Digit ratio (2D:4D) researchers on 2D:4D research: An expert survey

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Abstract

Research into the second-to-fourth digit ratio (2D:4D), an assumed negative correlate of prenatal testosterone, has grown substantially over the past decade, so interim stocktaking of this field seems appropriate. Forty-four (38% of all) corresponding authors of 2D:4D articles participated in an expert opinion survey, indicating their perceptions of 2D:4D research (top insights/achievements, gaps/desiderata, problems/pitfalls, prospects/expectations). Major themes emerging from these researchers' content-analyzed survey responses included: calls for a general framework and research integration; for more theoretical rigor, experimental evidence, longitudinal studies, and animal research; and for measurement, methodology, study design, and data analysis standards in 2D:4D research. Mentioned high-priority issues of 2D:4D research, needed to be addressed and solved, included: lacking validation studies of 2D:4D (what it actually indexes, why it is influenced by prenatal hormones, including elucidation of its genetics), small effects, inconsistent or unreplicable findings, prevalence of correlational or underpowered studies, publication bias, and sparseness of meta-analyses.

Keywords: Digit ratio (2D:4D); Prenatal testosterone; Sex differences; Expert survey; Opinion poll; Research program evaluation; Content analysis; Qualitative data

Introduction

Expert surveys among researchers of one field constitute significant, concerted actions of accumulating scientific knowledge. Such studies are basically designed as opinion polls among researchers active along similar lines of inquiry, and the interest is in the experts' perceptions of their field. As for just a few examples of fruitful implementations of this approach, Wertz and Fletcher (1988) and Wertz, Fletcher, and Mulvihill (1990) surveyed perceptions of ethical problems in medical genetics among medical geneticists, both in the USA and internationally; the top-10 problems and unknowns pertaining to the Implicit Association Test have been listed twice by its originator (Greenwald, 2001, 2004); and a landmark monograph by Snyderman and Rothman (1988) reported on beliefs held about the nature of intelligence among intelligence researchers, as has been done more recently in another study (Reeve & Charles, 2008; see this latter source for further examples). Consequently, the pooled opinions and ideas of a researcher collective can potentially have a deep impact on their field, as exemplified by the report of an *American Psychological Association* Task Force devoted to knowns and unknowns in intelligence research (Neisser, Boodoo, Bouchard, Boykin, Brody, Ceci, et al., 1996), which, according to ISI Web of Science, up to now has received more than 600 citations.

As such, the expert survey is a commonly employed research design, but truly a novel initiative within the ongoing research on the second-to-fourth digit ratio (2D:4D). A literature of presently well over 300 studies (bibliography and scientometric analysis: Voracek & Loibl, 2009) has been triggered by the seminal report of Manning, Scutt, Wilson, and Lewis-Jones (1998), first mentioning the hypothesis 2D:4D might be a useful retrospective biomarker (specifically, a negative correlate) of prenatal androgen action.

Owing to this research program's rapid growth, existing reviews (Cohen-Bendahan, van de Beek, & Berenbaum, 2005; McIntyre, 2006; Neave, 2008) as well as the two monographs (Manning, 2002, 2008) available on the topic are already outdated. That is, these accounts cover only small fractions of the 2D:4D literature accessible now. On the other hand, inconsistent findings and replication failures emerging in 2D:4D research have led to assumptions of

publication bias (e.g., Vehmas, Solovieva, & Leino-Arjas, 2006), while meta-analytic summaries (starting with Hönekopp, Bartholdt, Beier, & Liebert, 2007) still are scarce in this field.

On the whole, the evidence from the 2D:4D literature may well appear more scattered and less consolidated than hoped-for after one decade of exploration. Hence, the present study sought to survey 2D:4D researchers' perceptions of 2D:4D research, in order to make use of the expert opinions of this collective for an interim stocktaking of the field and for fostering its progress.

