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AN EXPLORATORY STUDY OF THE RELATIONSHIP BETWEEN SECOND TOE LENGTH AND ANDROGEN-LINKED BEHAVIORS

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Abstract
Ontogenetic evidence suggests a possible link between second toe length and prenatal androgenization, and therefore it is possible that a longer second toe is related to behaviors and traits previously shown to be associated with testosterone. In an exploratory analysis of this phenomenon, respondents provided self-reports of various behaviors and traits previously shown to be related to testosterone and finger-length ratios and also indicated whether or not their second toe was the longest of their toes (i.e., extended beyond their other toes). Results yielded a significant association between longer second-toe length and left-handedness for both men and women. For women only, relationships between a longer second toe and a competitiveness orientation, a winning orientation, and physical aggression were found. For men only, a relationship between a longer second toe and exercise frequency was found. There was no association between second toe length and sociosexual orientation or sexual orientation for either sex. The implications and limitations of these findings and the potential for future research are discussed.

Keywords: Second toe, digit length, Greek foot, prenatal androgen, competitiveness, aggression

Introduction

Human toes, fingers, and genitalia all form at about eight to thirteen weeks of gestation (Zakany, Fromental-Ramain, Warot, & Duboule, 1997), and studies have shown that their development is influenced by the same directive actions of the homeobox gene complex—in particular HoxA and HoxD groups 11, 12, and 13 (Zakany et al., 1997). Disruptions of this genetic process can lead to malformations in the digits and urogenital tract such as those seen in hand-foot-genital syndrome (Innis, 2006).

Testosterone production also begins at about week eight of gestation, coinciding with the critical period for digit elongation (Garn, Burdi, Babler, & Stinson, 1975; see Manning, 2002, for review). It is therefore possible, as noted by Manning and Dowrick

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(1999), that testosterone influences not only genitalia development but also both finger and toe digit lengths. It follows from this that testosterone-related behaviors, traits, and cognitions may be related to toe and finger length.

Considerable literature is devoted to examining connections between finger-length ratios and behaviors related to androgenization; many studies have linked a lower 2D:4D to masculinized behaviors and traits (e.g., Manning, 2002; Manning, Barley, Walton, Lewis-Jones, Trivers, et al., 2000; Manning, Stewart, Bundred, & Trivers, 2004; Puts, Gaulin, Sporter, & McBurney, 2004; Puts, McDaniel, Jordan, & Breedlove, 2007; Vermeersch, T'Sjoen, Kaufman, & Vincke, 2008). Not surprisingly, as men are exposed to greater levels of androgens prenatally and have higher average salivary and plasma testosterone than women (see Dabbs, 2000), studies have shown more consistent relationships between 2D:4D and testosterone-related behavior in males. For example, low 2D:4D ratios in males are related to sports performance (Manning & Taylor, 2001; Voracek, Reimer, Ertl, & Dressler, 2006), advanced musical skills (Sluming & Manning, 2000), perceived dominance (Neave, Laing, Fink, & Manning, 2003), attention-deficit/hyperactivity disorder (Martel, Gobrogge, Breedlove, & Nigg, 2008), a higher sperm count (Manning, Bundred, & Flanagan, 2002), numerical literacy (Brosnan, 2008), greater reproductive success (Manning et al., 2000), and depression (Manning & Dowrick, 1999).

Several studies, however, have yielded opposite and null results regarding the predicted associations between 2D:4D and behavior in men (Honekopp & Watson, 2010; Puts, Gaulin, Sporter, & McBurney, 2004; Puts, McDaniel, Jordan, & Breedlove, 2007). For example, Neave, Laing, Fink, and Manning (2003) showed that 2D:4D is negatively correlated with social dominance in men, but Koehler, Simmons, and Rhodes (2004) could not replicate these findings. Similarly, contrary to the findings of Manning and Taylor (2001), Vermeersch et al. (2008) showed no relationship between 2D:4D and depression in men or women. Further, in contrast to Manning et al. (2002), Firman and colleagues (2003) could not find an association between 2D:4D and sperm count.

With respect to women, some studies have substantiated a relationship between lower 2D:4D and androgen-mediated behaviors. The predicted relationship was reported between masculinized 2D:4D and reactional aggression (Benderlioglu & Nelson, 2004), congenital adrenal hyperplasia (Brown, Hines, Fane, & Breedlove, 2002), homosexuality (McFadden & Shubel, 2002), and sensation-seeking (Austin, Manning, McInroy, & Mathews, 2002). However, the predicted relationship was not found with respect to spatial ability (Manning, 2002) and musical ability (Slumming & Manning, 2000).

