Center of Functionally Integrative Neuroscience
Aarhus University/ Aarhus University Hospital - DENMARK

Sex/gender differences in language and brain: Findings and methodological challenges

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Abstract

- Sex/gender is a highly studied and debated issue in research and politics. Here I present the evidence for behavioral and neurologic sex/gender differences related to language and discuss the methodological challenges that such investigations face. These challenges that are generalisable to many fields beyond the realm of sex/ gender.

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Women's brains work better in warmer offices, study finds

Researchers say workplaces may be able to increase productivity by setting thermostat higher

Australian Associated Press

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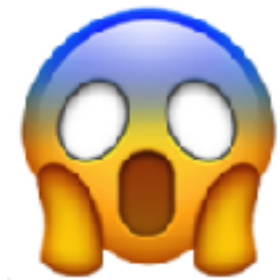

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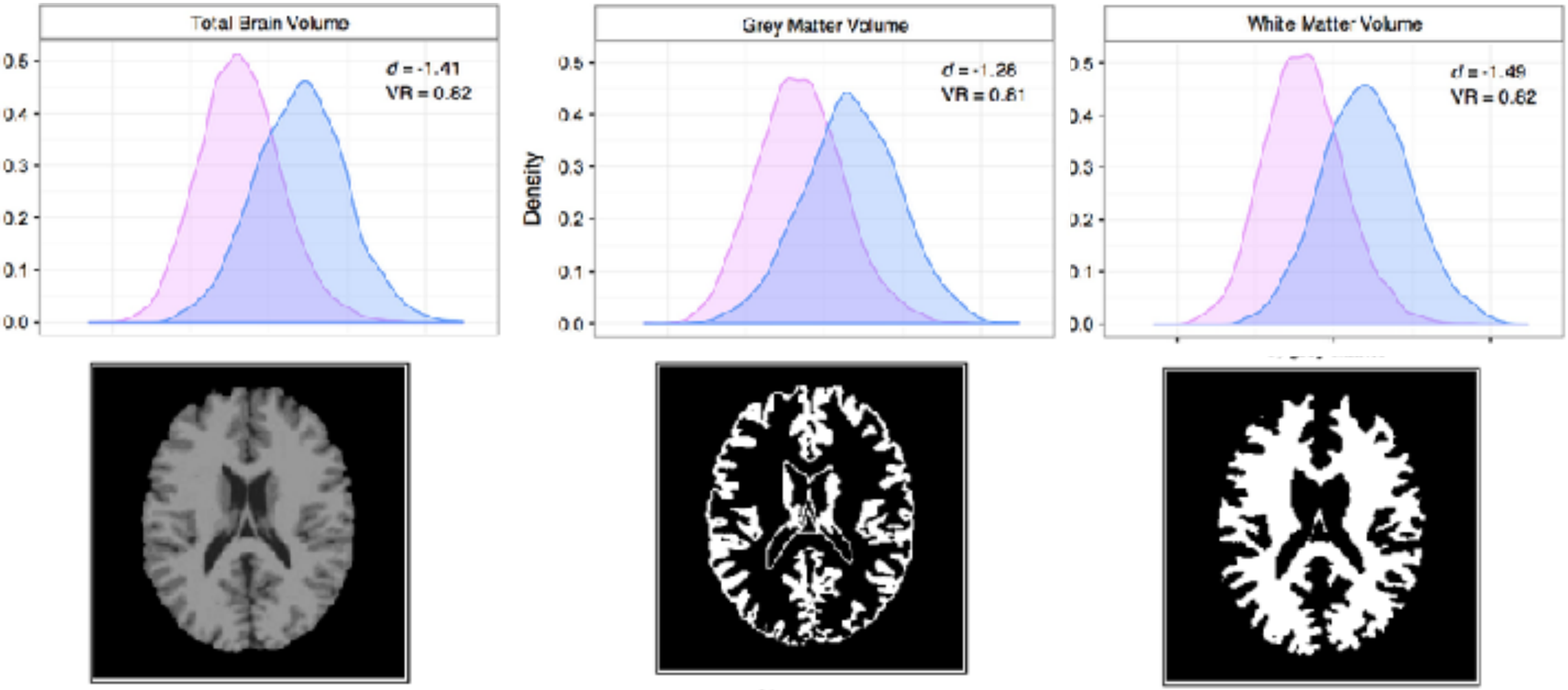
The kind of studies that I have been reviewing for the past 13 years

Brain sex/gender differences galore



(2750 female, 2466 male participants; mean age 61.7 years, range 44–77 years)

Ritchie, S. J., Cox, S. R., Shen, X., Lombardo, M. V., Reus, L. M., Alloza, C., Harris, M. A., Alderson, H. L., Hunter, S., Neilson, E., Liewald, D. C. M., Auyeung, B., Whalley, H. C., Lawrie, S. M., Gale, C. R., Bastin, M. E., McIntosh, A. M., & Deary, I. J. (2018). Sex Differences in the Adult Human Brain: Evidence from 5216 UK Biobank Participants. *Cerebral Cortex, 28*, 2959-2975, 10.1093/cercor/bhy109, https://doi.org/10.1093/cercor/bhy109.

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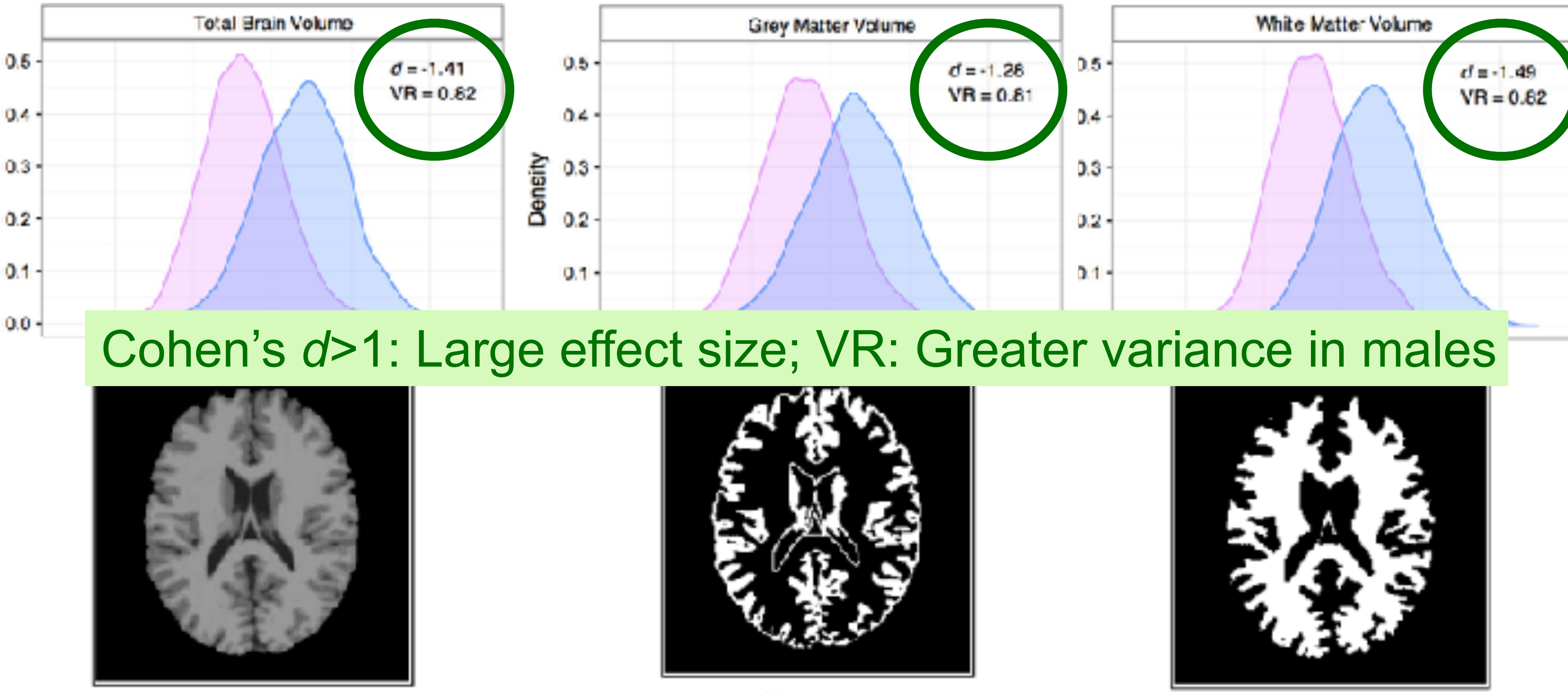

Cohen's *d*>1: Large effect size; VR: Greater variance in males

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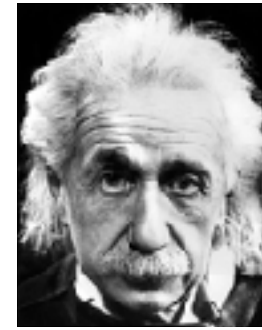
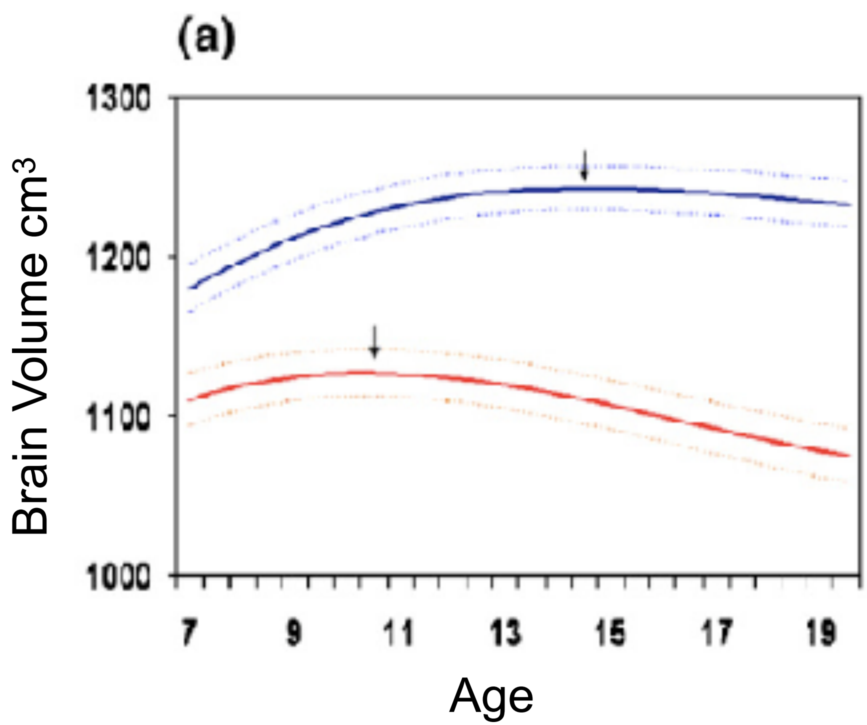
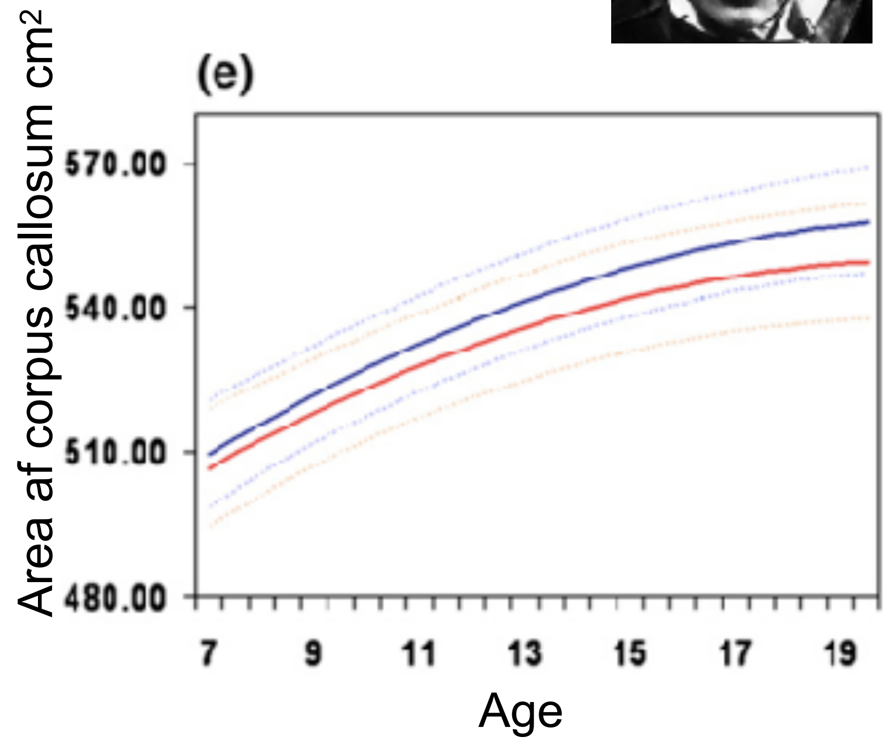
Differences present during development