Method

On May 1, 2008, invitations to participate anonymously in an expert survey on 2D:4D researchers' perceptions of 2D:4D research were e-mailed to all 121 corresponding authors (study guarantors; present writer excluded) of the available 2D:4D literature (see Voracek & Loibl, 2009). The most recent corresponding author contacted was from Vermeersch, T'Sjoen, Kaufman, and Vincke (2008; Epub ahead of print: March 7, 2008). Pre-announced reminders were sent on May 9 and May 16, 2008. Deadline for participation was May 23, 2008, all three e-mails were sent with read receipt requests, and the final reminder additionally with the urgency attribute.

Addressees were kindly requested to state their personal perceptions of the current state and progress of 2D:4D research, responding to a structured, four-item survey with open-ended response format. Specifically, researchers indicated their respective top-3 of insights and achievements made through 2D:4D research (Item 1), gaps and desiderata in 2D:4D research (Item 2), problems and pitfalls of 2D:4D research (Item 3), and prospects and expectations for 2D:4D research (Item 4).

No active e-mail address could be ascertained in five cases. Of the remainder, 54.3% (63/116) did not reply to any of the three e-mails sent (of these, 14.2% [9/63] returned read receipts), and 7.8% (9/116) declined the invitation. Participation rate was therefore 37.9% (44/116). All nine researchers declining the invitation stated their reasons for nonparticipation, as requested in the study invitation e-mail. These reply mails totalled 511 words (range: 12-107;

$Md = 57$). Eight researchers indicated they published a single 2D:4D research paper and therefore lacked pronounced opinions or sufficient overview regarding the vastly expanding field; one researcher indicated lack of time.

In response to the four-item survey, the 44 participating researchers produced a text corpus totalling 9,066 words (range of individual responses: 58-548 words; $Md = 188$). Using standard procedures of content analysis (Krippendorff, 2004; Weber, 1990), individual, anonymized statements were aggregated to successively refined major content categories within items (recursively, i.e., over the course of several coding rounds). To give an example, Item 1 responses (with their exact wording given here) such as “There is sexual dimorphism in 2D:4D”, “It is sexually dimorphic”, “The basic sex difference is well established”, “The most sure thing is that there is a sex difference in 2D:4D”, “2D:4D research almost always provides a highly reliable sex difference”, “There is a small (and apparently somewhat consistent) sex difference”, and further statements similar to these were all coded under one content category labelled “Sex differences in 2D:4D”. Total word count of coded responses (using the content category names) was 3,332, i.e., coding condensed the initial text corpus to about one-third.

Results

General findings

On each survey item, researchers provided a range of 0 to 5 statements. Exactly complying with the request to provide top-3 lists on Items 1-4 were 41%, 52%, 41%, and 34%, respectively. Mean number (and SD) of statements were slightly higher for Items 2 and 3 (gaps/desiderata, problems/pitfalls), 3.2 (1.0) and 3.3 (1.3), than for Items 1 and 4 (insights/achievements, prospects/expectations), 2.9 (1.1) and 2.9 (1.4), albeit not significantly so (Friedman test: $\chi^2(3) = 3.47, p = .33$). Also, there were no differences in length of statements across Items 1-4 ($Md = 38.5, 42, 38, \text{ and } 43.5$ words; Friedman test: $\chi^2(3) = 2.76, p = .43$). As expected, number of statements provided corresponded to their length across Items 1-4, $r_s = .28$ ($p = .07$), $.43$ ($p = .004$), $.67$, and $.68$ (both $ps < .001$). Both number and length of statements were consistent across survey items, Cronbach $\alpha = .63$ (for number) and $.58$ (for words).

Overall, researchers provided 46, 54, 57, and 67 (altogether, 224) different content categories for Items 1-4. These are listed in decreasing frequency (and within identical frequencies ordered alphabetically) in Table 1. From this table's layout alone (entries with identical frequencies across different items are horizontally aligned), it is already discernible that researchers' statements, notwithstanding their great variety seen on all 4 items, were somewhat more diverse and variegated in response to Items 3 and 4 (more discordant regarding problems/pitfalls and prospects/expectations), whereas less so for Items 1 and 2 (more concordant regarding insights/achievements and gaps/desiderata). Quantifying content category diversity across items confirmed this visual impression: the index of diversity (1 – Simpson's D , this quantity being a dominance measure for categorical data; Magurran, 1988, p. 39) was .956, .958, .968, and .966 for Items 1-4 (perfectly homogeneous vs. heterogeneous content would have yielded values of zero vs. unity, respectively).

