medians for religious fundamentalism are negative because the scale was scored from -48 to 48). No significant sex differences were observed: general religiosity, U = 5326.00, p = .845; spirituality, U = 5461.50, p = .805; religious fundamentalism, U = 4616.50, p = .054; religious commitment, U = 4667.50, p = .181. As expected, across the whole sample, spirituality, religious fundamentalism, and religious commitment were highly significantly (p < .008 correcting for multiple testing), and positively, correlated with one another (**Table 2**). Likewise, compared to those who did not affiliate with a religion, those who did had higher levels of general religiosity, U = 1099.00, p < .001, spirituality, U = 2289.00, p < .001, religious fundamentalism, U = 2306.00, p < .001, and religious commitment, U = 1410.00, p < .001.

Table 1. *Descriptive statistics for religiosity and spirituality measures in Study 1*

		N	*Median*	*IQR*
General religiosity	Total sample	208	4.00	4.00
	Males	104	4.00	3.00
	Females	104	4.00	4.00
Spirituality	Total sample	211	2.00	2.00
	Males	106	2.00	2.00
	Females	105	2.00	2.00
Religious fundamentalism	Total sample	209	-32.00	18.50
	Males	105	-35.00	17.00
	Females	104	-30.00	21.75
Religious commitment	Total sample	204	11.00	6.00
	Males	103	12.00	8.00
	Females	101	11.00	4.00

Table 2. *Correlations between religiosity and spirituality measures in Study 1*
Note. All correlations are Spearman's (two-tailed)

	Spirituality			**Religious fundamentalism**			**Religious commitment**		
	N	*rho*	*p*	*N*	*rho*	*p*	*N*	*rho*	*p*
General religiosity	208	.665	< .001	206	.374	< .001	201	.607	< .001
Spirituality		-		209	.208	.003	204	.424	< .001
Religious fundamentalism		-			-		202	.189	.007

3.3 Associations between 2D:4D, sex, and religious affiliation

Most participants considered themselves to be atheist (41.7%) or agnostic (28.2%), 26.7% claimed to follow a denomination of Christianity, and 3.4% were listed as 'other'. To investigate whether digit ratios were associated with religious belief, participants were dichotomised as 'religious' (any claim to following an organised religion; 29 males, 29 females) or 'not religious' (any claim to atheism or agnosticism; 74 males, 71 females). Due to providing ambiguous responses, three participants were not classified into either group. There was no sex difference regarding the likelihood of claiming affiliation to a religion, $\chi 2$ (1, 203) = .018, p = .894.

To determine whether digit ratio was related to religious affiliation, 2 (sex: male or female) x 2 (religious affiliation: religious or not religious) ANOVAs upon the dependent variables of R2D:4D, L2D:4D, and $D_{[R-L]}$ were conducted. For R2D:4D there was a highly-significant main effect of sex, F (1, 196) = 7.642, p = .006, ηp^2 = .038, no main effect of religious affiliation, F (1, 196) = 1.755, p = .187, ηp^2 = .009, and a highly-significant interaction, F (1, 196) = 7.661, p = .006, ηp^2 = .038 (**Figure 1**). Similarly, for L2D:4D, there was a main effect of sex, F (1, 197) = 5.692, p = .018, ηp^2 = .028, no main effect of religious affiliation, F (1, 197) = .336, p = .563, ηp^2 = .002, and a significant interaction, F (1, 197) = 5.152, p = .024, ηp^2 = .025 (**Figure 2**). According to generally accepted criteria, the effect sizes observed were small (Cohen, 1988; .01 = small, .06 = medium, .14 = large). Simple effects analyses revealed that religious females exhibited higher R2D:4D, F (1, 196) = 8.310, p = .004, ηp^2 = .041, and L2D:4D, F (1, 197) = 4.095, p = .044, ηp^2 = .020, than non-religious females. There were no differences between the digit ratios of religious and non-religious males: R2D:4D, F (1, 196) = 1.049, p = .307, ηp^2 = .005; L2D:4D, F [1, 197] = 1.416, p = .236, ηp^2 = .007. After Bonferroni adjustment determined α to be $p < .013$, the effect for R2D:4D in females remained statistically significant, though that for L2D:4D did not.

Two Way ANOVA found no effects in regard to $D_{[R-L]}$: sex: F (1, 195) = .837, p = .361, ηp^2 = .004; religious affiliation, F (1, 195) = 1.581, p = .210, ηp^2 = .008; sex x religious affiliation, F (1, 195) = .275, p = .601, ηp^2 = .001.

3.4 Associations between 2D:4D and questionnaire measures of religiosity

Spearman's correlations were conducted to examine whether R2D:4D, L2D:4D, and $D_{[R-L]}$ were associated with any of the questionnaire measures of religiosity. These analyses were performed for males and females separately. No significant correlations were observed after Bonferroni adjustment determined the required α level to be $p < .002$. To examine possible sex differences, the slopes observed for males and females were compared using Fisher's *r*-to-*z* tests. No significant differences were observed after Bonferroni adjustment determined α to be $p < .004$ (**Table 3**).