Researchers have noted various methodological issues with many 2D:4D studies, underscoring inconsistent measurement techniques (Honekopp & Watson, 2010; Puts et al., 2004). The body of evidence with respect to the relationship between 2D:4D and various androgen-dependent behaviors is thus inconclusive.

Although researchers have noted the connection between the ontogeny of toes and fingers (cf. Manning, Callow, & Bundred, 2003), few have investigated the connection between finger and toe ratios and toe ratios and behavior. Only one study known to this author, conducted by McFadden and Shubel (2002), attempted to gauge the relationship between toe lengths and finger lengths, but in their effort they encountered severe measurement problems in that many participants' toes were so arched they could not be pressed flat on a digital scanner. Therefore, toes could not be precisely measured resulting in a low sample size insufficient for generalization. However, their data do suggest the presence of small sex differences in toe-length ratios similar to the sex

differences found in finger-length ratios, i.e., lower and therefore masculinized 2D:4D ratios in men than in women. This study did not address, however, connections between toes lengths and androgen-mediated behaviors.

Whereas most studies have examined finger digit ratios and androgen-linked behaviors, some have focused on the importance of the length of the fourth finger alone as a predictor of testosterone and of behaviors and traits related to testosterone. Manning, Scutt, Wilson, and Lewis-Jones (1998) found that a longer fourth finger is related to higher testosterone in men. In addition, Martin, Manning, and Dowrick (1999) reported a link between fourth finger length and depression in men but not in women. Interestingly, since a long fourth finger may be an honest signal of mate value as higher-testosterone males, and high-testosterone females are found to be more attractive (Dabbs, 2000), Manning (2002) commented that this may be why people in many cultures sport wedding rings on the fourth digit, conspicuously noting, "I am not available." Thus, the length of a single digit (versus ratios) may offer valuable, non-invasive information about an individual's prenatal hormonal milieu.

Second Toe Length May Be Androgenized

Just as there appears to be a relationship between fourth finger length and testosterone, there may be a relationship between second toe length and testosterone. Notably, the second toe is longer in fetuses (Tax, 1980; as cited in Bernhardt, 1988). In addition, chondrification (formation of cartilage) of the second metatarsal begins at about seven weeks of embryological development, before that of the hallux ("big" toe) (Bareither, 1995). Furthermore, Bareither (1995) noted that a 2>3>1>4>5 length formula is attained by about eight weeks in utero. At about eight weeks in utero, also, the hallux becomes adducted with respect to the other toes, while chondrification of the second through fourth digits continues (see Bareither, 1995, for review). It is at this time during embryonic development that androgens are exerting their effects on the urogenital tract, and the same Hox genes appear to be controlling both digit and genital developmental processes (Garn et al., 1975). As such, due to the timing of toe development and genital development, and because the second toe is the longest during this critical juncture, it may be more sensitive/susceptible than other toes to the influence of prenatal testosterone.

Morton's Toe

"Morton's toe" is a term used to describe a condition in which second toe is longer than first toe (the "big toe" or hallux). This name is taken from Dudley Joy Morton's syndrome, described by Morton in his 1935 book, *The Human Foot*. It is a condition where a longer second relative to the hallux toe bears excessive weight, causing pain, tenderness, and calluses (see Decherchi, 2005). Contemporary evidence, however, is conflicting with respect to whether or not possessing a longer second toe interferes with human locomotion. Some research suggests that Morton's toe may interfere with multiarticular muscular function of the hallux (Kirane, Michelson, & Sharkey, 2008), and shortness of other bones in the foot and toes may be indicative of disease (Dogan, Uslu, Aydinlioglu, Harman, & Akpinar, 2007). Conversely, one study addressing Morton's toe showed a connection between a longer second toe and skilled athleticism. Kulthanan, Techakampuch, and Donphongam (2004) examined footprint parameters for flatness and

ground contact in professional athletes, non-professional athletes, and non-athletes. They found that professional athletes had a significantly longer heel-to-second-toe length (24.22 cm) than heel-to-first-toe lengths (24.13 cm), whereas in non-athletes, the pattern was reversed. Thus, if higher-caliber athletes tend to display a longer second than first toe, and athletic ability is related to testosterone (see Dabbs, 2000, for review), it may be the case that a long second toe is related to testosterone.