The content categories listed in Table 1 would lend themselves to extensive referencing with background citations from the 2D:4D literature. For space limitations, this was not done here (for a bibliography of 2D:4D research, see Voracek & Loibl, 2009). In the remainder, the focus is on those content categories occurring 5 or more times in researchers' statements (i.e., mentioned by at least 10% of researchers: $5/44 = 11.4\%$).

Insights and achievements of 2D:4D research

Most frequently listed under this theme was the hypothesized characteristic of 2D:4D as a (non-invasive and easily applicable) pointer to prenatal testosterone, followed by the sex differences (as well as sexual orientation and ethnic/geographic differences) seen in this trait, its associations with many sex-hormone dependent traits (as well as associations of 2D:4D with sex hormones in the amniotic fluid and with sporting ability in particular), and a further understanding of factors influencing sex differences gained through 2D:4D research. For the multitude of additional statements provided by less than 10% of the sample (but partly echoing or complementing several of the main themes listed here, as was also true for response patterns on the further three survey items), see Table 1.

Gaps and desiderata in 2D:4D research

As most challenging questions of 2D:4D research respondents listed what 2D:4D actually indexes and why 2D:4D is influenced by prenatal hormones (which points were also taken up by less frequently occurring calls for empirical evidence in support of the Hox genes hypothesis of 2D:4D expression). These two major points were followed by interest in the relative contributions of hormonal vs. genetic factors to 2D:4D, calls for more experimental (instead of correlational) evidence, for more animal research, and for a clarification of the veridicality vs. spuriousness of 2D:4D research findings. Further research into the causes and meaning of ethnic/geographic differences in 2D:4D was mentioned by more than 10% of the researcher sample as well.

Problems and pitfalls of 2D:4D research

Corresponding to one key point already appearing under gaps/desiderata, the preponderance of correlational (instead of experimental) studies was listed most frequently under problems/pitfalls of 2D:4D research. This was complemented by another frequently occurring statement, namely “correlation is not causation”. Researchers saw as further important problems/pitfalls the lack of a gold standard for 2D:4D measurement and measurement method differences in 2D:4D (directly measured vs. via image-based methods), publication bias, generally small effect sizes, inconsistent findings and replication failures, small-N studies, Type 1 errors and chance/spurious findings, a lack of validation of 2D:4D as a marker of prenatal testosterone, and the use of ethnically/geographically heterogeneous samples.

Prospects and expectations for 2D:4D research

On this final survey item, the statement most frequently made concerned the understanding of prenatal hormone effects (either general or domain-specific) as prospect of 2D:4D research. This was followed by expectations of more animal, longitudinal (or follow-up), and experimental studies in 2D:4D research and the possibility of having a (proxy) marker for prenatal testosterone.

Discussion

This study, drawing on a unique database, is only the second one in 2D:4D research (after Voracek & Loibl, 2009) using qualitative data in aiming for a field synopsis. Also, it constitutes one of the few collaborative efforts so far in this field (McFadden, Loehlin, Breedlove, Lippa, Manning, & Rahman 2005: comparative reanalysis of 2D:4D studies on sexual orientation: Voracek, Manning, & Dressler, 2007: agreement of 2D:4D measurements among 17 corresponding authors of 2D:4D articles).