Figure 1. Interaction between sex and religious affiliation on R2D:4D in Study 1.
Note. Error bars are standard error.

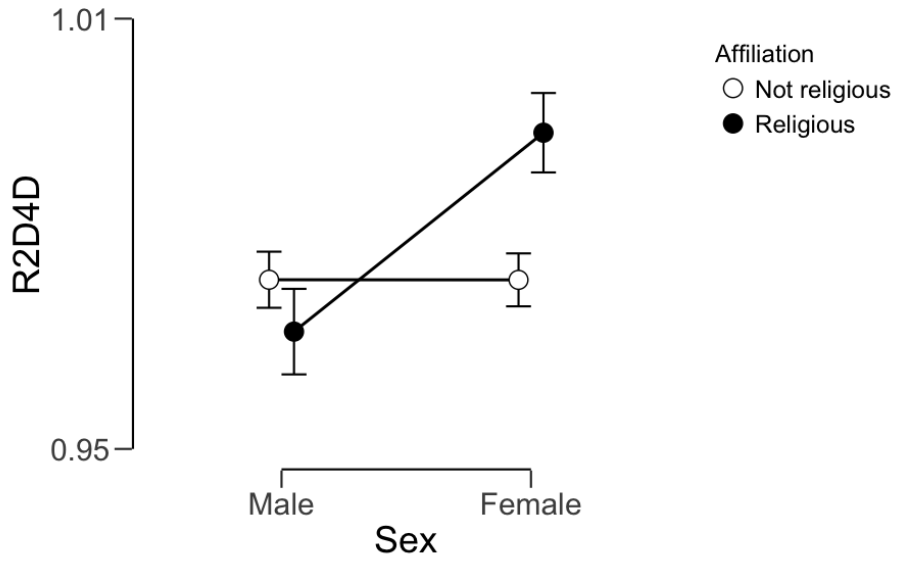

Figure 2. Interaction between sex and religious affiliation on L2D:4D in Study 1.
Note. Error bars are standard error.

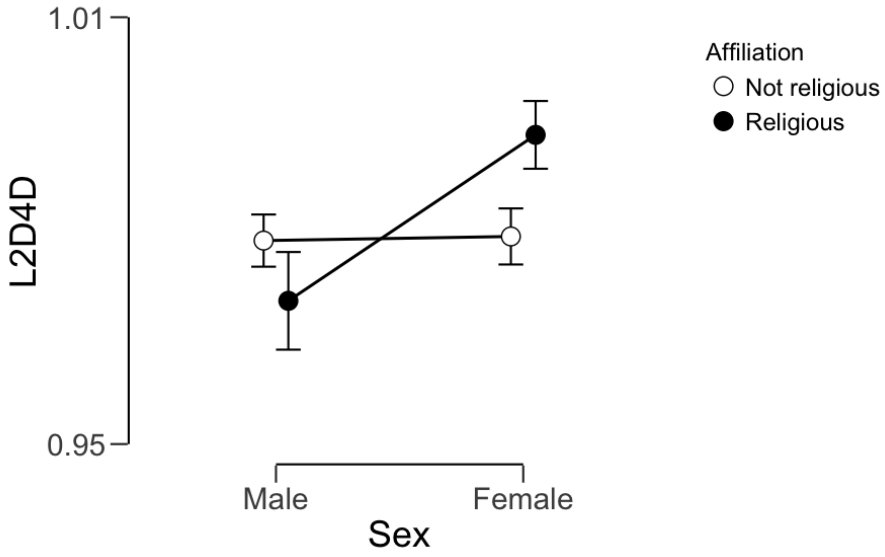

Table 3. Correlations between 2D:4D and questionnaire measures of religiosity and spirituality in Study 1.
Note. All correlations are Spearman's (two-tailed); comparisons of slopes are Fisher's r-to-z tests (two-tailed).

		Males			**Females**			**Difference in slopes**	
		N	*rho*	*p*	*N*	*rho*	*p*	*z*	*p*
General religiosity	R2D:4D	103	.006	.954	102	-.025	.807	0.22	.826
	L2D:4D	102	-.079	.432	104	.128	.194	-1.47	.142
	$D_{[R-L]}$	102	.102	.306	102	-.089	.376	1.35	.177
Spirituality	R2D:4D	105	.058	.557	103	-.057	.565	0.82	.412
	L2D:4D	104	-.045	.651	105	.080	.417	-0.89	.374
	$D_{[R-L]}$	104	.138	.163	103	-.102	.306	1.71	.087
Religious fundamentalism	R2D:4D	104	-.168	.088	102	-.004	.968	-1.17	.242
	L2D:4D	103	-.150	.129	104	.057	.566	-1.48	.139
	$D_{[R-L]}$	103	-.018	.860	102	-.037	.714	0.13	.897
Religious commitment	R2D:4D	102	-.044	.662	99	-.011	.910	-0.23	.818
	L2D:4D	101	-.127	.205	101	.135	.177	-1.84	.066
	$D_{[R-L]}$	101	.070	.489	99	-.077	.447	1.03	.303