Is a Longer Second Toe a "Throwback?"

Capecchi (1984) reported that the Laetoli footprints, discovered by Mary Leaky and presumed to have been made by *Australopithecus afarensis* ("Lucy's" conspecifics) over 3.5 million years ago, display a longer second toe. Capecchi detailed the anthropological consideration for a longer second toe, often called "Greek foot," as representative of early hominid ancestors, whereas a shorter second toe, often called "Egyptian foot," was thought to be more "progressive" and "recent" in hominid evolution (p. 84). Similarly, Schultz (1924) qualified non-human primates as having lower and therefore masculinized digit ratios (as cited by Manning et al., 2003). Interestingly, the United States' Statue of Liberty, a national symbol of freedom and triumph, exhibits a longer second toe than hallux, i.e., a Greek foot. Sculptor Frederic Bartholdi studied Greek and Roman sculpture and modeled the Statue wearing sandals and displaying a toe configuration typical of Greek art, "defining her heritage from the earliest days of civilization" (National Park Service, 2004, p. 2). Perhaps, then, a longer second toe has historically been noted as indicative of a more robust and therefore formidable phenotype.

The Present Study

This pilot study assessed the relationship between a longer second toe length and behaviors that have been shown to be related to testosterone. Specifically, it was predicted that participants who reported having a second toe longer than their other toes would display a greater frequency of left-handedness, competitiveness, aggression, physical fitness, sociosexuality, and sexual orientation—behaviors, cognitions, and traits previously shown to be related to androgenization and masculinized finger 2D:4D.

Method

Participants and Procedure

All procedures were approved by the local Institutional Review Board. A total of 107 college students (70 females and 37 males) participated in this study in exchange for course credit. Participants completed an online survey independently and privately. Mean age of participants was 20.13 (SD = 3.96). Ethnic data were not obtained in this exploratory study.

Materials

A self-report instrument was created to assess the relationship between longer second toe length and behaviors and traits previously associated with testosterone and/or the 2D:4D finger ratio. The questionnaire consisted of a compilation of the measures describe below.

Left-handedness. As left-handedness has been associated with androgenization (Geschwind & Galaburda, 1985) and with a lower 2D:4D (masculinized) finger ratio (cf. Manning, 2002), it was predicted that left-handedness would be related to a longer second toe length. This study incorporated the widely-used Edinburgh Handedness Inventory (EHI) (Oldfield, 1971), a 10-item instrument that generates a score indicating laterality of hand preference. In the EHI, participants are asked to report if they have a strong preference, preference, or no preference for either hand use in tasks such as writing, drawing, throwing, brushing one's teeth, etc. Responses were scored negatively for left-hand preferences and positively for right-hand preferences. This test has face validity (White & Ashton, 1976) and good test-retest reliability (r = .75-.86) (McMeekan & Lishman, 1975).

Competitiveness. Testosterone has been linked to competitiveness (Dabbs, 2000), and numerous studies have linked a lower 2D:4D finger ratio to competitiveness, especially in athletes (c.f. Manning & Taylor, 2001). Thus, the present study tested for this trait with the Competitiveness Orientation Inventory (Gill, 1986), a 30-item instrument that measures *winning*, *goal*, and *competitiveness* orientations and is shown to have internal consistency (Cronbach's alpha = .79-.95), test-retest reliability (r = .73-.89), and construct validity in terms of discriminating competitive sport participants from non-participants (Gill, 1986; Gill & Deeter, 1988; Gill, Kelley, Martin, & Caruso, 1991). In this instrument, participants are presented with a series of items pertaining to the criterion traits and asked to rate on a 5-point Likert scale whether they *strongly disagree*, *disagree*, *neither disagree nor agree*, *agree*, or *strongly agree* with each statement. Sample statements include, "I am a competitive person," "I try my hardest to win," "I want to be the best every time I compete," and "The best test of my ability is competing against others."