2D:4D researchers' views of 2D:4D research, compiled here, are multifaceted, instructive, and a rich source. 2D:4D as a biomarker for prenatal testosterone emerged as the top insight/achievement of 2D:4D research. This still is a hypothesis, with suggestive, but not conclusive, evidence. Accordingly, researchers noted a lack of validation studies (what 2D:4D actually indexes and why it is influenced by prenatal hormones) under gaps/desiderata. Second most common under insights/achievements was 2D:4D being sexually differentiated. This is the most credible finding from this field, although not an accomplishment of modern 2D:4D research since 1998. Meanwhile classified under "the most certain universal sex differences" (Ellis, Hershberger, Field, Wersinger, Pellis, Geary, et al., 2008, p. 938), it was already known in late 19th century (references: Manning, 2002; Voracek & Loibl, 2009). Ethnic/geographic differences in 2D:4D were mentioned as well. There still is little understanding of how these come about and what they may mean. Many statements regarding gaps/desiderata in and problems/pitfalls of 2D:4D research could be subsumed under a call for a general framework, research integration, theoretical rigor, elucidation of the genetics of 2D:4D, and measurement, methodology, study design, and data analysis standards in 2D:4D research. Concerns about small effects, inconsistent or unreplicable findings, prevalence of correlational or underpowered studies, publication bias, and sparseness of cumulative empirical knowledge (meta-analyses) were expressed as well. Allocating efforts to address and solve these issues should have high priority. Researchers' call for more experimental evidence in this field would necessarily lead to more animal research. Finally, checking the Table 1 entries against conjectures about future 2D:4D research trends

(compiled prior to the survey; Voracek & Loibl, 2009) shows all those within the survey's scope (Table 2; Hypotheses 5-15) covered in the survey responses.

While this study's strengths—including its face validity—seem evident, its conceivable limitations are more subtle, manifold, mainly related to its specific design (survey method and content analysis combined), and thus deserve elaboration. In particular, content analysis is a hermeneutic method and “interpretation is in part an art” (Weber, 1990, p. 62).

To begin with, content analysis typically is an unobtrusive technique, using data not generated with foreknowledge that they will be content-analyzed. This was not the case here and could have influenced survey responses and participation itself. Also, materials were human-coded, not computer-coded. With a single coder involved, inter-coder reliability could not be established. One perennial problem of content analysis, namely how narrow vs. broad categories should be coded, likewise applied here. On the other side, many content analyses start from whole texts and thus coding units are neither given nor natural. Due to the pre-defined units (open-ended questions), there was no unit-finding problem here.

Content frequency listing, by far the most commonly used technique to render content analysis results comprehensible (Krippendorff, 2004, p. 191), was utilized here (Table 1). This potentially has two disadvantages. First, a frequency fallacy (majority bias) might occur. The basic idea of frequency listing is that higher counts should indicate higher attention, concern, or emphasis and thus higher category importance, with absent categories interpreted as unawareness. This is not necessarily always true, as less frequent (non-mainstream) content might as well be inventive and important (see bottom part of Table 1: e.g., occupational differences in or occupational effects on 2D:4D). Second, mere frequency listing omits category contingencies. Such above-chance associations between categories might additionally be informative. Co-occurrence analysis was waived here because of a low person-to-data ratio (44 respondents produced 224 different categories).

A final limitation was that researcher demographics and bibliometric data on their 2D:4D papers could not be used for analysis, since this could potentially undermine the anonymous

survey participation assured. One could also object that two-thirds of the eligible population did not participate, but then again, the participation rate (37.9%) was comparable to similar endeavors (in fact almost identical to Reeve & Charles, 2008: 38.3%).

This research could be followed up and expanded in several ways: e.g., repeated or periodically updated with the ever increasing population of corresponding authors; widened to all article co-authors or even to thesis authors and their supervisors and committee members; or administered to experts from disciplines relevant for 2D:4D research (behavioral endocrinology, developmental biology, embryology, neuroscience, etc.) who are aware of (but have not contributed to) this literature. Still another alternative would be to obtain endorsement ratings on the content categories listed in Table 1 from any of these groups. At any rate, there seem ample opportunities to build up from the present evidence and materials. It is hoped these ideas will be picked up and the current findings will stimulate appropriate efforts of researchers active in this field—all towards clarification, consolidation, and progress of 2D:4D research.