Study 2

4. Materials and Methods

4.1 Participants

Participants in Study 2 were members of the public attending the National Eisteddfod, a week-long festival that celebrates Welsh culture, language, and heritage, and attracts a diverse cross-section of the Welsh population, as well as tourists from other parts of the UK and beyond. Four hundred and twenty-nine adults (172 male, 257 female) aged 18-89 (*median* = 49.00, *IQR* = 27.00) completed the study.

4.2 Apparatus/Materials

A Hewlett Packard ENVY 4500 portable photocopier was used to scan participants' hands, and a brief questionnaire was administered to record information relating to demographics and religiosity. The information sheet, consent form, questionnaire, and debrief form were all available in English or Welsh, with participants choosing their preferred language. Although the researcher who collected the data was not a Welsh speaker, bilingual volunteers were available if translation was required.

All participants were asked to state their age and sex, as well as their ethnicity. Religious affiliation was recorded with a single-item, which asked "How would you describe your religion or belief?" (Response options: Christian, Buddhist, Hindu, Jewish, Muslim, Sikh, None, Prefer not to say, Other). As with Study 1, participants also completed the General Religiosity and Spirituality Measure. For the three items used to calculate general religiosity, Cronbach's α was .927.

4.3 Design & Procedure

Study 2 utilised a cross-sectional design, and all data were collected from a stand held by the British Psychological Society's (BPS) Welsh Branch at the National Eisteddfod in Abergavenny, South Wales. Members of the public volunteered to complete the study, and no monetary reward was offered in exchange for participation. The nature of the research was explained, and written informed consent was acquired prior to

beginning the study. Participation took around three minutes, and participants were debriefed on completion.

Scans of participants' hands were made using a portable scanner. Greyscale images (optimised for quality rather than scanning speed) were made at a resolution of 300ppi. 2D:4D values were subsequently calculated from these images using AutoMetric 2.2 for Windows (DeBruine, 2006). Two sets of measurements were made by the same researcher (several weeks apart). Intra-class correlation coefficients (two-way mixed, single measures with absolute agreement) determined that the repeatability of measurements was high for both R2D:4D, $ICC = .931$, $F = 29.156$, $p < .001$, and L2D:4D, $ICC = .917$, $F = 22.935$, $p < .001$. These two sets of measurements were therefore averaged to create the R2D:4D and L2D:4D values used in all subsequent analyses. The research was conducted under the approval of Cardiff University School of Psychology Ethics Committee, and in compliance with the Declaration of Helsinki.

4.4 Statistical analysis

The same statistical approach as used in Study 1 is again used here. Shapiro-Wilk tests determined that each digit ratio measure was non-normally distributed (although the effect was only marginally significant for R2D:4D, $p = 0.057$). Age, general religiosity, and spirituality were also non-normally distributed, so non-parametric tests were used. However, when associations between 2D:4D, religious affiliation, and sex were examined, ANCOVA was used (in which age was entered as a covariate). This was to allow for more direct comparison with findings from Study 1, and because ANCOVA is considered relatively robust to violations of normality. Non-parametric partial correlations (controlling for age) were conducted to examine relationships between digit ratio variables and general religiosity and spirituality.

5. Results

5.1 Associations between 2D:4D, age, and sex

Male 2D:4D was significantly lower than female 2D:4D for both the right hand (males, *median* = .954, *IQR* = .046; females, *median* = .969, *IQR* = .040), $U = 16797.00$, $p < .001$) and left hand (males, *median* = .953, *IQR* = .047; females, *median* = .967, *IQR* =

.041), U = 17041.50, p < .001). For $D_{[R-L]}$, there was no difference between males (*median* = .001, *IQR* = .039) and females (*median* = .002, *IQR* = .037), U = 20883.00, p = .546. R2D:4D and L2D:4D were both significantly negatively correlated with age in males (see Richards et al., 2017 for these analyses).

5.2 Associations between religious affiliation, age, and sex

One hundred and two males (61.1%) claimed affiliation to a religion, whereas 65 (38.9%) did not. In females, 177 (69.7%) affiliated with a religion, whereas 77 (30.3%) did not. There was no significant sex difference in religious affiliation, $\chi 2$ (1, 421) = 3.339, p = .068. Those who affiliated with a religion were significantly older than those who did not, and this was the case for both males, U = 2639.00, p = .026, and females, U = 4050.00, p < .001.