475 male/ 354 female participants

Lenroot et al. NeuroImage 2007

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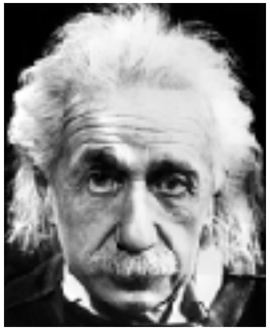

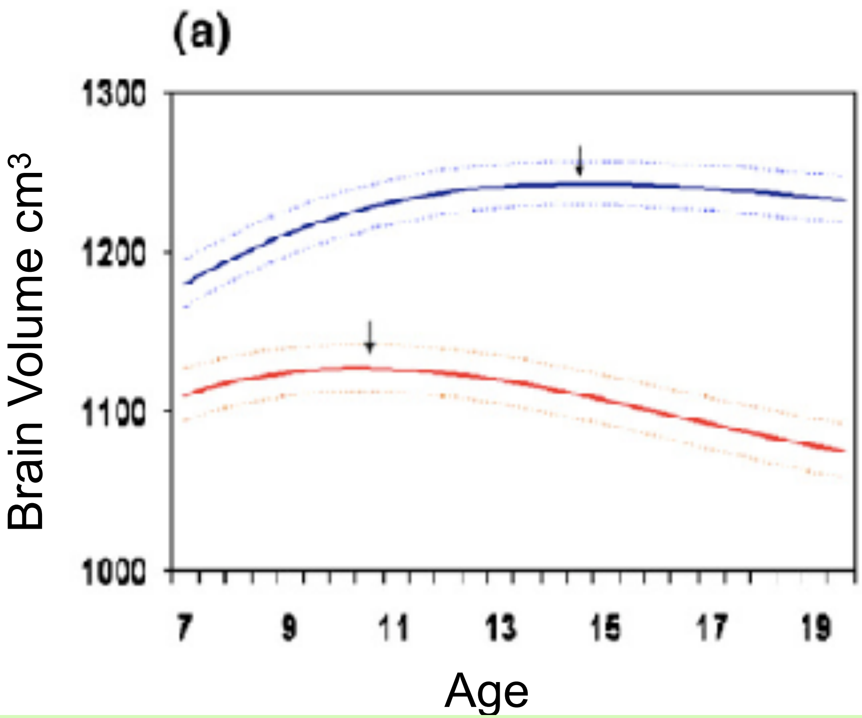

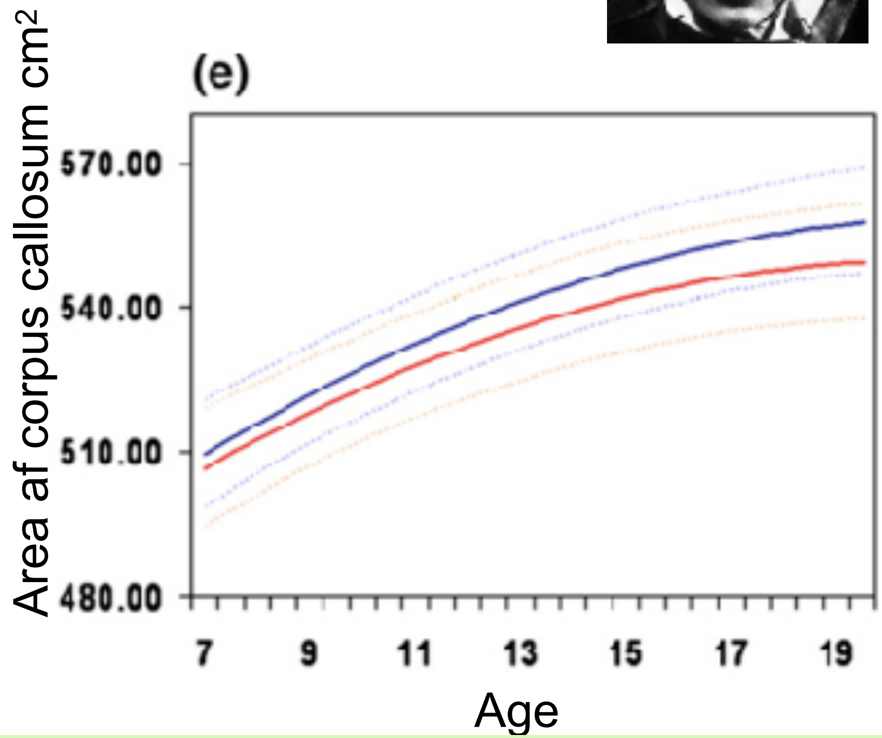

Brain volume peaks at 11-15 years, but when does performance peak?

475 male/ 354 female participants

Lenroot et al. NeuroImage 2007

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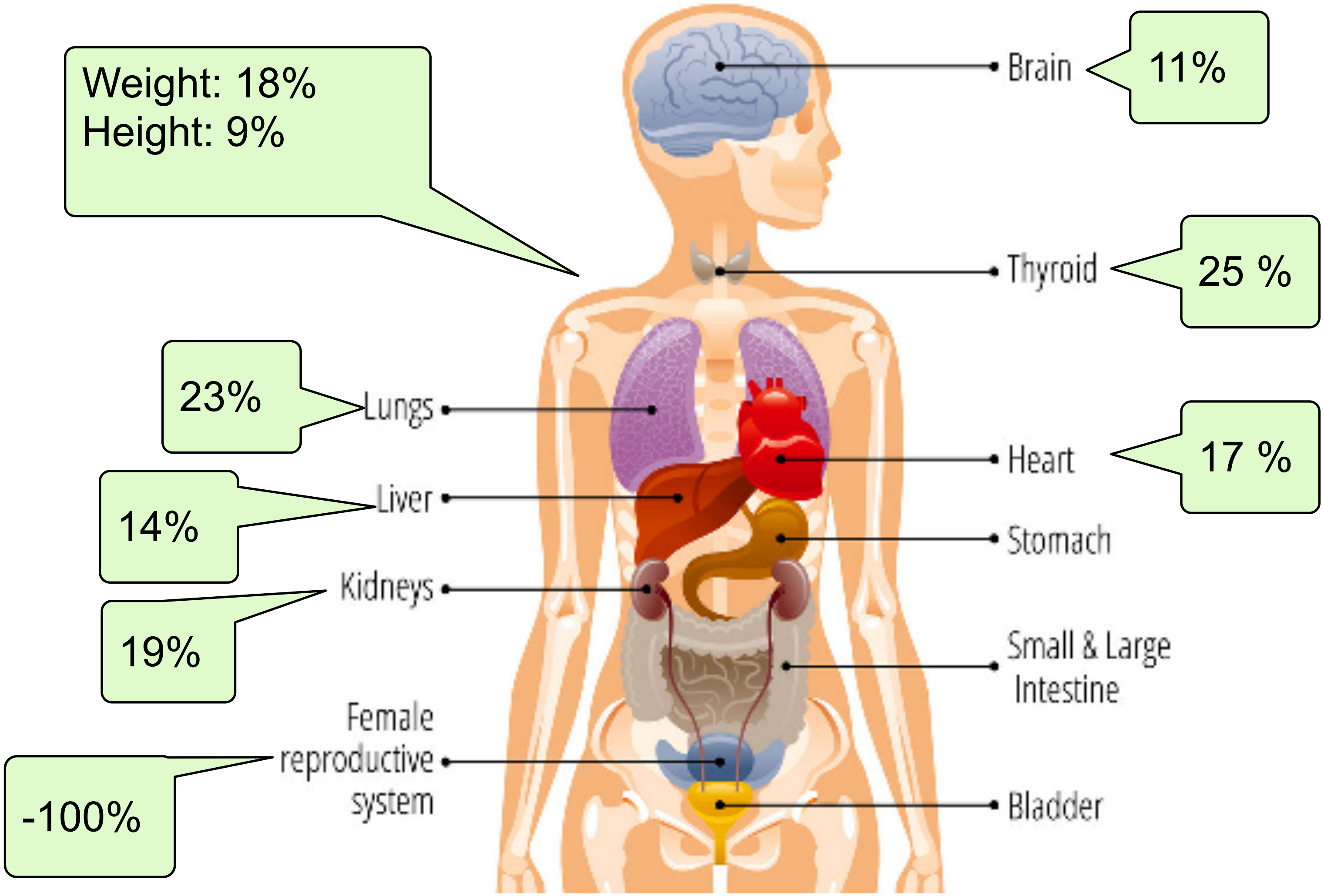
Men are bigger in general



Eliot, L., Ahmed, A., Khan, H., & Patel, J. (2021). Dump the “dimorphism”: Comprehensive synthesis of human brain studies reveals few male-female differences beyond size. *Neuroscience and Biobehavioral Reviews, 125*, 667-697, https://doi.org/10.1016/j.neubiorev.2021.02.026, https://www.sciencedirect.com/science/article/pii/S0149763421000804.

Size matters in body size: What about the brain?

Brain size matters for cognitive abilities

Table S9: Brain size and fluid intelligence, by sex

Ordinary least squares (OLS) regression with *fluid intelligence* as the dependent variable, stratified by sex. Table reports 95% confidence intervals in parentheses. Brain volume is in cm^3. Regression includes all control variables specified in Table 1, including controls for population structure using the first 40 principal components of the genome. Coefficients for control variables are not displayed.

	Females		Males	
	Standardized betas	Marginal effects (dy/dx)	Standardized betas	Marginal effects (dy/dx)
Brain volume	0.16*** (0.14 - 0.18)	0.0013*** (0.0011 - 0.0015)	0.15*** (0.13 - 0.17)	0.0011*** (0.0010 - 0.0013)
R^2	0.13	0.13	0.14	0.14
N	7,183	7,183	6,425	6,425

* $p<0.05$; ** $p<0.01$; *** $p<0.001$

Nave, G., Jung, W. H., Karlsson Linnér, R., Kable, J. W., & Koellinger, P. D. (2018). Are Bigger Brains Smarter? Evidence From a Large-Scale Preregistered Study. *Psychological Science, 30*, 43-54, 10.1177/0956797618808470, https://doi.org/10.1177/0956797618808470.

Brain size matters for educational attainment

Table S12: Brain size and educational attainment - by sex

Ordinary least squares (OLS) regression with *educational attainment* as the dependent variable, by sex. Table reports 95% confidence intervals in parentheses. Brain volume is in cm^3. Regression includes all control variables specified in Table 2, including controls for population structure using the first 40 principal components of the genome. Coefficients for control variables are not displayed.

	Females		Males	
	Standardized betas	Marginal effects (dy/dx)	Standardized betas	Marginal effects (dy/dx)
Brain volume	0.11*** (0.08 - 0.13)	0.0047*** (0.0036 - 0.0057)	0.09*** (0.07 - 0.12)	0.0035*** (0.0025 - 0.0044)
R^2	0.06	0.06	0.04	0.04
N	7,183	7,183	6,425	6,425

Nave, G., Jung, W. H., Karlsson Linnér, R., Kable, J. W., & Koellinger, P. D. (2018). Are Bigger Brains Smarter? Evidence From a Large-Scale Preregistered Study. *Psychological Science, 30*, 43-54, 10.1177/0956797618808470, https://doi.org/10.1177/0956797618808470.