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Table 1

Frequency listing (#) of content categories in expert survey on 2D:4D research

#	Insights/Achievements of 2D:4D research	#	Gaps/Desiderata in 2D:4D research	#	Problems/Pitfalls of 2D:4D research	#	Prospects/Expectations for 2D:4D research
16	2D:4D as a non-invasive, easily applicable biomarker for prenatal testosterone					15	Understanding of prenatal hormone effects (general, or domain-specific)
		14	What 2D:4D actually indexes				
		13	Why 2D:4D is influenced by prenatal hormones				
		11	Relative contributions of hormonal vs. genetic factors to 2D:4D				
10	Sex differences in 2D:4D			10	Correlational (non-experimental) research		
				8	Lack of gold standard for 2D:4D measurement; Publication bias		
7	2D:4D as a correlate of many sex-hormone dependent traits; Understanding of factors influencing sex differences	7	More experimental (non-correlational) evidence	7	Correlation is not causation; Measurement method (direct vs. image-based) differences in 2D:4D; small effect sizes in 2D:4D research	7	More animal research
6	Sexual orientation differences in 2D:4D	6	Clarification of veridicality vs. spuriousness of 2D:4D research findings; More animal research	6	Ethnically/geographically heterogeneous samples; Inconsistent findings and replication failures	6	Longitudinal (follow-up) studies; More experimental research
5	Ethnic/geographic differences in 2D:4D; Relationship of 2D:4D with amniotic fluid sex hormones; Relationship of 2D:4D with sporting ability	5	Causes and meaning of ethnic/geographic differences in 2D:4D; empirical evidence for the Hox genes hypothesis	5	Lack of validation of 2D:4D as a marker; Small-N studies; Type 1 error, chance/spurious findings	5	A (proxy) marker for prenatal testosterone
4	(High) heritability of 2D:4D (twin studies); Organizing hormone effects on medical conditions (fetal programming of disease); Organizing hormone effects on psychological traits	4	Clarification of 2D:4D measurement matters and issues; Relationships with circulating hormone levels	4	Measurement error in 2D:4D ascertainment; Side (right-left) differences in 2D:4D (and 2D:4D effects)	4	A predictor of certain pathologies (for preventive use); Declining interest in 2D:4D research (could be a fad); Meaning of 2D:4D associations with candidate variables/traits; Understanding what influences 2D:4D
3	2D:4D associated with childhood psychopathology (autism, ADHD); Organizing hormone effects on human cognition; Prenatal origin of sex differences in 2D:4D	3	Causes and meaning of side (right-left) differences in 2D:4D; Developmental stability vs. change in 2D:4D; Genetics of 2D:4D; More cross-species comparisons; Relationships of 2D:4D to other markers of prenatal testosterone; Research on other finger-length ratios than 2D:4D; The precise developmental window (critical period)	3	Ethnic/geographic differences in 2D:4D; General skepticism to anthropometric research ("pseudoscience"); Lack of consideration of other markers than 2D:4D; Lack of knowledge what 2D:4D actually indexes	3	Cross-species comparisons of 2D:4D; Standard methodology, design, and data analysis of 2D:4D studies; Understanding developmental stability (vs. change) in 2D:4D
2	2D:4D associated with gender identity; Organizing hormone effects on human behavior; Relationship of 2D:4D to	2	Clarification of the significance of individual differences in 2D:4D; Extent of file-drawer problem (publication bias) in 2D:4D	2	Developmental changes in 2D:4D; Lack of animal research; Lack of data analysis standards; Lack of general	2	Discovery of other markers for prenatal testosterone than 2D:4D; General framework/theoretical rigor; Meta-