There was no significant sex difference for general religiosity, U = 18785.50, p = .099, though females had significantly higher levels of spirituality, U = 17452.50, p = .004. Age was positively correlated with general religiosity in males, *rho* (164) = .207, p = .007, and in females, *rho* (248) = .355, p < .001; spirituality was positively correlated with age in females, *rho* (246) = .337, p < .001, though a similar trend in males was not significant, *rho* (166) = .135, p = .081. Participants who reported affiliation to a religion had higher levels of general religiosity, U = 1748.50, p < .001, and spirituality, U = 6743.00, p < .001, compared to those who did not affiliate with a religion. General religiosity and spirituality were significantly positively correlated, *rho* (409) = .698, p < .001.

5.3 2D:4D and religious affiliation

Study 1 indicated a significant 'sex x religious affiliation' interaction with respect to 2D:4D in a university student population. To test whether such an interaction was also observable in a general population sample, we performed ANCOVA with between-subjects factors of sex (male or female) and religious affiliation (yes or no), and using age as a covariate (given the substantial age range, and the aforementioned associations between age, religious affiliation, and 2D:4D). For the right hand, age, F (1, 414) = 11.041, p = .001, ηp^2 = .026, and sex, F (1, 414) = 12.542, p < .001, ηp^2 = .029, were both significantly associated with 2D:4D ratio, whereas religious affiliation, F (1, 414)

= 1.462, p = .227, ηp^2 = .004, and the interaction between sex and religious affiliation, F (1, 414) = .630, p = .428, ηp^2 = .002, were not. The same pattern of results was observed for L2D:4D: age, F (1, 413) = 4.480, p = .035, ηp^2 = .011; sex, F (1, 413) = 8.153, p = .005, ηp^2 = .019; religious affiliation, F (1, 413) = .578, p = .448, ηp^2 = .001; sex x religious affiliation, F (1, 413) = .189, p = .664; $\eta p^2 < .001$. For $D_{[R-L]}$, no significant effects were observed: age, F (1, 412) = .784, p = .377, ηp^2 = .002; sex, F (1, 412) = .366, p = .546, ηp^2 = .001; religious affiliation, F (1, 412) = .180, p = .672, $\eta p^2 < .001$; sex x religious affiliation, F (1, 412) = 1.757, p = .186, ηp^2 = .004. To facilitate comparison with the results obtained in Study 1, the mean values for R2D:4D and L2D:4D as a function of sex and religious affiliation are shown in **Figure 3** and **Figure 4**, respectively (note that these values have not been adjusted for age).

5.4 Associations between 2D:4D and religiosity and spirituality

Non-parametric partial correlations (controlling for age) were used to examine relationships between digit ratio variables and general religiosity and spirituality (**Table 4**). Although it is noted that all correlations in males were positive, and all correlations in females were negative, none were statistically significant (Bonferroni corrected α was $p < 0.004$). Likewise, there were no significant differences in the slopes observed for males and females (Bonferroni corrected α was $p < 0.008$).

Figure 3. Interaction between sex and religious affiliation on R2D:4D in Study 2.
Note. Error bars are standard error.

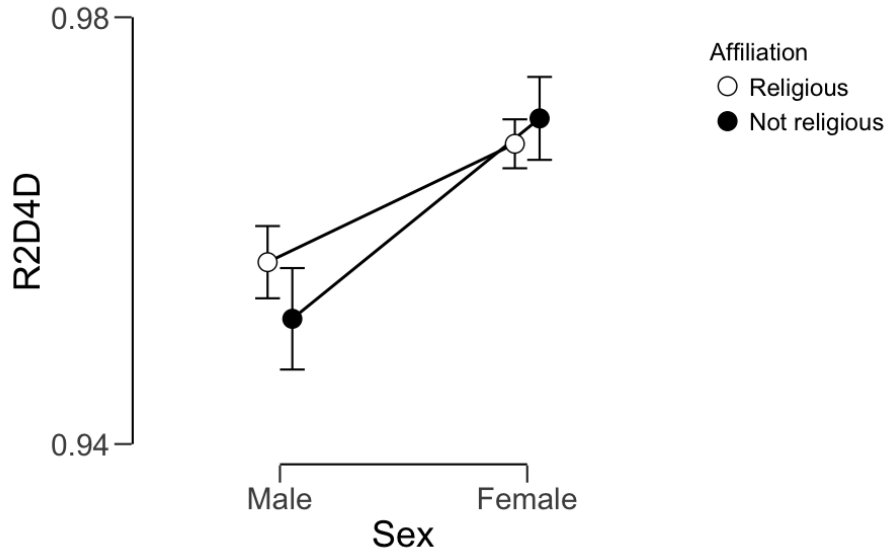

Figure 4. Interaction between sex and religious affiliation on L2D:4D in Study 2.
Note. Error bars are standard error.