“Controlling” and “correcting”

Table S2: Pairwise correlations between key variables in the analysis

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(1)	Brain volume	1.00												
(2)	Fluid IQ	0.21	1.00											
(3)	Numeric memory	0.14	0.36	1.00										
(4)	Reaction time	-0.11	-0.17	-0.10	1.00									
(5)	Visual memory	-0.07	-0.28	-0.13	0.17	1.00								
(6)	G-factor	0.22	0.78	0.65	-0.47	-0.60	1.00							
(7)	EA	0.14	0.31	0.14	-0.08	-0.08	0.25	1.00						
(8)	Male	0.62	0.08	0.09	-0.09	0.00	0.10	0.09	1.00					
(9)	Age at scan	-0.04	-0.05	-0.09	0.29	0.19	-0.23	-0.05	0.07	1.00				
(10)	Height	0.59	0.16	0.12	-0.14	-0.07	0.18	0.11	0.73	-0.07	1.00			
(11)	PC1	-0.07	-0.12	-0.03	0.05	0.08	-0.09	0.04	0.01	-0.09	-0.03	1.00		
(12)	PC2	0.06	0.08	0.01	-0.01	-0.02	0.05	-0.04	-0.01	0.05	0.06	-0.20	1.00	
(13)	PC3	-0.03	-0.01	-0.01	0.04	0.04	-0.00	0.02	0.04	-0.01	0.01	-0.02	0.14	1.00
(14)	PC4	0.02	-0.05	-0.00	0.05	0.02	-0.03	-0.06	-0.02	-0.00	0.00	-0.05	0.05	-0.04

Among the different cognitive measures, fluid intelligence was most strongly correlated with *g* as well as educational attainment and TBV. Male sex and body height had strong positive correlations with TBV and weak positive correlations with cognitive performance in the UKB sample. These findings highlight the importance of controlling for sex and height in our analyses.

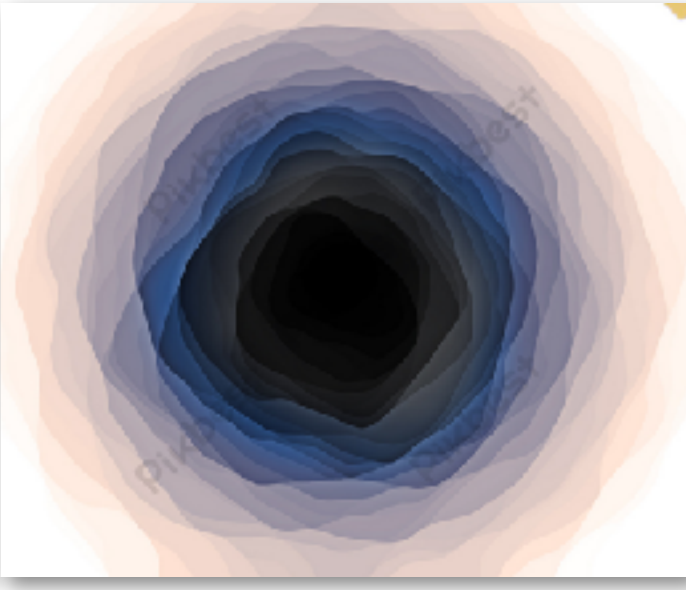
Nave, G., Jung, W. H., Karlsson Linnér, R., Kable, J. W., & Koellinger, P. D. (2018). Are Bigger Brains Smarter? Evidence From a Large-Scale Preregistered Study. *Psychological Science, 30*, 43-54, 10.1177/0956797618808470, https://doi.org/10.1177/0956797618808470.

Statistical independence assumption

- A covariate must be independent of the other independent variables.

"Check that the covariate and any independent variables are independent. […] If you get a significant result then stop the analysis here. You have basically entered a bottomless pit of despair from which there is no escape."

Field, Andy. "Discovering Statistics Using R." iBooks.



The bottomless pit of control

- If your data are biased, you cannot control your way out of this
- “Controlling” may just be a way of removing effects that show that your data are biased.
- Determining what is meant by unbiased data is difficult…
- The best you can hope for is that your effect replicates on another (biased/unbiased) dataset.

Size matters, except when it doesn't

- there are no IQ sex differences
- there are sex differences in brain volume
- IQ correlates with brain volume
- brain volume across sexes is not related to IQ

Language

Language acquisition

MacArthur–Bates Communicative Development Inventories (CDI)

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- Questionnaire, where parents tick words that the child understands and/or produces from word-list

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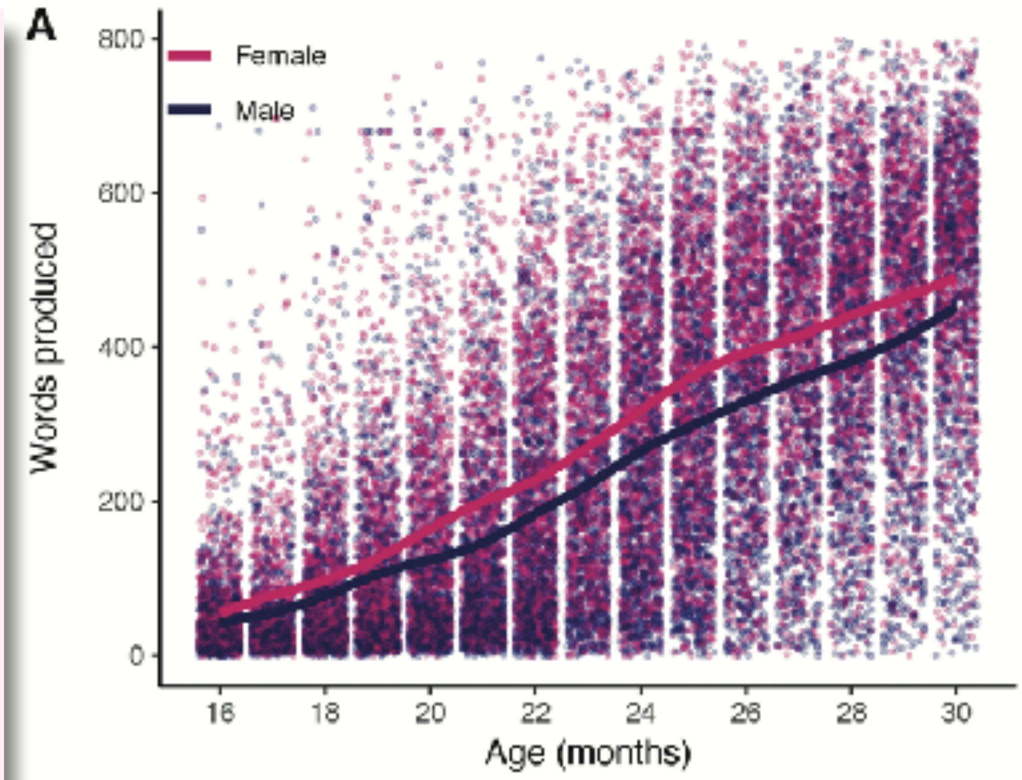
- Questionnaire, where parents tick words that the child understands and/or produces from word-list
- Data from the CDI: Words and Sentences is available from more than 28,000 children at http://wordbank.stanford.edu. This database covers a large number of languages, including Cantonese (Tardif et al., 2009), Croatian (Kovacevic et al., 1996), Czech (Markova and Smolík, 2013), Danish (Bleses et al., 2008), English (US) (Fenson et al., 2007; Thal et al., 2013), English (AU) (Kalashnikova et al., 2016) , German (Szagun et al., 2009), Hebrew (Hila Gendler Shalev, Tel-Aviv University), Italian (Caselli et al., 1995), Korean (Pae and Kwak, 2011), Latvian (Urek et al., to appear), Mandarin (Tardif et al., 2009; 劉惠美 and 陳昱君, 2015), Norwegian (Simonsen et al., 2013), Portuguese (European) (Irene Cadime, University of Minho), Russian (Елисеева and Вершинина, 2009), Slovak (Svetlana Kapalková, Comenius University), Spanish (European) (López Ornat et al., 2005), Spanish (Mexican) (Jackson-Maldonado et al., 2003), Swedish (Eriksson and Berglund, 2002) and Turkish (Acarlar et al., 2009).

Gender in CDI across 21 language areas

Wallentin, M. (2020). Gender differences in language are small but matter for disorders. In R. Lanzenberger, G. S. Kranz & I. Savic (Eds.), *Handbook of Clinical Neurology* (Vol. 175, pp. 81-102): Elsevier, https://doi.org/10.1016/B978-0-444-64123-6.00007-2,

Gender in CDI across 21 language areas

- Across the age span, girls produce slightly more words than boys (NB: large variability)



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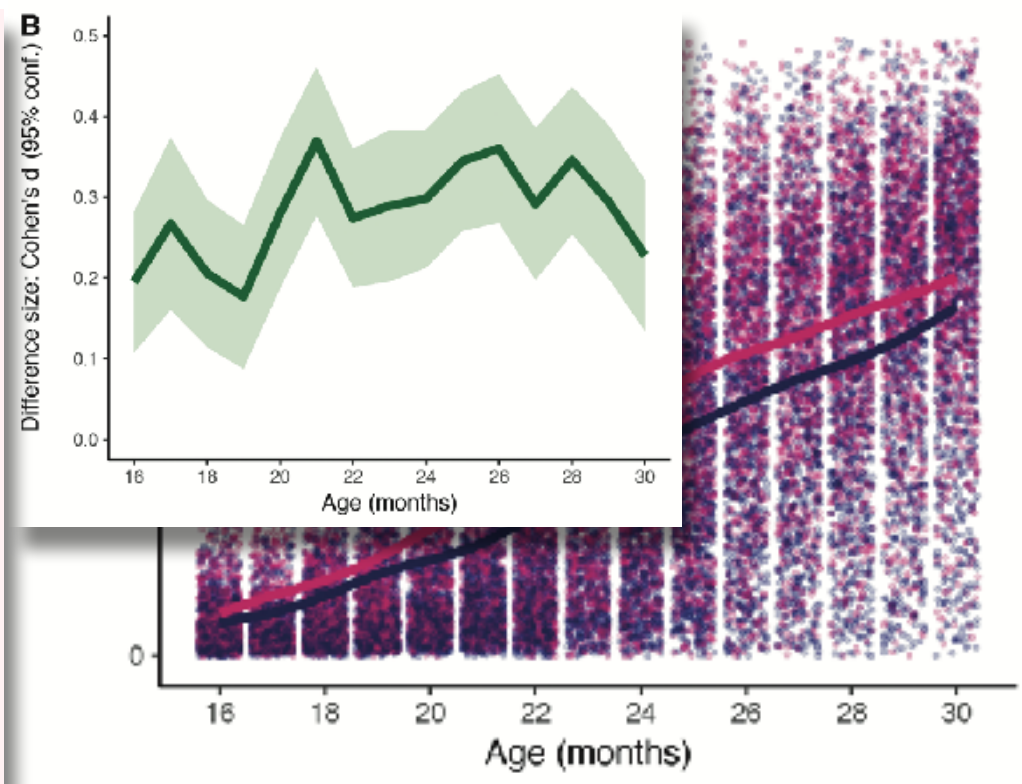
- Effect size in the "small" range. Gender explains 1% of the variance



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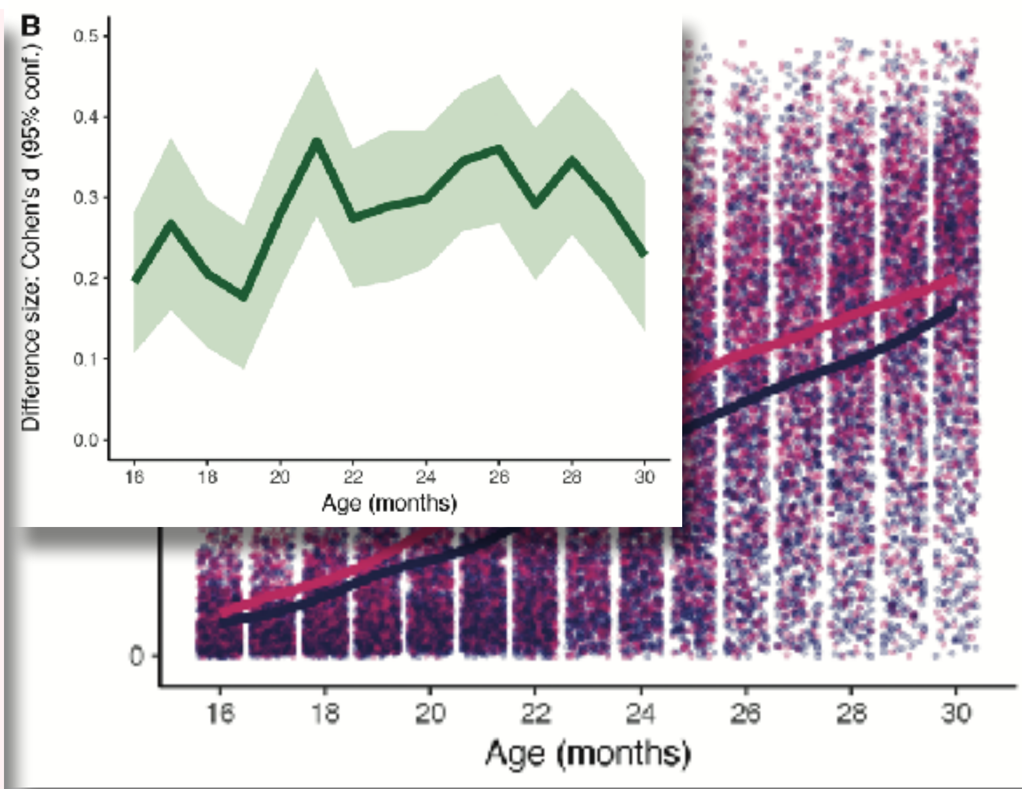