#	Insights/Achievements of 2D:4D research	#	Gaps/Desiderata in 2D:4D research	#	Problems/Pitfalls of 2D:4D research	#	Prospects/Expectations for 2D:4D research
	(visuo)spatial ability, targeting; Relationship of 2D:4D to androgen receptor gene variation; Relationship of 2D:4D to congenital adrenal hyperplasia (CAH); Relationship of 2d:4D to fertility; Relationship of 2D:4D to traits relevant for evolutionary fitness; Research expanded to non-human models (emergence of a new field of animal research); Sex determination of cave artists		research; Genotype-environment interactions in 2D:4D expression; Meta-analyses/systematic reviews; More large-N studies; Role of prenatal estrogens; Why effects in 2D:4D research typically are small		framework/theoretical rigor; Lack of replications; Measure-driven (instead of theory-driven) research; Measurement matters and issues in 2D:4D research; Multiple measures and statistical tests; Small sex differences (and substantial overlap between sexes) in 2D:4D; Statistical problems with 2D:4D as a ratio variable		analyses/systematic reviews; More validation studies of 2D:4D; Understanding of factors influencing 2D:4D; Understanding of molecular genetic bases of 2D:4D (and its correlates); Understanding of sex differences
1	2D:4D associated with toxoplasmosis infection; Availability of abundant, global data on 2D:4D; Comparative approach to explore the development of brain and behavior; Developmental change in 2D:4D; Developmental stability in 2D:4D; Ethnic/geographic differences in the sex effect seen in 2D:4D; Experimental approaches; Interplay of Hox genes and endocrine factors; Larger sex difference in 2D:4D in European Upper Paleolithic than modern European populations; Maternal hormonal effects (long-term consequences); Maternal hormonal effects (on offspring phenotype); More limited role in development of gender identity than expected; More limited role in development of sexual orientation than expected; No maternal testosterone effects on 2D:4D; Organizing hormone effects on psychopathology; Organizing hormone effects on personality; Progress in 2D:4D measurement; Public relations (increasing awareness of biological influences on behavior); Relationship of 2D:4D to age of menarche; Relationship of 2D:4D to circulating testosterone in adults; Relationship of 2D:4D with masculinity/femininity (sex-role orientation); Relative contributions of prenatal vs. adult circulating testosterone to human aggression; Reliability issues in 2D:4D measurement; Renewed interest in developmentally relevant anatomical traits; Side (right-left) differences in the strength of associations between 2D:4D and target traits; Understanding of factors influencing within-sex individual differences	1	Archaeologic research on 2D:4D; Clarification of cross-species differences in 2D:4D; Clarification of 2D:4D to childhood psychopathology; Clarification of sexual orientation differences in 2D:4D; Collaborative work with endocrinologists; Consensus regarding data-analytical approaches in 2D:4D research; Differentiation of organizational vs. activational effects; Effects of (occupational) hand use on 2D:4D; Elucidation of pathways from prenatal testosterone to adult behavior/personality; Evolutionary meaning and significance of sex differences in 2D:4D; General framework of candidate correlates of 2D:4D; Integrated account of relationships of 2D:4D to cognitive abilities; Interaction effects of prenatal and circulating testosterone on adult behavior/personality; Link between maternal hormone effects and offspring phenotype; Magnitude of prenatal testosterone effects on 2D:4D; Mediating environmental effects during development; Moderation studies (person-situation interaction effects) in 2D:4D/behavior associations; More amniocentesis studies; More embryologic research; More field studies in animal research; Predictive value of 2D:4D for endocrine disorders; Relationships of 2D:4D to other than sex-linked variables/traits; Replication of relationships of 2D:4D to offspring sex ratio; Role of estrogens; Role of postnatal estrogens; Role of postnatal stress hormones; Role of prenatal gonadotrophins; Role of prenatal progesterone; Role of prenatal stress hormones; Subsumption of 2D:4D research findings in brain lateralization models	1	2D:4D measurement problems in children; Age-heterogeneous samples; Assumptions of 2D:4D associations with adult circulating hormones; Atypical samples (introductory-course psychology undergraduates); Cross-species differences in 2D:4D; Influence of outliers in correlational/regression analysis; Lack of anatomy/morphology background in 2D:4D research; Lack of attention to etiological pathways in 2D:4D/psychopathology studies; Lack of attention to postnatal effects on 2D:4D; Lack of attention to potential confounders of 2D:4D associations; Lack of consideration of context in studies (pre-exposure to stimuli); Lack of endocrinological research; Lack of evaluation of alternative hypotheses; Lack of examination of comorbidity in 2D:4D/psychopathology; Lack of field studies in animal research; Lack of functional significance of sex and individual differences in 2D:4D; Lack of genetic studies; Lack of medical/clinical usefulness; Lack of recognition of historical contributions to this field; Lack of specificity of candidate variables/traits in 2D:4D research; Lack of standards for behavioral measures; Lack of studies of maternal hormonal effects on offspring phenotype; Lack of study design standards; Non-consideration of androgen effects outside developmental window of 2D:4D; Overstated importance of radiographic 2D:4D studies; Preponderance of self-report measures in 2D:4D research; Public relations difficulties (explaining the complexities of 2D:4D research to general public); Sex-specificity of 2D:4D effects; Simplistic approaches to the development of sex differences; Study outcomes/interpretations influenced by strong a priori hypotheses	1	2D:4D as a moderator variable of effects on psychological variables; Beneficial for personality research; Beneficial for sex differences (gender) research; Better understanding of brain development; Clarification of developmental window for 2D:4D; Confirmatory evidence for hypothesis relating parental sex-hormone levels to offspring sex ratio; Discovery of genetic pathways (not including androgens) influencing 2D:4D; Effects of hand function on 2D:4D; Elucidation of environmental factors in 2D:4D development; Evolutionary developmental studies; Experimental behavioral economics research; Fetal imaging studies; Genetics of 2D:4D; Important role of 2D:4D research in research into brain development; Inclusion of 2D:4D research in mainstream textbooks; Large-N studies; Link between developmental instability and side (right-left) differences in 2D:4D; Link between mating/breeding systems and 2D:4D; Molecular genetic research; More adult circulating testosterone studies; More amniotic fluid (amniocentesis) studies; More anogenital distance studies; More archaeological research on 2D:4D; More experimental studies; More genetic studies; More moderation studies (person-situation interaction effects) on 2D:4D/behavior associations; More replication studies; More scientific credibility of 2D:4D research; More studies on maternal hormonal effects; Occupational differences in 2D:4D; Public engagement with science (much media interest in 2D:4D research); Reliability and validity issues need to be solved; Replacement of 2D:4D by better markers from genomics/proteomics; Research into other finger/toe-length ratios; The meaning of 2D:4D will be inconsequential to the human condition; Understanding (evolution of) cross-