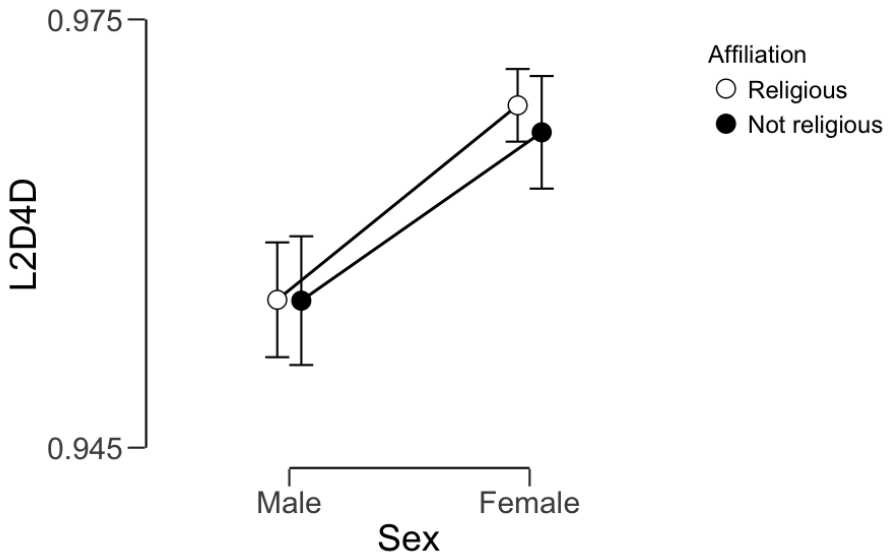

Table 4. Non-parametric partial correlations (controlling for age) between 2D:4D and religiosity and spirituality in Study 2.
Note. All tests are (two-tailed); comparisons of slopes are Fisher's r-to-z tests.

		Males			**Females**			**Difference in slopes**	
		N	*rho*	*p*	*N*	*rho*	*p*	*z*	*p*
General religiosity	R2D:4D	163	.064	.416	245	-.124	.053	1.85	.064
	L2D:4D	163	.026	.746	245	-.037	.566	.62	.535
	$D_{[R-L]}$	163	.034	.666	245	-.051	.423	.83	.407
Spirituality	R2D:4D	163	.113	.151	245	-.054	.405	1.64	.101
	L2D:4D	163	.024	.759	245	-.031	.628	.54	.589
	$D_{[R-L]}$	163	.095	.228	245	-.048	.457	1.41	.159

6. Discussion

There are theoretical grounds for suspecting a link between 2D:4D ratio (an index of early-life androgen exposure) and an individual's degree of religiosity. Here, we tested for a possible relationship between 2D:4D ratio and religiosity using a comprehensive battery of measures in two moderately-sized participant cohorts (a university participant sample, and a general population sample).

Our main finding was that, in the student cohort, having a religious affiliation (as opposed to self-identifying as agnostic or atheist) was associated with higher R2D:4D and L2D:4D in females (but not in males), and that the effect relating to R2D:4D remained statistically significant after applying Bonferroni correction. However, 2D:4D was not associated with any of the four questionnaire measures of religiosity (general religiosity, spirituality, religious fundamentalism, religious commitment), and we did not replicate the significant finding in a larger sample from the general population.

There are several possible explanations for the above pattern of results. First, the significant findings may be false positives (or, alternatively, the attempted replication may represent false negatives); this explanation is feasible given the relatively low number of female (N = 29) and male (N = 29) students who affiliated with a religion, and the consequent low power of the analysis. To resolve this question, it will be necessary to carry out analyses in much larger cohorts of students.

The difference in findings between the student and general populations could be due to demographic effects. For example, the average ages of the two cohorts were 20 years vs. 49 years respectively, and there was a significant difference in age between religious and non-religious individuals in the general population sample. It is also possible that factors such as IQ, socioeconomic status, or exposure to religious practices (e.g. daily worship), give rise to the differential results in the student and general population cohorts; as we did not measure these variables we cannot test for a moderating influence of them, and this would need to be undertaken in future studies.

Although pooling the data from the two studies would have increased overall power, this would have been problematic because, for practical reasons, 2D:4D was measured

directly in the student sample and from scanned images in the general population sample. It has been reported that photocopies and scans yield lower (i.e. more masculinised) 2D:4D ratios than direct measures (Manning et al., 2005; Ribeiro et al., 2016). For this reason, if significant effects were to be observed in the pooled data, it would not be possible to determine whether they might be explainable by differences in the samples examined, or by differences in the measuring techniques used.