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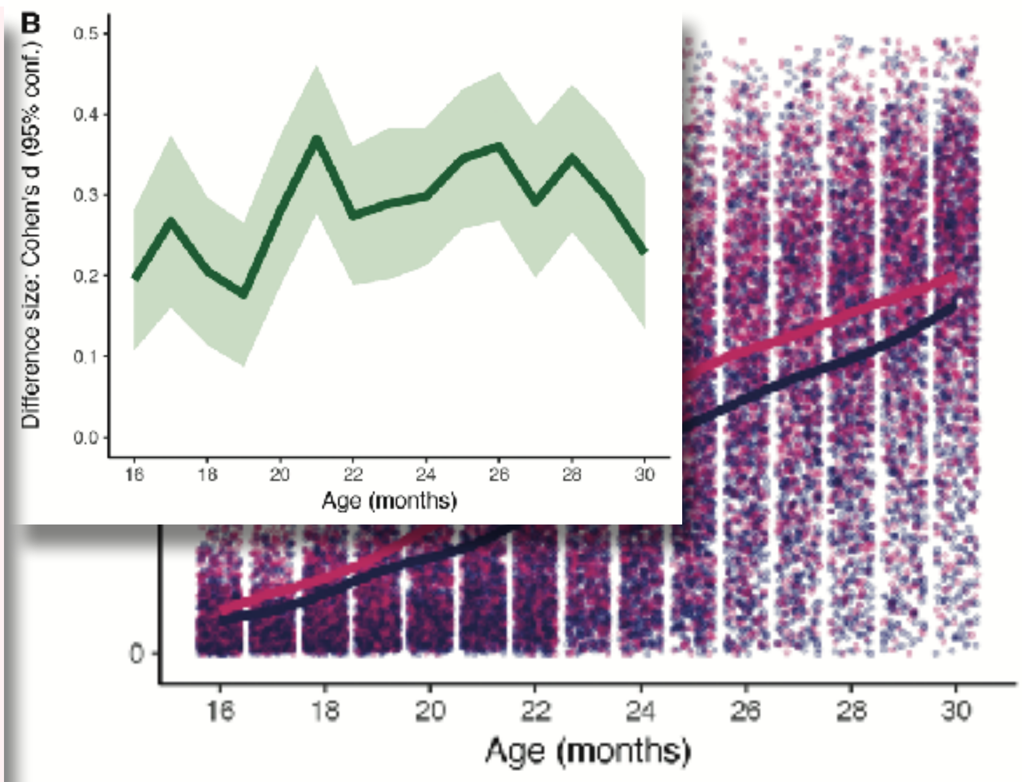

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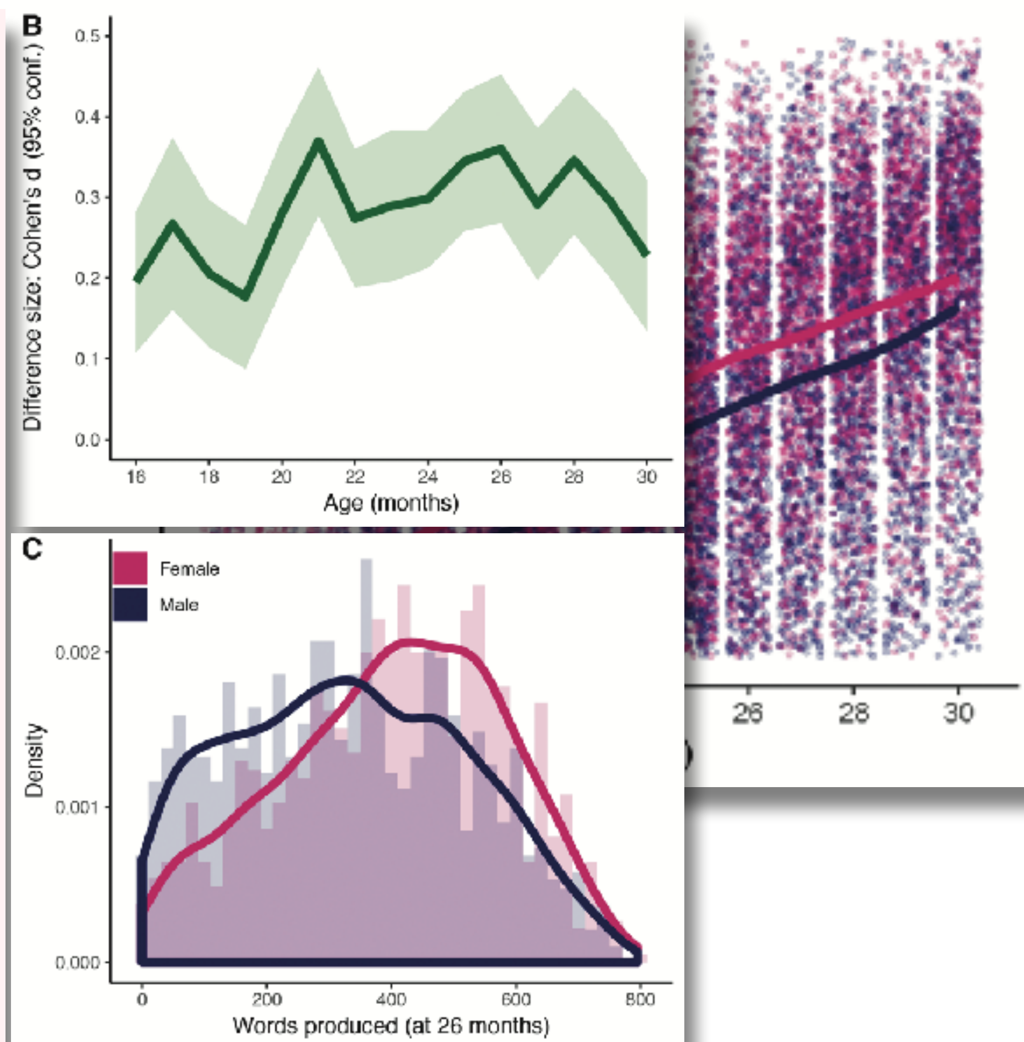
- Developmental language disorders have a similar distribution



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Childhood (2-12 years)

- Comparable acquisition slopes for boys and girls (boys being slightly delayed)
- An advantage for girls is found in most studies throughout
- Small effect size (Cohen's *d* ≈ 0.15-0.2)

Hayiou-Thomas ME, Dale PS & Plomin R (2012). The etiology of variation in language skills changes with development: a longitudinal twin study of language from 2 to 12 years. Dev Sci 15: 233-249.

Jiang H, Logan JA & Jia R (2018). Modeling the Nature of Grammar and Vocabulary Trajectories From Prekindergarten to Third Grade. J Speech Lang Hear Res 61: 910-923.

Strand S, Deary IJ & Smith P (2006). Sex differences in Cognitive Abilities Test scores: A UK national picture. Br J Educ Psychol 76: 463-480.

Boosting Language: Reading

- Reading habits and print exposure are known to be correlated with other elements of language proficiency
- Language ads gears to learning, reading ads a gear to language.

Unique Print Exposure Variance After Age and Raven Measure Are Partialed Out

Dependent variable	R	R^2	R^2 change	F to enter	Final β
Phonological coding					
Age	.047	.002	.002	0.30	−.135
Raven	.424	.179	.177**	28.08	.353
TRT	.474	.225	.046**	7.57	.233
Spelling					
Age	.179	.032	.032*	4.31	.045
Raven	.414	.172	.140**	21.95	.248
TRT	.570	.325	.153**	29.36	.428
Word checklist					
Age	.103	.011	.011	1.41	−.038
Raven	.457	.209	.198**	32.57	.317
TRT	.606	.368	.159**	32.45	.436
Verbal fluency					
Age	.043	.002	.002	0.24	−.071
Raven	.231	.053	.051**	6.89	.100
TRT	.471	.222	.169**	27.40	.445
PPVT–R					
Age	.230	.053	.053**	7.29	.115
Raven	.393	.154	.101**	15.60	.211
TRT	.515	.266	.112**	19.58	.365
General information					
Age	.224	.050	.050**	6.84	.122
Raven	.362	.131	.081**	12.05	.187
TRT	.476	.227	.096**	15.83	.337

Note. Raven = Raven Standard Progressive Matrices; TRT = Title Recognition Test; PPVT–R = Peabody Picture Vocabulary Test—Revised.
*$p < .05$. **$p < .01$.

Acheson et al. (2008). Behav Res Methods 40: 278-289; Cunningham & Stanovich (1991). J Educ Psychol 83: 264-274.

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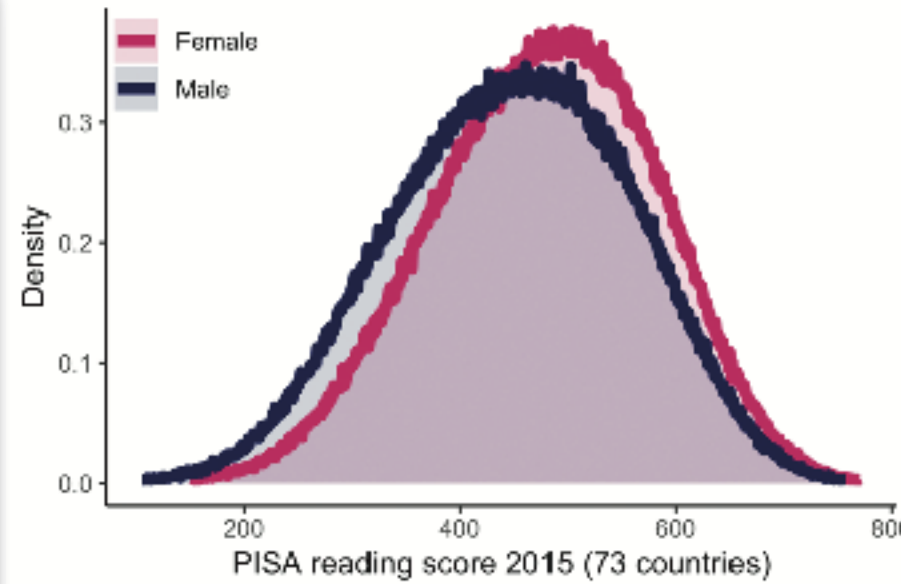
Title Recognition Test: A proxy for print exposure

Acheson et al. (2008). Behav Res Methods 40: 278-289; Cunningham & Stanovich (1991). J Educ Psychol 83: 264-274.