Aggression. Numerous studies have linked androgens with aggressive behaviors in humans and the rest of the animal kingdom (see Archer, 1991, for review), and studies have suggested a relationship between a lower 2D:4D finger ratio and aggression in men (Bailey & Hurd, 2005; Millet & Dewitte, 2007). The current study sought to document a connection between aggression and second toe length by employing the Buss-Perry Aggression Questionnaire-Short Form (BPAQ-SF), a 12-item instrument which measures subscales of *physical aggression*, *verbal aggression*, *anger*, and *hostility* (Buss & Perry, 1992). These scales have been shown to be reliable (Cronbach's alpha = .62 -.77) and to correlate strongly with other measures of aggression such as the Personality Assessment Inventory and the Psychology Services Inmate Questionnaire (Diamond & Magaletta, 2006). In the BPAQ-DF, participants are presented with a series of statements and asked to indicate on a 5-point Likert-type scale the extent to which each is like them, with answers ranging from *very unlike me* to *very like me*. Sample items include, "Given

enough provocation I may hit another person," "I can't help getting into arguments when people disagree with me," and "Sometimes I fly off the handle for no good reason."

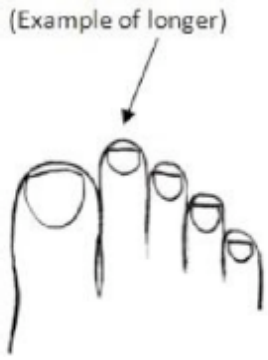
Exercise/physical fitness. Several studies have suggested a connection between a lower finger 2D:4D ratio and both athleticism (Manning, 2002; Manning & Taylor, 2001; Voracek, Reimer, Ertl, & Dressler, 2006) and physical fitness (Honekopp, Manning, & Muller, 2006). The current study aimed to examine the relationship between longer second toe length and athleticism as measured by exercise regularity. The Godin Leisure-Time Exercise Questionnaire (Godin & Shephard, 1985) was used. Items ask the participant to report how frequently each week they engage in mild, moderate, and strenuous activities. This 4-item instrument has been shown to correlate with several other measures of physical activity such as treadmill time, lung capacity, oxygen consumption, self-reports of exercise activity, and calorie burn (Godin & Shephard, 1985; Jacobs, Ainsworth, Hartman, & Leon, 1993; Miller, Freedson, & Kline, 1994) and has good reliability (Cronbach's alpha = .74-.81) (Godin & Shephard, 1985; Sallis, Buono, Roby, Micale, & Nelson, 1993).

Sociosexual orientation. Sexual behavior has been strongly linked to testosterone (cf. Brown, Monti, & Corriveau, 1978; Dabbs, 2000; Guay & Jacobson, 2002; Simon et al., 2004). In addition, a lower 2D:4D finger ratio has been linked to sexuality (Honekopp, Voracek, & Manning, 2006), although the evidence is often weak and/or conflicting (see Puts et al., 2004, for review). To test the association between second toe length and sexual behavior, the Sociosexuality Orientation Inventory (SOI) developed by Simpson and Gangestad (1991) was used. The items in this instrument have variable weighting as prescribed by Simpson and Gangestad (1991) and are summed to produce an SOI score. Sample items include, "With how many partners have you had sexual intercourse within the past year?" and "How often do you fantasize about having sex with someone other than your current dating partner?" Simpson and Gangestad (1991) showed that the instrument has acceptable internal consistency and that instrument was reliable (Cronbach's alpha = .73) (Simpson & Gangestad, 1991). Schmitt (2005) further demonstrated the reliability (.65) of the SOI across 48 countries.

Sexual orientation. Some studies have suggested a link between sexual orientation and lower 2D:4D finger ratios in both men and women (Rahman & Wilson, 2003; Robinson & Manning, 2000; Puts et al., 2004). Thus, the present study considered sexual orientation in relation to second toe length by use of the Kinsey Scale developed by Kinsey, Pomeroy, and Martin (1948). This scale is a 0-6 continuum of sexual orientation, with a self-rating of 0 indicating complete heterosexuality and a 6 indicating complete homosexuality. The scale has face validity, and it is one of the most widely-used indices of sexual orientation (Bailey, 2009).

Second toe length. As reported by McFadden and Shubel (2002), it is extremely difficult to measure toe lengths objectively. Thus, for the purpose of this exploratory study, participants were simply asked, "Is your second toe longer than all your other toes (does it extend beyond your other toes)?" They were provided with a graphical depiction, as shown in Figure 1, to help them make the categorization. Participants answered "Yes" or "No" to this question.

Figure 1. Illustration Used to Guide Participants' Self-assessment.