It is worth noting that statistically significant sex differences on measures of religiosity were not reliably detected in either sample examined here. This is surprising considering that sex differences in religiosity variables have been commonly reported (e.g. Beit-Hallahmi & Argyle, 1997; Schmitt & Fuller, 2015). In fact, Collett and Lizardo (2009) stated: "The fact that women are more religious than men is one of the most consistent findings in the sociology of religion" (p.213). A lack of statistically significant sex differences for most religiosity variables may therefore cast doubt on the validity of the measures used here. As 2D:4D is proposed to provide an indication of the prenatal conditions associated with the establishment of sex differences (Manning, 2002), and only behaviours that show sex differences are expected to relate to prenatal androgen exposure (Constantinescu & Hines, 2012; Hines, Constantinescu, & Spencer, 2015), the absence of reliably detected sex differences in religiosity variables in the two studies presented here might be a reason for the lack of statistically significant findings.

Besides the explanations presented above, our data also suggest the intriguing possibility of a true association between 2D:4D and religious affiliation in females, an effect which may be specific to young, educated individuals. Given that 2D:4D is thought to reflect early-life androgen exposure, it might be hypothesised that some females may be exposed to relatively low levels of testosterone during early life, or that some females may be relatively insensitive to the *in utero* or perinatal effects of androgens, and that this lack of exposure and/or insensitivity may predispose their developing brains to later religiosity. The magnitude of this hormonal effect on subsequent behaviour may be affected by the exposed individual's personality or cognitive abilities (e.g. IQ) and their age, with the influence declining over time. This idea is consistent with studies that have observed positive relationships between 2D:4D

and paranormal and superstitious beliefs (Rogers et al., 2017; Voracek, 2009; though see also Richards, 2017c).

In terms of the neural substrates of religiosity, Kapogiannis et al. (2009) reported three psychological dimensions of religious belief (God's perceived level of involvement, God's perceived emotion, and doctrinal/experiential religious knowledge), which fMRI localised to brain networks associated with theory of mind. This is relevant to the current study, as theory of mind deficits are associated with autism spectrum conditions (Baron-Cohen et al., 1985; Baron-Cohen & Wheelwright, 2004), which are themselves associated with low religiosity (Caldwell-Harris et al., 2011), low 2D:4D ratios in males (Manning et al., 2001; Milne et al., 2006) (although high 2D:4D ratios in females; Schieve et al., in press), and high levels of foetal androgen exposure (Baron-Cohen et al., 2015). Considering that foetal testosterone is also a predictor of variance in autism-related traits in typically developing individuals (Auyeung et al., 2009, 2013; Baron-Cohen et al., 2004, though see also Constantinescu & Hines, 2012; Kung et al., 2016), we can speculate that exposure to high levels of testosterone during the prenatal period influences the development and function of circuitry in the brain related to theory of mind, and promotes areligious behaviour. Conversely, exposure to low androgen levels, or insensitivity to circulating androgens, in early-life may predispose towards the development of brain circuitry related to theory of mind that is associated with a high degree of religiosity.

Future research could examine associations between 2D:4D and religiosity and religious affiliation in larger samples of university students. As the student sample examined here was comprised entirely of Caucasians, relatively few of whom considered themselves to be religious, future studies should also aim to recruit participants from a broader range of backgrounds. In addition, studies that have recorded prenatal/perinatal sex hormones from amniotic fluid or umbilical cord blood could follow-up their cohorts to determine whether early exposure to androgens and oestrogens predicts religiosity in adulthood.

7. Conclusions

Although Study 1 found high 2D:4D in female students who affiliated with organised religions, the same effect was absent in the general population sample examined in

Study 2. No significant relationships were observed between 2D:4D and general religiosity, spirituality, religious fundamentalism, or religious commitment. The findings presented here therefore suggest that if relationships do exist between 2D:4D and religiosity, the effects are likely to be small, and may depend on sex, age, level of education, and the aspect of religiosity being measured.

Conflict of interest statement

None declared.

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Author contributions

GR wrote the research proposal, wrote the statistical analysis plan, collected and analysed the data, and drafted the initial manuscript. GR, WD, and SS-W designed the study. WD, SS-W, and PR contributed to statistical analysis and interpretation, and WB translated English language questionnaires into Welsh. WD, SS-W, PR, and WB revised the paper for important intellectual content. All authors read and approved the final article prior to submission.

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References

Alatalo, R. V., Höglund, J., Lundberg, A. et al. (1996). Testosterone and male mating success on the black grouse leks. *Proceedings of the Royal Society B: Biological Sciences, 263*, 1697–1702.

Altemeyer, B. & Hunsberger, B. (2004). A revised religious fundamentalism scale: The short and sweet of it. *International Journal for the Psychology of Religion, 14*, 47–54.

Austin, E. J., Manning, J. T., McInroy, K. & Mathews, E. (2002). A preliminary investigation of the associations between personality, cognitive ability and digit ratio. *Personality and Individual Differences, 33*, 1115–1124.

Auyeung, B., Baron-Cohen, S., Ashwin, E. et al. (2009). Fetal testosterone and autistic traits. *British Journal of Psychology, 100*, 1–22.