Gender and reading: PISA scores

- Girls outperform boys in all 73 OECD and partner countries (n=519,000)
- Effect size small-medium ($d \approx 0.4$), explains 2-6% of variance
- In the lowest 10th percentile, boys outnumber girls 2.4:1
- Dyslexia has an outspoken gender difference



Data from: http://www.oecd.org/pisa/data/2015database/ .
Analyzed using Caro & Biecek (2017)

Gender: Negligible but important

- When looking across the normal population, gender is not very predictive for language competences
- The small difference in distributions, however, means that boys are much more frequent in the lower bounds than girls
- This leads to an overrepresentation in diagnoses of Developmental language disorder, Autism spectrum disorder, Stuttering and/or Dyslexia

Word use predictive of sex/gender

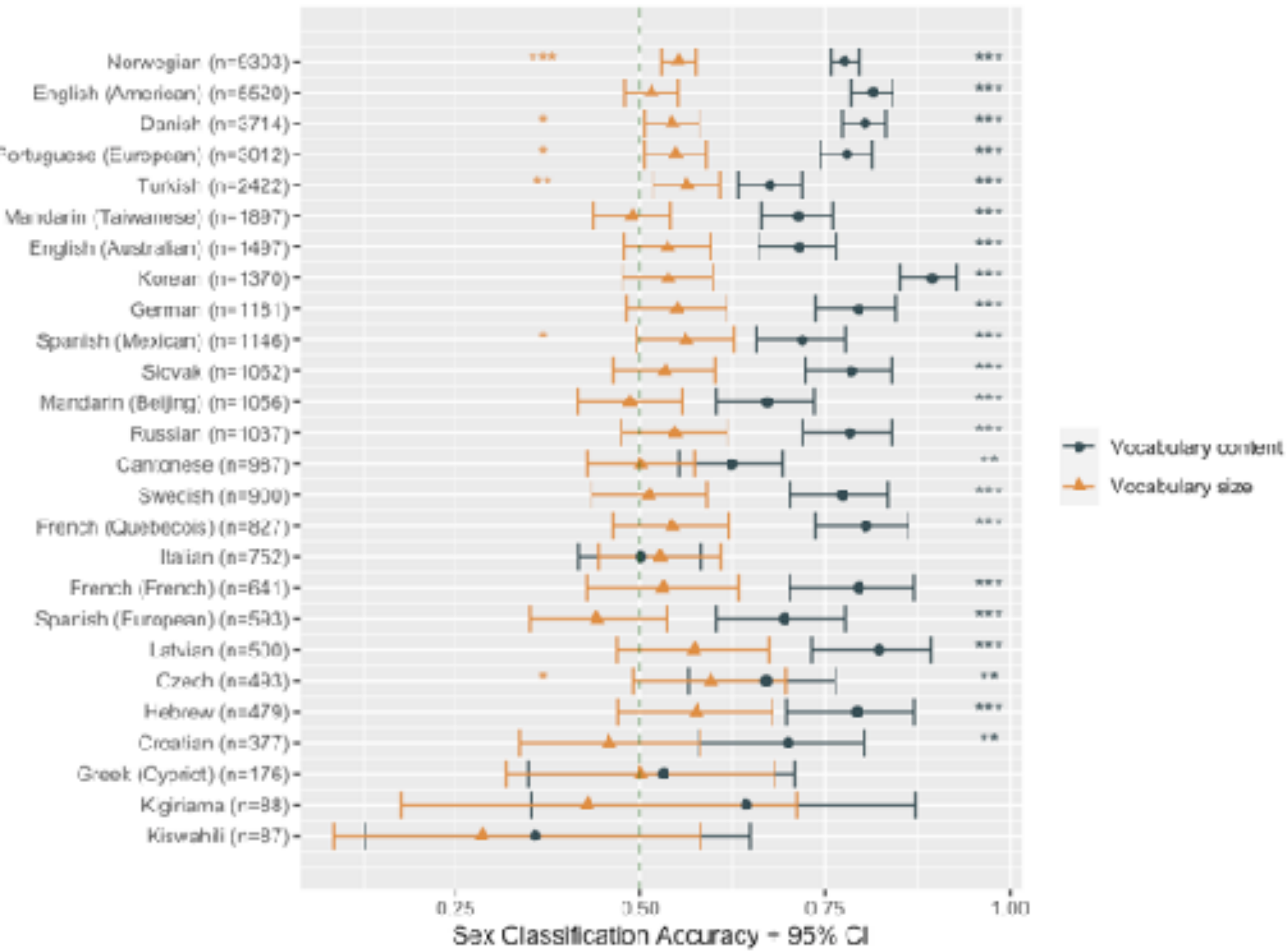
Sap M, Park G, Eichstaedt JC, et al. Developing Age and Gender Predictive Lexica over Social Media. Proceedings of the 2014 Conference on Empirical Methods in Natural Language Processing (EMNLP), October 25-29 2014 Doha, Qatar. 1146–1151.

Word use predictive of sex/gender

- Gender can be predicted with 80-90% accuracy based on word use on Facebook
- e.g. females use more first-person singular pronouns (“I”, “me”, “my”) while males use more articles (“a”, “an”, “the”), proxy for using more nouns
  - effect sizes for pronouns are small (Cohen’s *d* ≈ 0.2)

Sap M, Park G, Eichstaedt JC, et al. Developing Age and Gender Predictive Lexica over Social Media. Proceedings of the 2014 Conference on Empirical Methods in Natural Language Processing (EMNLP), October 25-29 2014 Doha, Qatar. 1146–1151.

Already before 36 months of age



Wallentin & Trecca (submitted). Cross-cultural sex/gender differences in word item production before the age of three years

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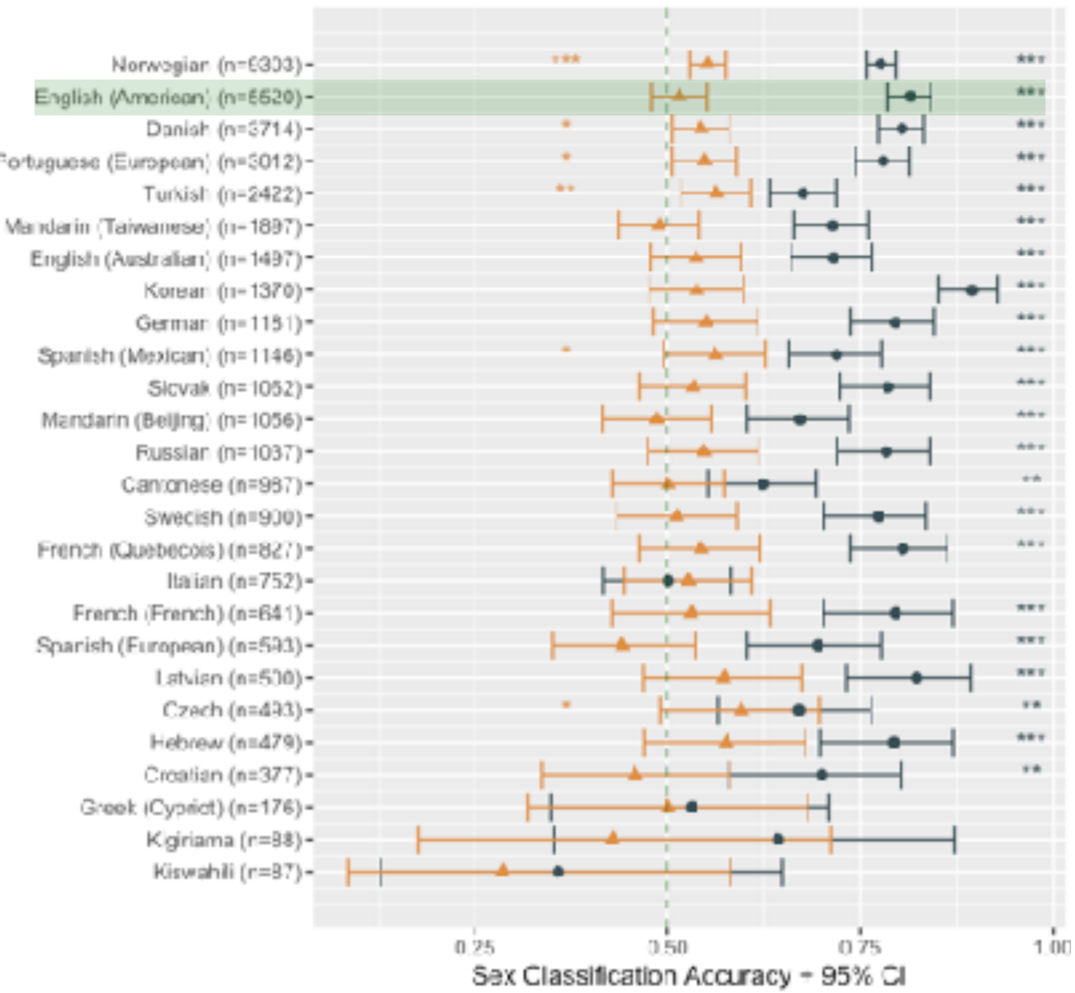
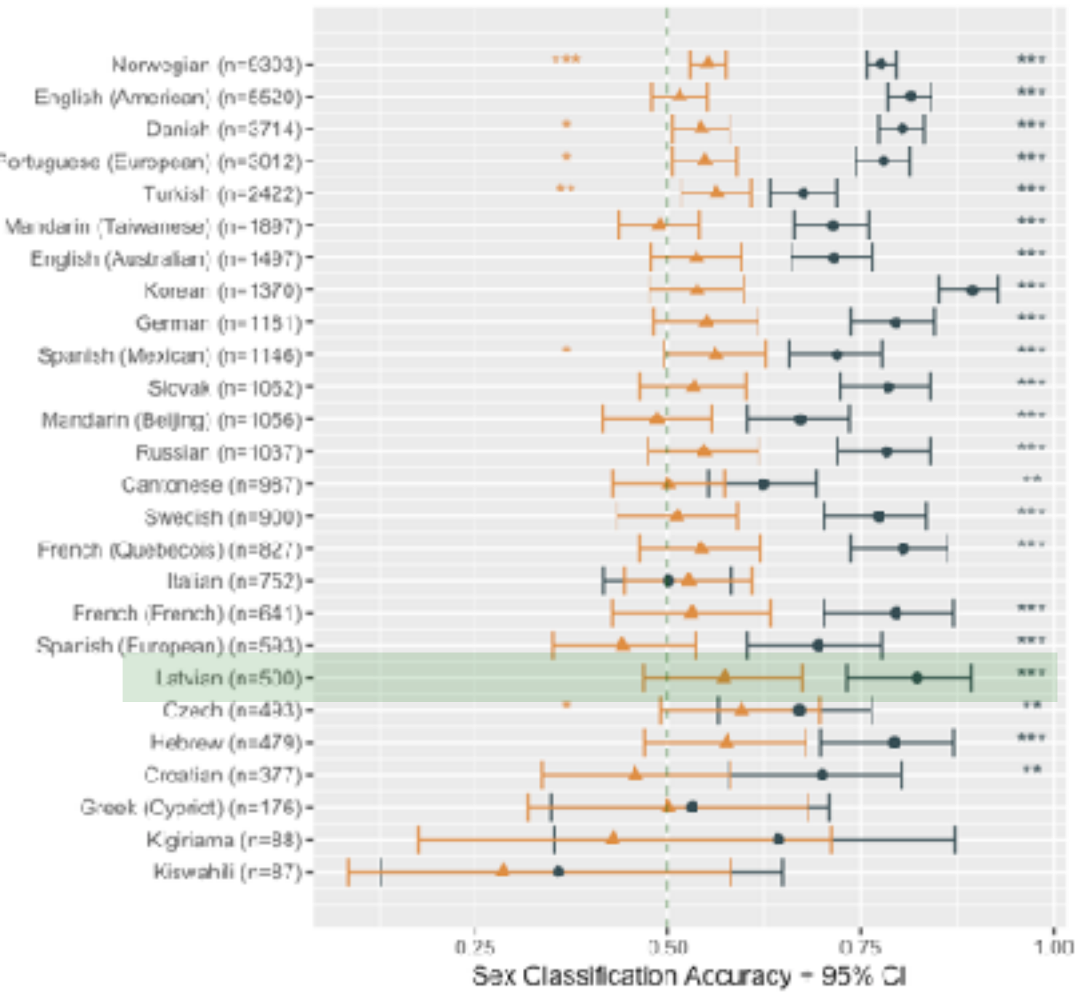


Wallentin & Trecca (submitted). Cross-cultural sex/gender differences in word item production before the age of three years

Latvian



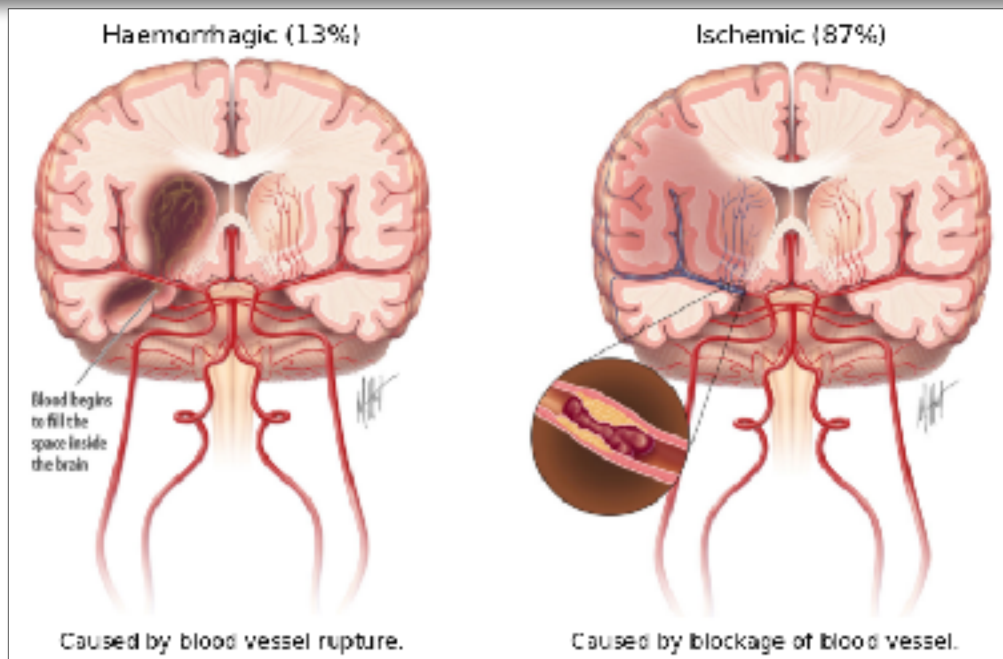
Wallentin & Trecca (submitted). Cross-cultural sex/gender differences in word item production before the age of three years

Brain differences?