#	Insights/Achievements of 2D:4D research	#	Gaps/Desiderata in 2D:4D research	#	Problems/Pitfalls of 2D:4D research	#	Prospects/Expectations for 2D:4D research
							species differences in 2D:4D; Understanding (evolution of) ethnic/geographic differences in 2D:4D; Understanding genotype-environment interaction on 2D:4D expression; Understanding hormone-related disorders; Understanding of androgen effects on finger bones and tissues; Understanding of autism-spectrum disorders; Understanding of evolution of human sexuality/physiology; Understanding of evolutionary forces maintaining greater sexual dimorphism in the past; Understanding of interaction of biological and social factors in childhood behavior; Understanding of interactions of brain development, hormones, neurotransmitters; Use of radiographic and direct 2D:4D measurement; Useful, but imperfect, tool for investigating brain-hormone-body relationships; Valuable teaching tool (for undergraduate research)

Table 2

Conjectures about future 2D:4D research trends

Hypothesis number	Hypothesis
1	Field diversification (i.e., researchers, institutions, countries, disciplines, journals involved)
2	Non-English publications in local journals
3	Publications in core journals of psychology
4	Special sections in and special issues of journals
5	Reviews and meta-analyses
6	Replication studies of findings awaiting independent replication
7	Research collaborations (e.g., multi-sample studies, cross-national comparisons)
8	Embryological studies
9	Longitudinal studies
10	Methodology papers, critical discussions, attempts of consensus statements and standard protocols (focus on study designs, measurement issues, conventions of data analysis)
11	Research on non-human species (particularly, animal experimentation studies, phylogenetic comparisons between anthropoid species)
12	Research including all six possible finger-length ratios
13	Search for alternative biomarkers superior to 2D:4D
14	Research on physical health implications and possible medical applicability (cf. fetal programming of disease) of such biomarkers
15	Integrative work (in association with endocrinology, developmental biology, molecular genetics)

Adapted from Voracek & Loibl (2009).