Auyeung, B., Lombardo, M. V. & Baron-Cohen, S. (2013). Prenatal and postnatal hormone effects on the human brain and cognition. *Pflugers Archive - European Journal of Physiology, 465*, 557–571.

Baron-Cohen, S. & Wheelwright, S. (2004). The Empathy Quotient: An investigation of adults with Asperger syndrome or high functioning autism, and normal sex differences. *Journal of Autism and Developmental Disorders, 34*, 163–175.

Baron-Cohen, S., Auyeung, B., Nørgaard-Pedersen, B. et al. (2015). Elevated fetal steroidogenic activity in autism. *Molecular Psychiatry 20*, 369–376.

Baron-Cohen, S., Leslie, A. M. & Frith, U. (1985). Does the autistic child have a "theory of mind"? *Cognition, 21*, 37–46.

Baron-Cohen, S., Lutchmaya, S. & Knickmeyer, R. (2004). *Prenatal testosterone in mind*. Cambridge, MA: MIT Press.

Beit-Hallahmi, B. & Argyle, M. (1997). *The psychology of religious behaviour, belief and experience*. London; New York, NY: Routledge.

Breedlove, S. M. (2010). Minireview. Organizational hypothesis: Instances of the fingerpost. *Endocrinology, 151*, 4116–4122.

Caldwell-Harris, C. L., Murphy, C. F., Velazquez, T. & McNamara, P. (2011). Religious belief systems of persons with high functioning autism. *Proceedings of the Annual Meeting of the Cognitive Science Society, USA, 33*, 3362–3366.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Hillsdale, NJ: Erlbaum.

Collett, J. L. & Lizardo, O. (2009). A power-control theory of gender and religiosity. *Journal for the Scientific Study of Religion, 48*, 213–231.

Constantinescu, M. & Hines, M. (2012). Relating prenatal testosterone exposure to postnatal behavior in typically developing children: Methods and findings. *Child Development Perspectives, 6*, 407–413.

DeBruine, L. (2006). AutoMetric software for measurement of 2D:4D ratios. Available: http://facelab.org/debruine/Programs/autometric.php

Ellis, L., Hoskin, A. W. & Ratnasingam, M. (2016). Testosterone, risk taking, and religiosity: Evidence from two cultures. *Journal for the Scientific Study of Religion, 55*, 153–173.

Galis, F., Ten Broek, C. M. A., van Dongen, S. & Wijnaendts, L. C. D. (2009). Sexual dimorphism in the prenatal digit ratio (2D:4D). *Archives of Sexual Behaviour, 39*, 57–62.

Garbarino, E., Slonim, R. & Sydnor, J. (2010). Digit ratios (2D:4D) as predictors of risky decision making for both sexes. *Journal of Risk and Uncertainty, 42*, 1–26.

Halpern, C. T., Udry, J. R., Campbell, B. et al. (1994). Testosterone and religiosity as predictors of sexual attitudes and activity among adolescent males: A biosocial model. *Journal of Biosocial Science, 26*, 217–234.

Hines, M., Constantinescu, M. & Spencer, D. (2015). Early androgen exposure and human gender development. *Biology of Sex Differences, 6*.

Hönekopp, J. & Watson, S. (2010). Meta-analysis of digit ratio 2D:4D shows greater sex difference in the right hand. *American Journal of Human Biology, 22*, 619–630.

Kapogiannis, D., Barbey, A. K., Su, M. et al. (2009). Cognitive and neural foundations of religious belief. *Proceedings of the National Academy of Sciences of the United States of America, 106*, 4876–4881.

Knickmeyer, R. C., Woolson, S., Hamer, R. M. et al. (2011). 2D:4D ratios in the first 2 years of life: Stability and relation to testosterone exposure and sensitivity. *Hormones and Behavior, 60*, 256–263.

Kung, K. T. F., Spencer, D., Pasterski, V. et al. (2016). No relationship between prenatal androgen exposure and autistic traits: Convergent evidence from studies of children with congenital adrenal hyperplasia and of amniotic testosterone concentrations in typically developing children. *Journal of Child Psychology and Psychiatry, 57*, 1455–1462.

Lima de Miranda, K., Neyse, L. & Schmidt, U. (2018) Risk preferences and predictions about others: No association with 2D:4D ratio. *Frontiers in Behavioral Neuroscience, 12*.

Lindeman, M. & Aarnio, K. (2006). Paranormal beliefs: Their dimensionality and correlates. *European Journal of Personality, 20,* 585–602.

Malas, M. A., Dogan, S., Evcil, E. H. & Desdicioglu, K. (2006). Fetal development of the hand, digits and digit ratio (2D:4D). *Early Human Development, 82,* 469–475.

Manning, J. T. (2002). *Digit ratio: A pointer to fertility, behaviour and health*. New Brunswick, NJ: Rutgers University Press.