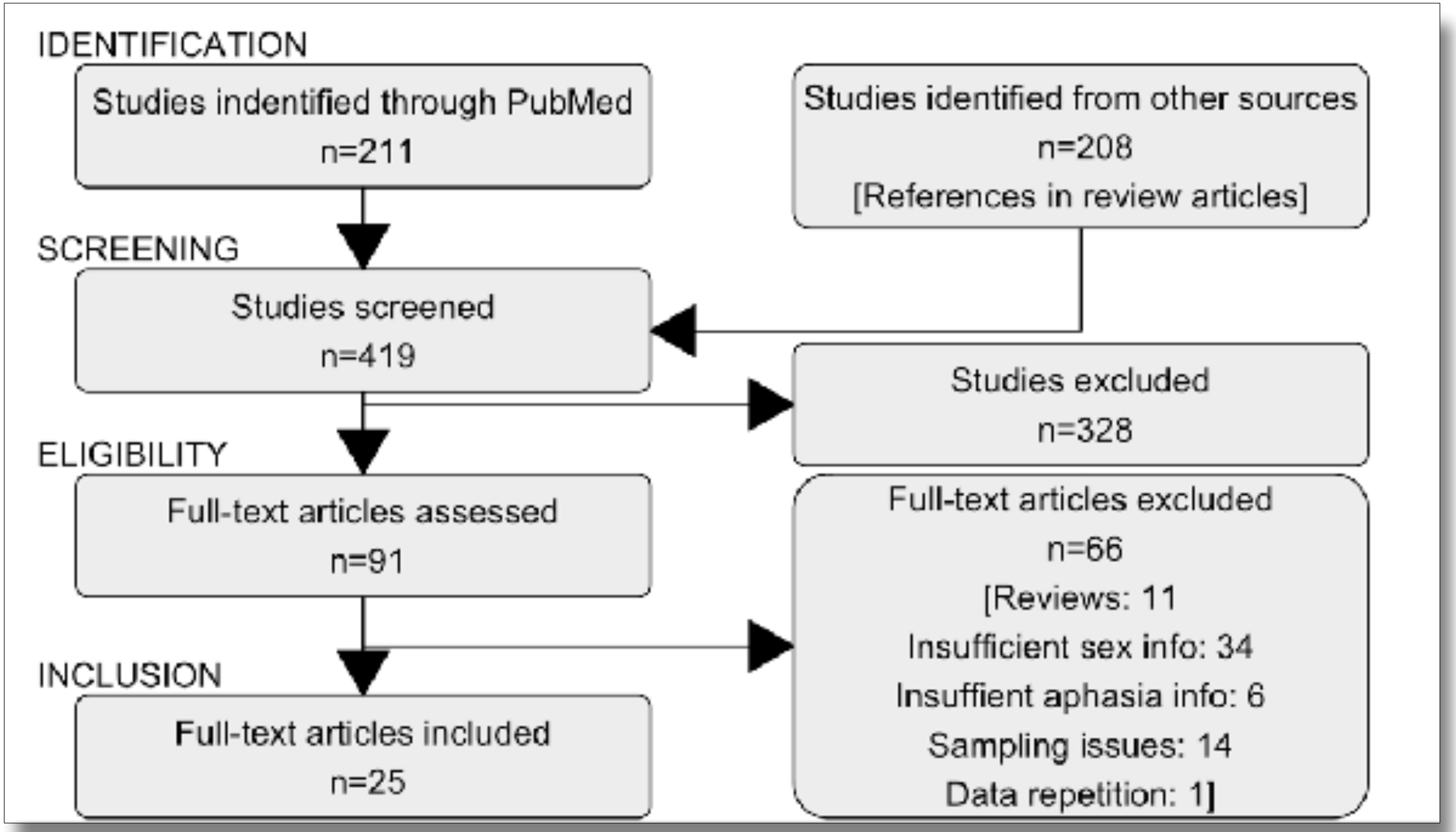
- Large-scale sex differences in brain-systems subserving language should be observable as differences in incidence for aphasia following stroke

Stroke

- A stroke is a medical condition in which blood flow to the brain is restricted, due to occlusion (ischemic stroke) or hemorrhage (hemorrhagic stroke), resulting in cell death (WHO).

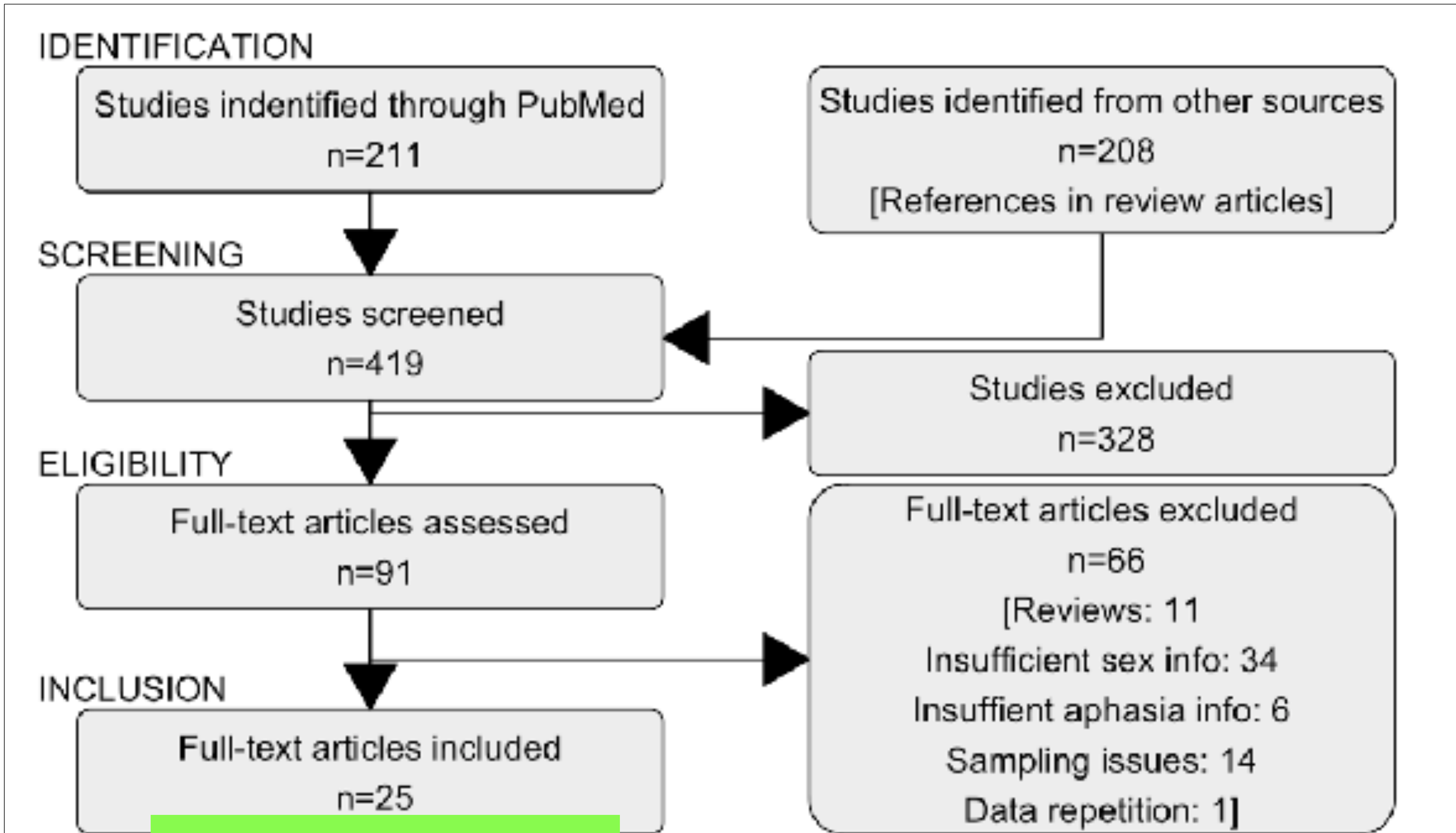


Meta-analysis



Wallentin M (2018). Sex differences in post-stroke aphasia rates are caused by age. A meta-analysis and database query. PLoS One 13: e0209571.

Meta-analysis



(48,362 patients)

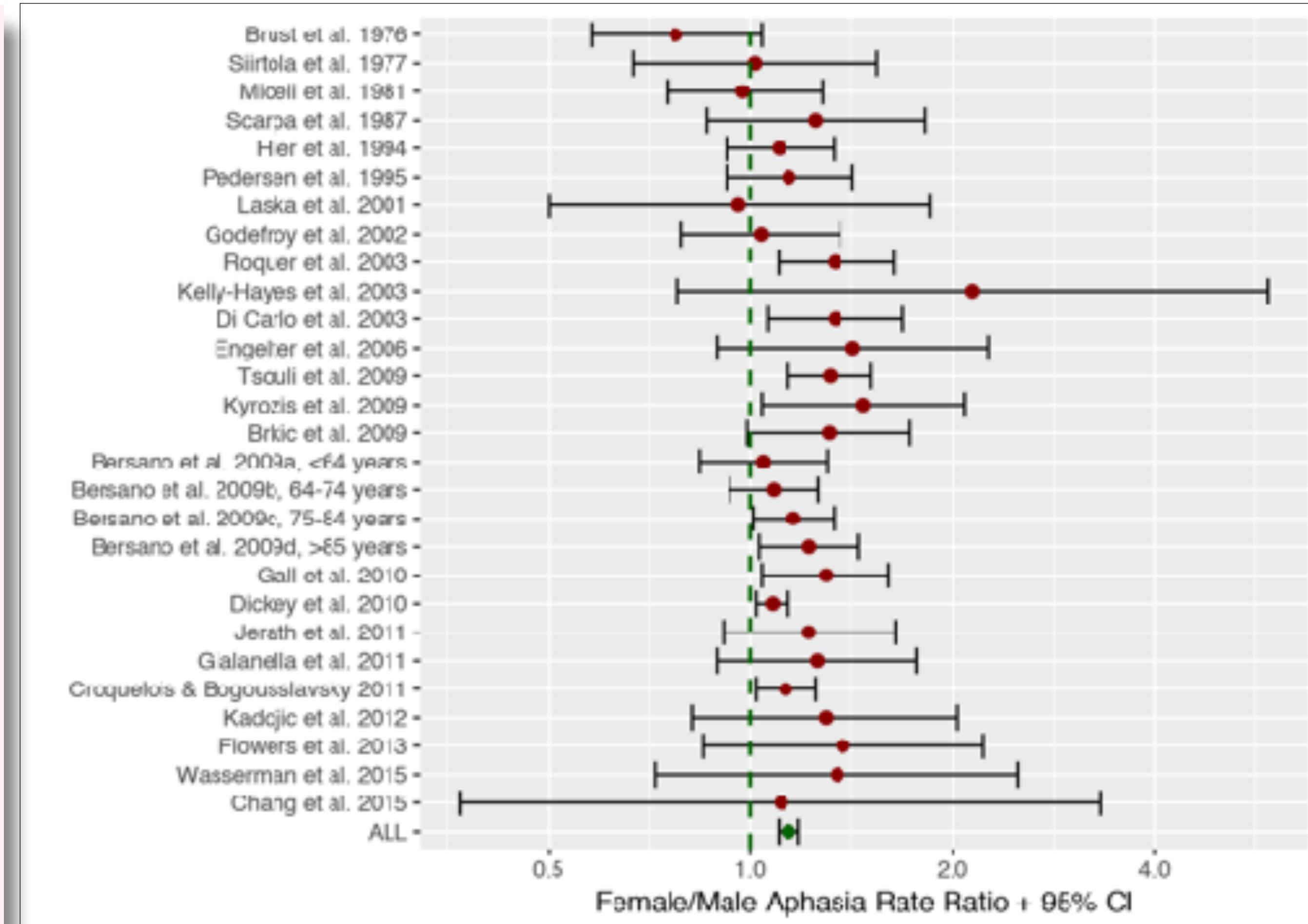
Wallentin M (2018). Sex differences in post-stroke aphasia rates are caused by age. A meta-analysis and database query. PLoS One 13: e0209571.