Results

Analyses revealed that 42.2 % of participants indicated that their second toes were their longest toes. There was no significant sex difference in the frequency (45.7% of men and 40.3% of women), χ^2 (1, N = 102) = .277, p = .599. However, since sex differences have been consistently reported in testosterone and 2D:4D finger ratios, subsequent data were analyzed separately for males and females.

Point-biserial correlations were calculated between having a second toe longer than one's other toes (1 = "No" or 2 = "Yes") and scores on the measures of androgen-mediated behaviors and traits assessed herein. Analyses revealed that there was a significant relationship between left handedness (negative scores on the Edinburgh Handedness Inventory) and having a longer second toe for both males, $r_{pb}(33) = -.333$, p = .034, and females, $r_{pb}(65) = -.231$, p = .031.

With respect to competitiveness, for males, there was no relationship between having a longer second toe and total Competitiveness Orientation Inventory (COI) score, $r_{pb}(33) = .172$, p = .162, or between having a longer second toe and scores on the subscales of *winning*, $r_{pb}(33) = .237$, p = .085, *goals*, $r_{pb}(33) = .142$, p = .208, or *competitiveness*, $r_{pb}(33) = .116$, p = .253. On the other hand, for females, there were relationships between having a longer second toe and total COI score, $r_{pb}(65) = .271$, p = .013, scores the subscale of *winning*, $r_{pb}(65) = .268$, p = .014, and scores on the subscale of *competitiveness*, $r_{pb}(65) = .257$, p = .018. For females, there was no relationship between having a longer second toe and scores on the subscale of *goals*, $r_{pb}(65) = .165$, p = .091.

In addition, for males, there was no significant relationship between having a longer second toe and total scores on the Buss-Perry Aggression Questionnaire-Short Form (BPAQ-SF), $r_{pb}(33) = .138$, p = .214, or any of its subscales: *physical* = $r_{pb}(33) = .109$, p = .266; *verbal* = $r_{pb}(33) = .109$, p = .267; *anger* = $r_{pb}(33) = .125$, p = .236; and *hostility* = $r_{pb}(33) = .154$, p = .188. For females, there was also no relationship between having a longer second toe and BPAQ-SF total score, $r_{pb}(65) = .117$, p = .172, or scores on the *verbal*, $r_{pb}(65) = .048$, p = .349, *anger*, $r_{pb}(65) = .072$, p = .282, or *hostility* subscales, $r_{pb}(65) = .039$, p = .377. However, there was a relationship between having a longer second toe and scores on the *physical* subscale, $r_{pb}(65) = .203$, p = .050.

Further, for males, there was a significant relationship between having a longer second toe and exercise frequency as measured by scores on the Godin Exercise Questionnaire, r_{pb} (30) = .420, p = .008. However, there was no such relationship for females, $r_{pb}(58) = -.018$, p = .445.

With respect to sexuality, there was no relationship between having a longer second toe and Sociosexual Orientation Inventory (SOI) scores for males, $r_{pb}(30) = .092$, p = .309, or for females, $r_{pb}(61) = .204$, p = .054. Likewise, there was no relationship between having a longer second toe and sexual orientation as measured by the Kinsey Scale (higher scores indicate increased homosexual orientation) for men, $r_{pb}(33) = -.226$, p = .096, or for women, $r_{pb}(65) = -.086$, p = .244.

Discussion

Previous studies of finger 2D:4D have yielded consistent sex differences, with men possessing a lower ratio (cf. Puts, 2004). The present study did not find a statistically significant sex difference in frequency of having a second toe longer than one's other toes. The frequency did exhibit the predicted difference, however, and a larger sample size in future studies may clarify this issue.

Of the present hypotheses, some did receive support. There was an association between left-handedness and having a longer second toe for both men and women. As this trait has been connected with androgenization (Geschwind & Galaburda, 1985) and with a lower 2D:4D (Manning, Trivers, Thornhill, & Singh, 2000; Voracek, et al., 2006), this is evidence for a relationship between second toe length and androgenization.

Other results were mixed. There was a relationship between having a longer second toe and self-ratings of competitiveness in women as indicated by total COI score and the sub-scores that demonstrate a competitive and a winning orientation. In contrast, there were no such relationships found for men. Competitiveness is a trait associated with androgenization and with a masculinized 2D:4D (Manning & Taylor, 2001), and therefore a link between this trait and a longer second toe may be indicative of second-toe androgenization.