Manning, J. T., Baron-Cohen, S., Wheelwright, S. & Sanders, G. (2001). The 2nd to 4th digit ratio and autism. *Developmental Medicine & Child Neurology, 43,* 160–164.

Manning, J. T., Fink, B., Neave, N. & Caswell, N. (2005). Photocopies yield lower digit ratios (2D:4D) than direct finger measurements. *Archives of Sexual Behavior, 34,* 329–333.

Manning, J. T., Kilduff, L., Cook, C. et al. (2014). Digit ratio (2D:4D): A biomarker for prenatal sex steroids and adult sex steroids in challenge situations. *Frontiers in Endocrinology, 5*.

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 levels of testosterone, luteinizing hormone and oestrogen. *Human Reproduction, 13,* 3000–3004.

Manning, J.T. & Fink, B. (2017) Are there any "direct" human studies of digit ratio (2D:4D) and measures of prenatal sex hormones? *Early Human Development, 113,* 73–74.

Miller, A. S. & Hoffman, J. P. (1995). Risk and religion: An explanation of gender differences in religiosity. *Journal for the Scientific Study of Religion, 34,* 63–75.

Milne, E., White, S., Campbell, R. et al. (2006). Motion and form coherence detection in autistic spectrum disorder: Relationship to motor control and 2:4 digit ratio. *Journal of Autism and Developmental Disorders, 36,* 225–237.

Pitel, L., Geckova, A. M., Kolarcik, P. et al. (2012). Gender differences in the relationship between religiosity and health-related behaviour among adolescents. *Journal of Epidemiology & Community Health, 66,* 1122–1128.

Ribeiro, E., Neave, N., Morais, R. N. & Manning, J.T. (2016). Direct versus indirect measurement of digit ratio (2D:4D): A critical review of the literature and new data. *Evolutionary Psychology, 14,* 1–8.

Richards, G. (2017a) What is the evidence for a link between digit ratio (2D:4D) and direct measures of prenatal sex hormones? *Early Human Development, 113,* 71–72.

Richards, G. (2017b). Digit ratio (2D:4D) and prenatal/perinatal sex hormones: A response to Manning and Fink (2017). *Early Human Development, 113,* 75–76.

Richards, G. (2017c). Digit ratio (2D:4D) and belief in superstitions, conspiracy theories, and the paranormal. *PsyPAG Quarterly, 103*, 21–26.

Richards, G., Bellin, W. & Davies, W. (2017). Familial digit ratio (2D:4D): Associations in a general population sample from Wales. *Early Human Development, 112*, 14–19.

Rogers, P., Caswell, N. & Brewer, G. (2017). 2D:4D digit ratio and types of adult paranormal belief: An attempted replication and extension of Voracek (2009) with a UK sample. *Personality and Individual Differences, 104*, 92–97.

Saroglou, V. & Galand, P. (2004). Identities, values, and religion: A study among Muslim, other immigrant, and native Belgian young adults after the 9/11 attacks. *Identity: An International Journal of Theory and Research, 4*, 97–132.

Saroglou, V. & Muñoz-García, A. (2008). Individual differences in religion and spirituality: An issue of personality traits and/or values. *Journal for the Scientific Study of Religion, 47*, 83–101.

Schieve, L. A., Tian, L., Dowling, N. et al. (in press). Associations between the 2nd to 4th digit ratio and autism spectrum disorder in population-based samples of boys and girls: Findings from the Study to Explore Early Development. *Journal of Autism and Developmental Disorders*.

Schmitt, D. P. & Fuller, R. C. (2015). On the varieties of sexual experience: Cross-cultural links between religiosity and human mating strategies. *Psychology of Religion and Spirituality, 7*, 314–326.

Stark, R. (2002). Physiology and faith: Addressing the "universal" gender difference in religious commitment. *Journal for the Scientific Study of Religion, 41*, 495–507.

Voracek, M. (2008). Digit ratio (2D:4D) as a marker for mental disorders: low (masculinised) 2D:4D in autism-spectrum disorders, high (feminized) 2D:4D in schizophrenic-spectrum disorders. *Behavioral and Brain Sciences, 31*, 283–284.

Voracek, M. (2009). Who wants to believe? Associations between digit ratio (2D:4D) and paranormal and superstitious beliefs. *Personality and Individual Differences, 47*, 105–109.

Worthington, E. L. (1988). Understanding the values of religious clients: A model and its application to counseling. *Journal of Counseling Psychology, 35*, 166–174.

Worthington, E. L., Wade, N. G., Hight, T. L. et al. (2003). The religious commitment inventory–10: Development, refinement, and validation of a brief scale for research and counseling. *Journal of Counseling Psychology, 50*, 84–96.

Zheng, Z. & Cohn, M. J. (2011). Developmental basis of sexually dimorphic digit ratios. *Proceedings of the National Academy of Sciences of the United States of America*, *108*, 16289–16294.