Meta-analysis results

Wallentin M (2018). Sex differences in post-stroke aphasia rates are caused by age. A meta-analysis and database query. PLoS One 13: e0209571.

Meta-analysis results

- 29.6 % female and 26 % male stroke patients got aphasia
- Small effect: Cohen's *d* = 0.37
- Not corrected for age differences



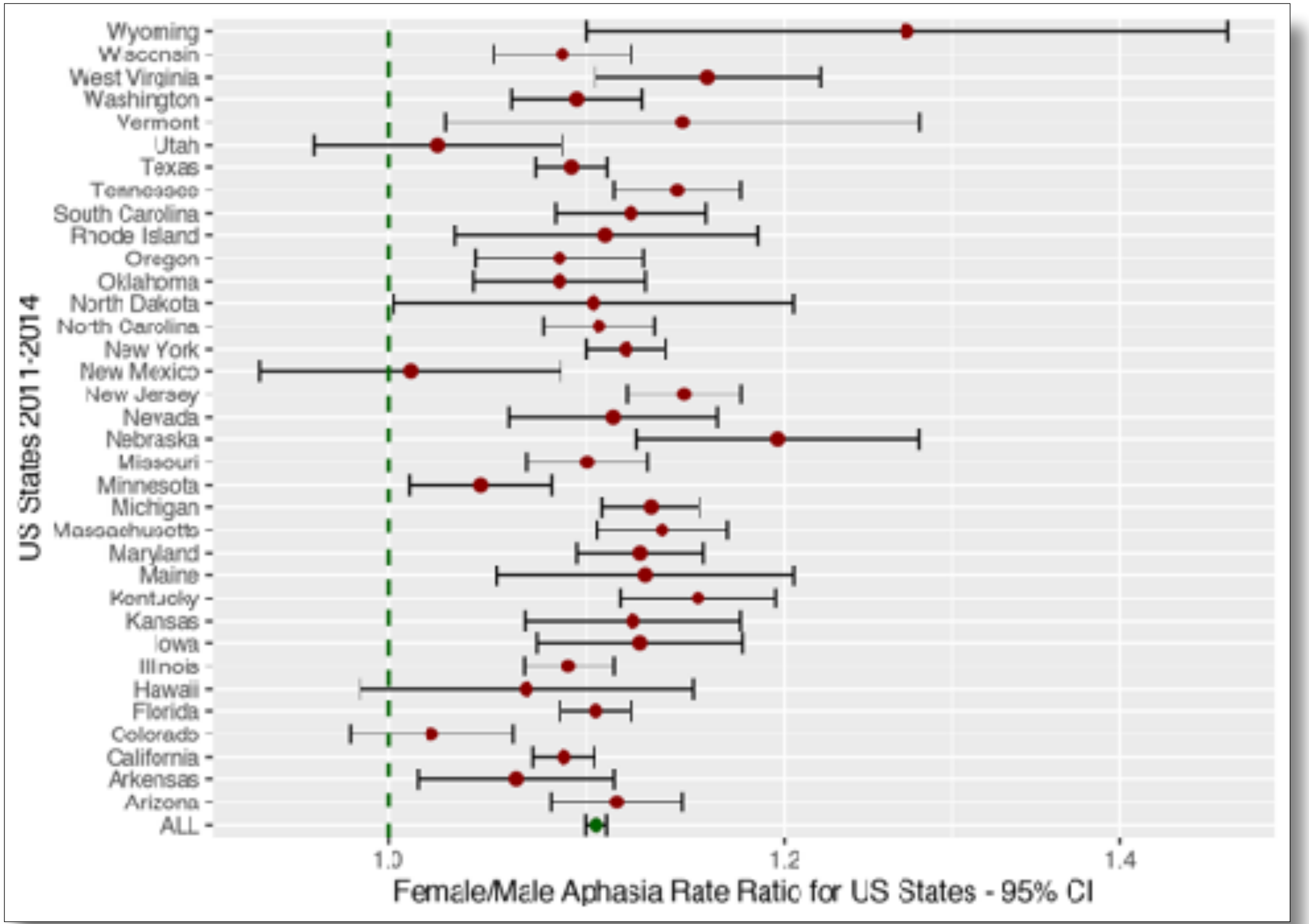
Wallentin M (2018). Sex differences in post-stroke aphasia rates are caused by age. A meta-analysis and database query. PLoS One 13: e0209571.

Database query

- Data:Healthcare Cost and Utilization Project (HCUP) from community hospitals in the United States
- from 35 US American states from the years 2011-2014.
- Both hemorrhagic and ischemic stroke cases included using ICD-9 codes
- A total of 1,967,038 stroke patients (1,014,239 female, 952,799 male)

Wallentin M (2018). Sex differences in post-stroke aphasia rates are caused by age. A meta-analysis and database query. PLoS One 13: e0209571.

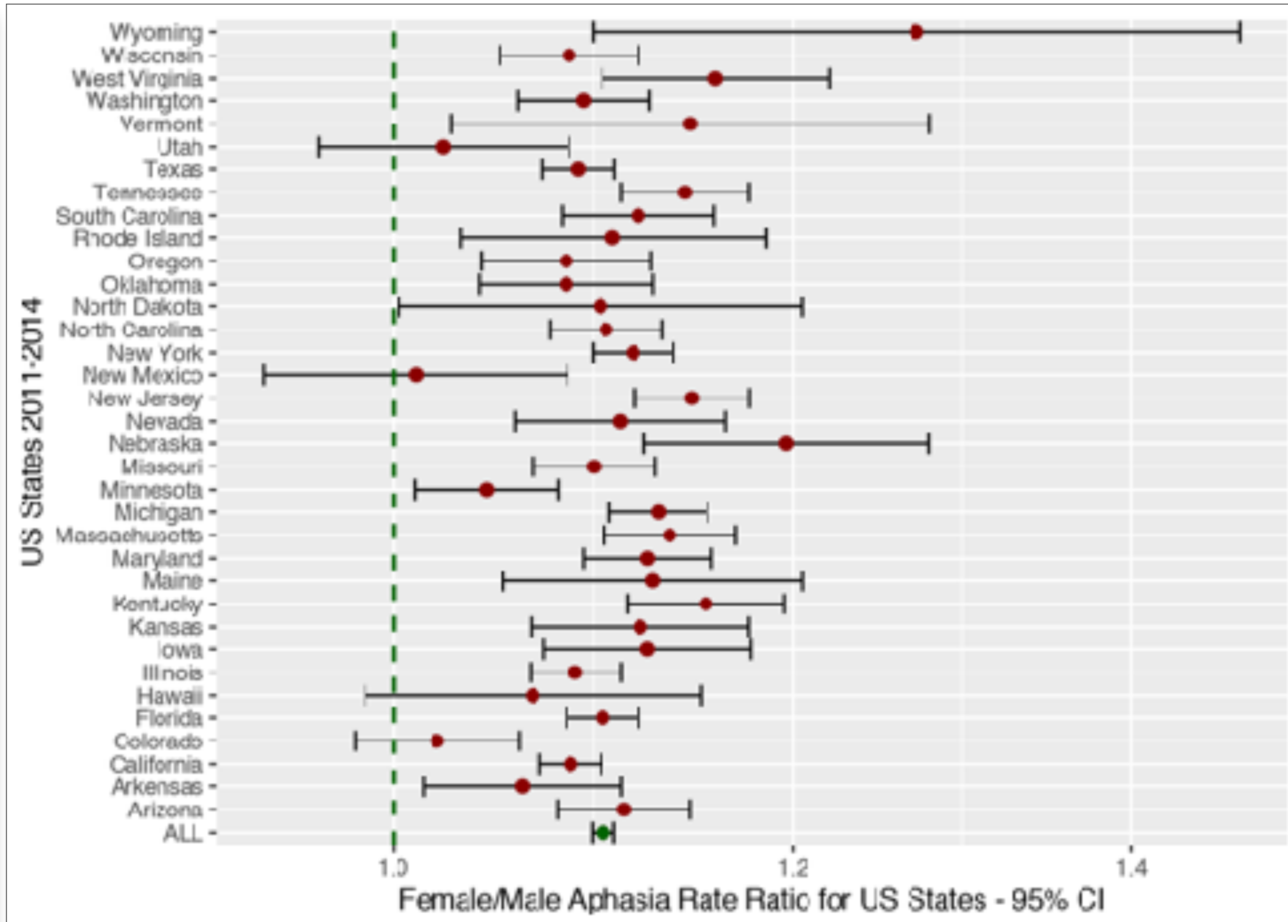
Database Results



Wallentin M (2018). Sex differences in post-stroke aphasia rates are caused by age. A meta-analysis and database query. PLoS One 13: e0209571.

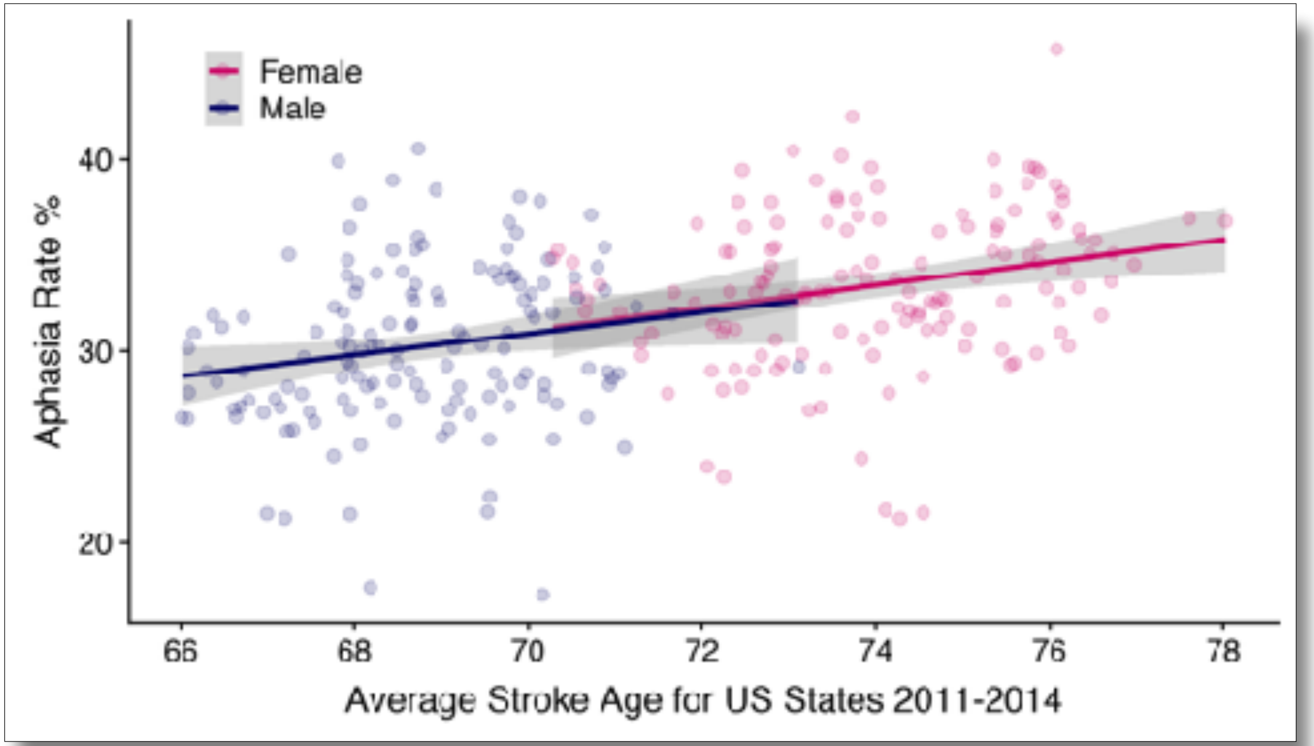
Database Results

- 33.2 % of females and 30.2 % males diagnosed with aphasia
- Replicates meta-analysis result
- Not corrected for age differences



Wallentin M (2018). Sex differences in post-stroke aphasia rates are caused by age. A meta-analysis and database query. PLoS One 13: e0209571.