For women, analyses also revealed a relationship between having a longer toe compared to one's other toes and self-ratings of physical aggression as indicated by this subscore on the BPAQ-SF. This was not found for men. The finding of a relationship between purportedly androgenized second toe morphology and some androgenized behaviors/traits for women but not for men is not entirely surprising, as Fink, Manning, and Neave (2004) and others have shown significant associations between digit lengths and androgenized behaviors for females and not males. Fink et al. (2004) explain this as resulting from males generally possessing a more competitive and aggressive personality type. Therefore, a greater within-sex variation in prenatal androgen exposure and circulating androgens is likely seen in females, thereby increasing the effectiveness of statistical comparisons. Further, it is suggested that females have a greater sensitivity to testosterone and may therefore have a lower threshold of response to the hormone (Bancroft, 2002); this may explain the behavioral correlates witnessed in the present study.

Wilson (1983) described the presence of a gene that mediates a shorter index finger relative to the ring finger as being dominant in men but recessive in women, and also noted considerable variation within the sexes. Wilson's data showed that more women who described themselves as "assertive and competitive" (p. 111) had a shorter

forefinger (2D) than ring finger (4D). A recessive genetic relationship between masculinized digit lengths could account for the weak data yielded by the present study. Although the present study did not address the relationship between finger length ratios and toe length ratios, McFadden and Shubel (2002) noted that toe ratios approximated finger ratios. Future studies employing precise measurements of toe lengths and ratios and the utilization of larger sample sizes may yield more robust results.

In contrast to the above, the results of the present study yielded the predicted relationship between having a longer second toe and exercise frequency for men but not for women. As previous studies have shown a relationship between masculinized finger ratios and physical fitness and athleticism (Manning & Taylor, 2001; Honekopp et al., 2006), this is further evidence that second toe length may be indicative of androgenization. Future studies may want to use alternative measures of athleticism, as frequency of exercise may not accurately tap into this trait thereby explaining the null results for women.

This exploratory study found no relationship between second toe length and measures of sexuality or sexual orientation in men or women. Although sexual drive and behavior has consistently been related to testosterone (Archer, 1991) and these traits been shown to be related to masculinized finger-length ratios (cf. Puts, 2004) results about the association of many traits and behaviors with finger 2D:4D have been consistently and curiously mixed, and the methodologies used to obtain said results may be responsible for some of the relationships found (Honekopp & Watson, 2010; Puts et al., 2004). Thus, establishing the link between toe lengths and androgenization and exploring further the link between toe lengths and finger 2D:4D may help to clarify these concerns.

Limitations

The present study has several limitations—the most obvious would be the use of a self-assessment of relative second toe length versus a direct, objective measurement. As finger-length differences are very subtle, toe-length differences may be subtle. This study was a preliminary investigation, however, and self-reports of relative second toe length were employed operating on the premise that college students are capable of examining their own toes to make a crude categorization of whether their second toes extend beyond their other toes. Admittedly, self-reports of toe lengths based on a rudimentary diagram likely produce error, but the data provided herein do suggest that future research is warranted. If it is possible to overcome the measurement problems identified by McFadden and Shubel (2002), researchers should aim to obtain precise, objective measures of toe lengths, and they may wish to take into account bone and/or soft-tissue lengths, as these appear to factor into the sex differences seen in some finger 2D:4D studies (Honekopp & Watson, 2010).

Additional limitations exist. It is possible that toe configuration is not the same for both feet, because researchers have reported finger length (2D:4D) differences between hands (e.g., Fink et al., 2004; Puts et al., 2004). Again, an objective measure would be ideal in determining this nuance. Further, this study had an arguably small sample size; particularly of males. Using a larger sample size can shed light on the associations between the morphology and behaviors/traits reported in the present study.

An obvious next step in this research is to determine the relationship between second toe length and finger 2D:4D. McFadden and Shubel (2002) noted that toe ratios approximated finger ratios, but had difficulty with measurements due to the arching of

participants' toes. As the present study employed self-report survey methodology, ascertaining precise finger digit measurements and therefore assessing this relationship was beyond its scope.

In conclusion, this study revealed connections between second toe length and androgenized behaviors/traits for women more so than for men. The results of this self-report-based pilot investigation do suggest that there is a phenomenon of interest here for future, technologically-sound measures to elucidate.

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