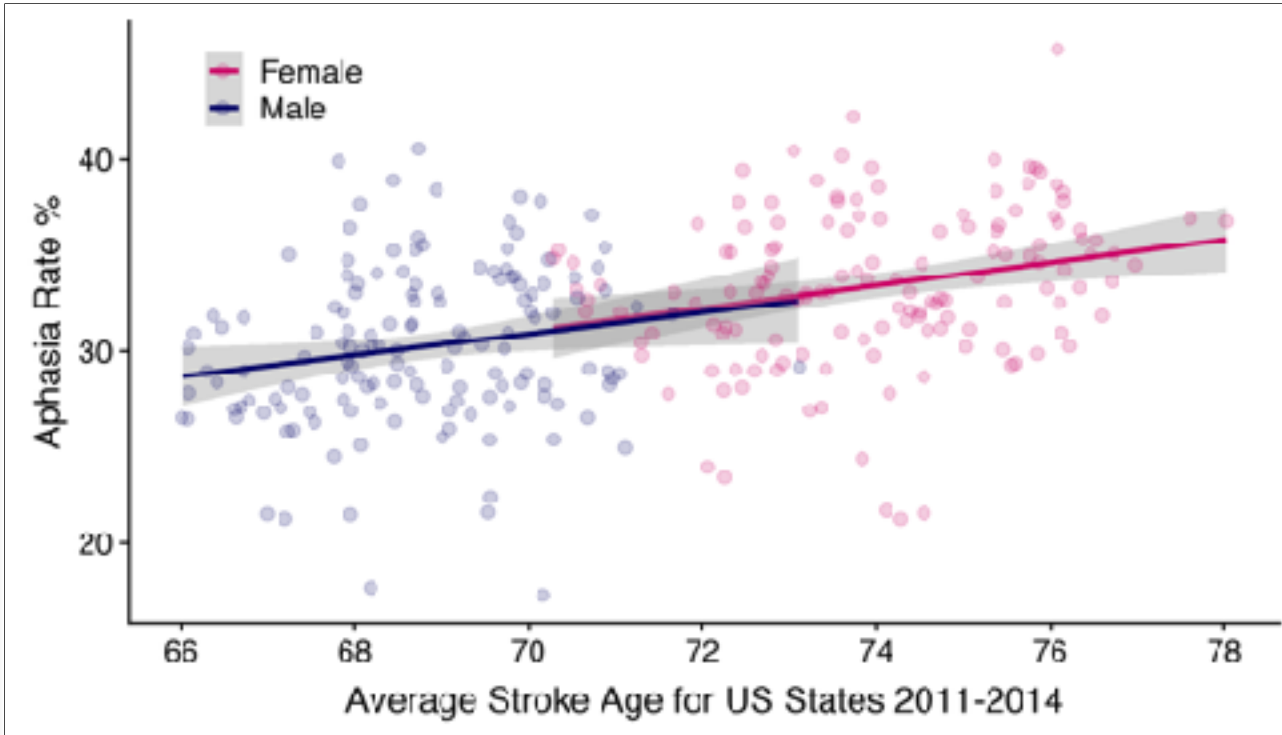
Database Results (age-corrected)



Wallentin M (2018). Sex differences in post-stroke aphasia rates are caused by age. A meta-analysis and database query. PLoS One 13: e0209571.

Database Results (age-corrected)

- After correcting for age difference at stroke:
- No significant effect of sex
- i.e. no support for sex/ language brain difference



Wallentin M (2018). Sex differences in post-stroke aphasia rates are caused by age. A meta-analysis and database query. PLoS One 13: e0209571.

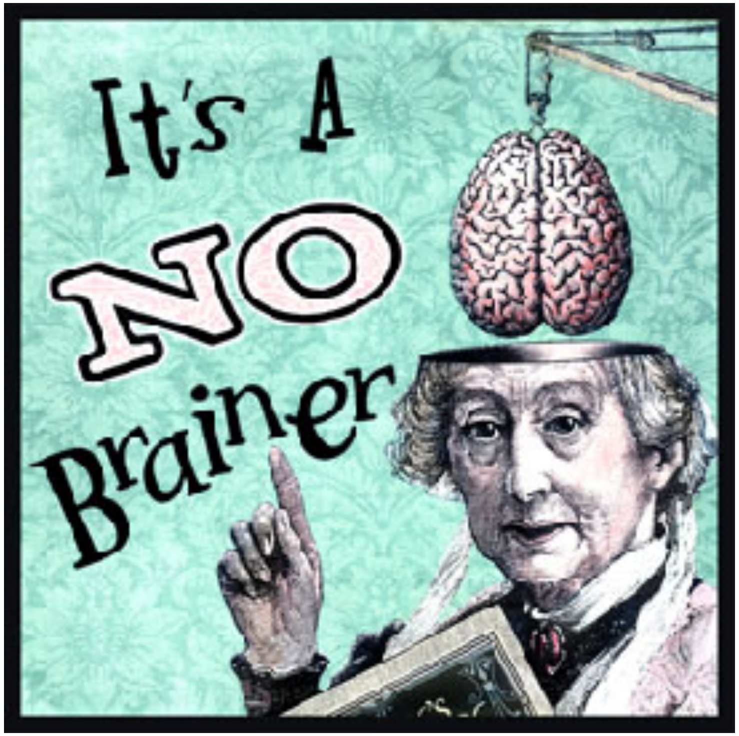
Neurodegenerative disorders

Wallentin M (in press). *Gender differences in language are small but matter for disorders*. In: Lanzenberger et al. (eds.) Handbook of Clinical Neurology : Sex differences in neurology and psychiatry. Elsevier.

Neurodegenerative disorders

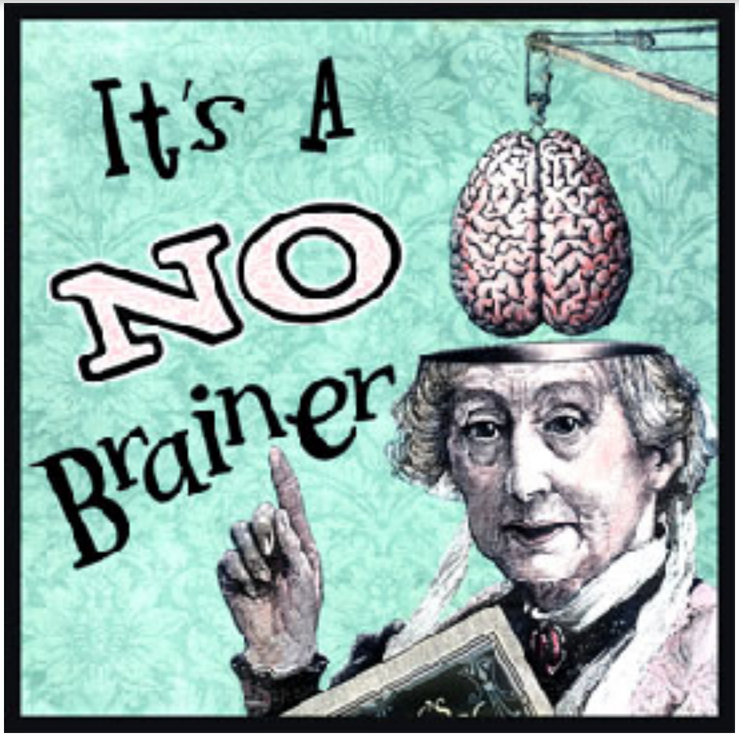
- Alzheimer's Dementia (AD)
  - involves language in late stages.
  - Meta-analysis by: Studies with more female AD patients observed less severe degradation of both semantic and phonemic fluency.
  - Either females' verbal reserves are less vulnerable or they are simply less affected by the disease at the time of testing.
- Primary Progressive Aphasia (PPA)
  - Disorders with declining language (Progressive Nonfluent Aphasia, Semantic Dementia, and Logopenic Progressive Aphasia).
  - No gender bias in the frequency of PPA
- Huntington's Disease
  - No gender bias in language symptoms
- Parkinson's Disease (PD)
  - No gender bias in language symptoms

A no-brainer?

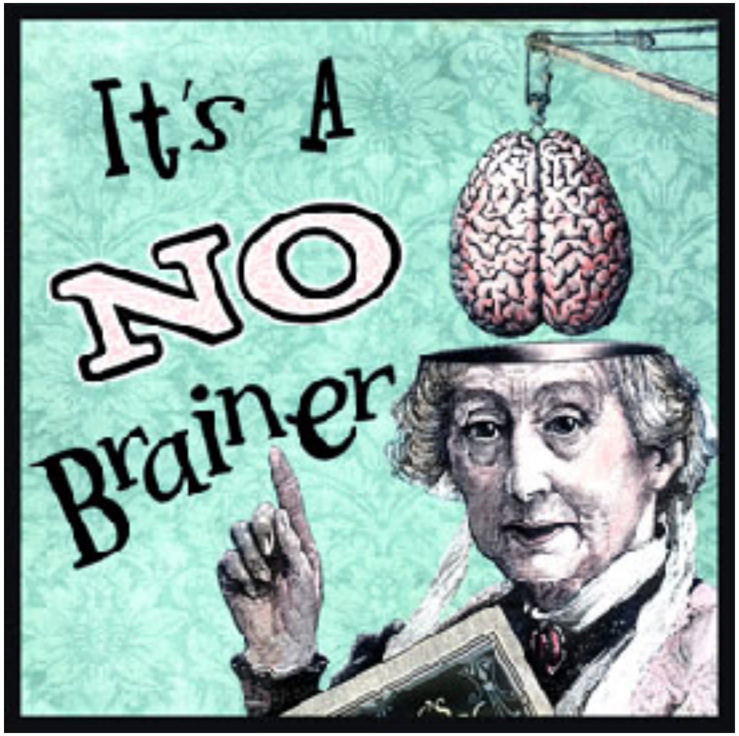


A no-brainer?

- Clear-cut evidence for sex/language-related brain differences is missing.



A no-brainer?



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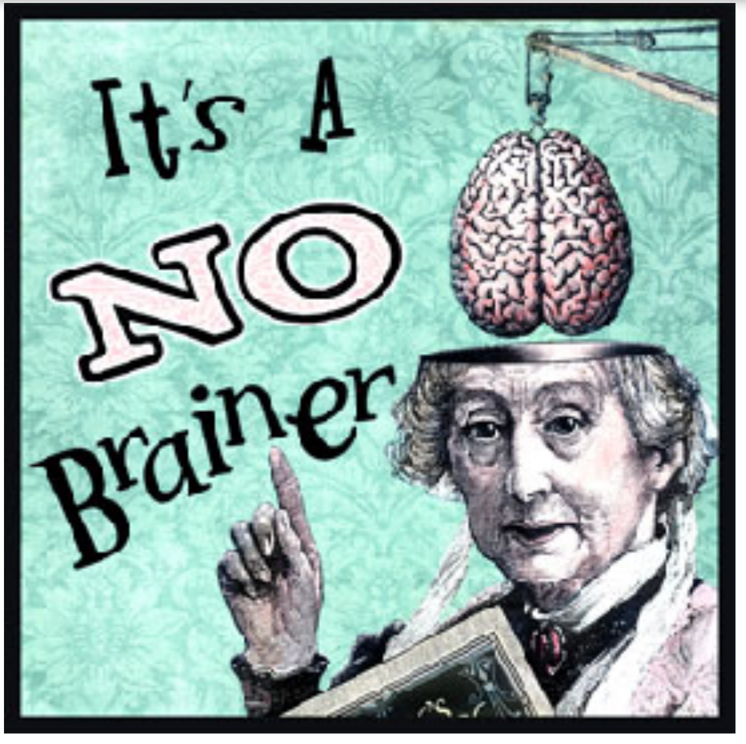

Thank you!