The “phonetics” of Chinese character stroke order

James Myers

(AKA 麥傑)

National Chung Cheng University

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Thanks!!!

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- Experimental participants
- Jane Tsay
- YOU!!!

Overview

- Stroke order in Chinese characters is like phonetics
- New evidence from a handwriting experiment
- Future plans

Chinese character grammar

- Myers (2019). *The grammar of Chinese characters: Productive knowledge of formal patterns in an orthographic system*. Routledge.
- **Character morphology**: Operations on interpretable components
  - 木 in 根 (affixation), 相 (semantic compounding), 林 (reduplication)
- **Character phonology**: Patterns in pure form (no interpretations)
  - **Segmental** (stroke-level): e.g. hooking in 食 & 手, diagonalization in 牛 vs. 物
  - **Prosody** (size/position): e.g. bottom/right "stress" in 土、川、尖、奇、媽、駐
- **Character phonetics**: Articulatory or perceptual processing

- **Is stroke order like phonetics or phonology?**

Is stroke order like phonology?

- Wang (1983). *Toward a generative grammar of Chinese character structure and stroke order*. U. of Wisconsin-Madison PhD thesis.
- Stroke order is conventionalized
  - Top to bottom, left to right: 三、川
  - Horizontal before vertical: 十
  - Left-falling diagonal before right-falling diagonal: 乂
  - Etc...
- Stroke form is explained by stroke order: hooking in 寸、長, 牛 vs. 物
- Ordering of L-shaped components is sensitive to “underlying” form
  - 建: 聿 is first because 廴 is in underlying form (downward order)
  - 起: 巳 is last because other component is derived from 走 (rightward order)

Why stroke order is not phonology

- Hooking does *not* depend on order: 手、丁, or 長、民、艮、衣、喪 …
- Instead, order depends on stroke form and position: 牛 vs. 牛 in 物
- Stroke order conventions are very weak
  https://en.wikipedia.org/wiki/Stroke_order#Stroke_order_per_polity

Traditional

Taiwan

Japan

China

Actual motivations for stroke ordering

- Modality-specific: production vs. perception
- Production
  - Top to bottom, left to right: pull pen towards hand (cf. left-handers)
    - van Sommers (1984). *Drawing and cognition: Descriptive and experimental studies of graphic production processes*. Cambridge: Cambridge University Press.
  - Minimize total pen path (more on this shortly)
- Perception
  - Symmetry: outer dots last in 小 or Japanese/Chinese orders for 必
  - Larger strokes early to establish layout: 女 or 方
- Interface with character prosody
  - Stroke groups are written together, like 必 as “crossed-out” 心 in Taiwan
  - 廴 in 建 vs. 走 in 起 are “wide” vs. “narrow” so must appear at bottom vs. left

Minimizing total pen path

- E.g. 林桂生 (2014). 汉字笔顺规范的理论是路径法. 黄冈师范学院学报, 34(1), 91-96.

https://commons.wikimedia.org/wiki/File:%E6%AD%A3-bw.png

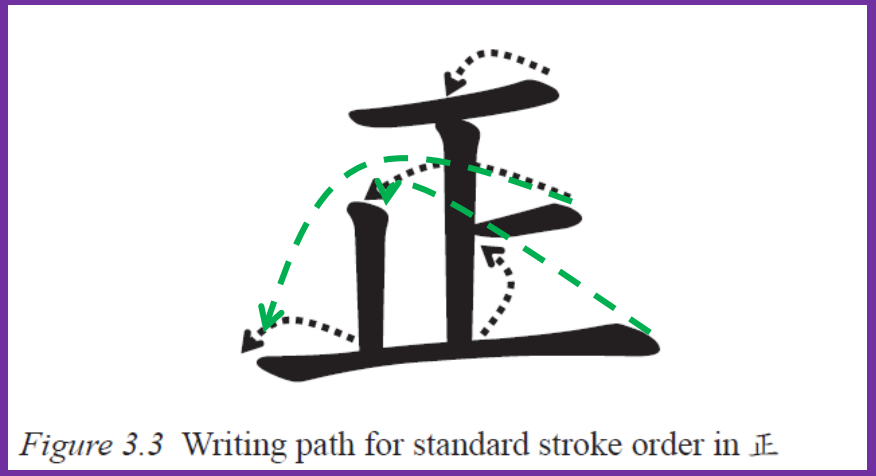


Figure 3.3 Writing path for standard stroke order in 正

(Myers, 2019)

What about the horizontal > vertical rule?

- Path length is inconclusive here, so order is indeed conventionalized

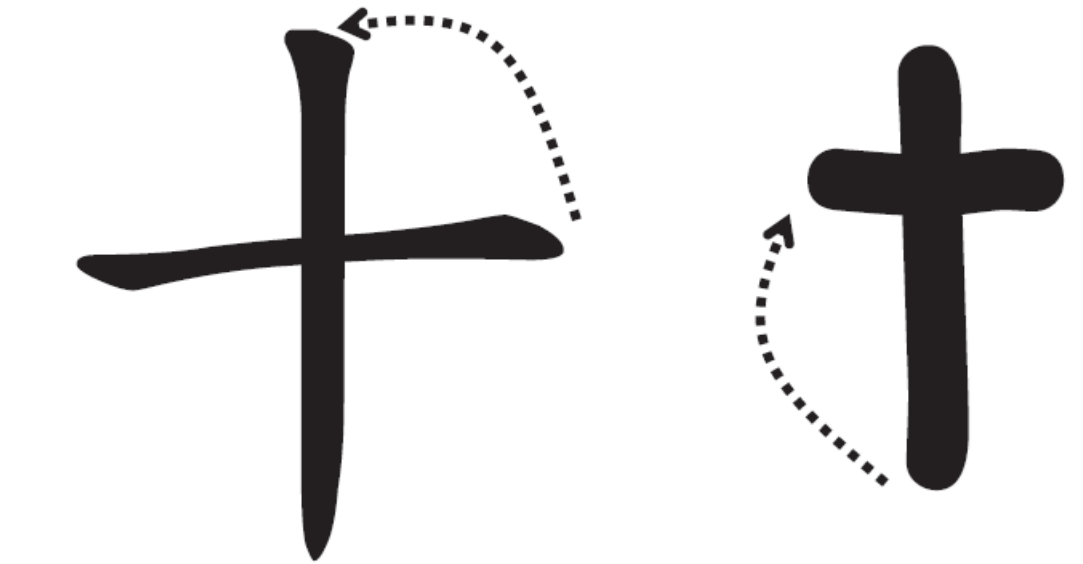


Figure 3.4 Writing paths for standard stroke orders in + and †

(Myers, 2019)

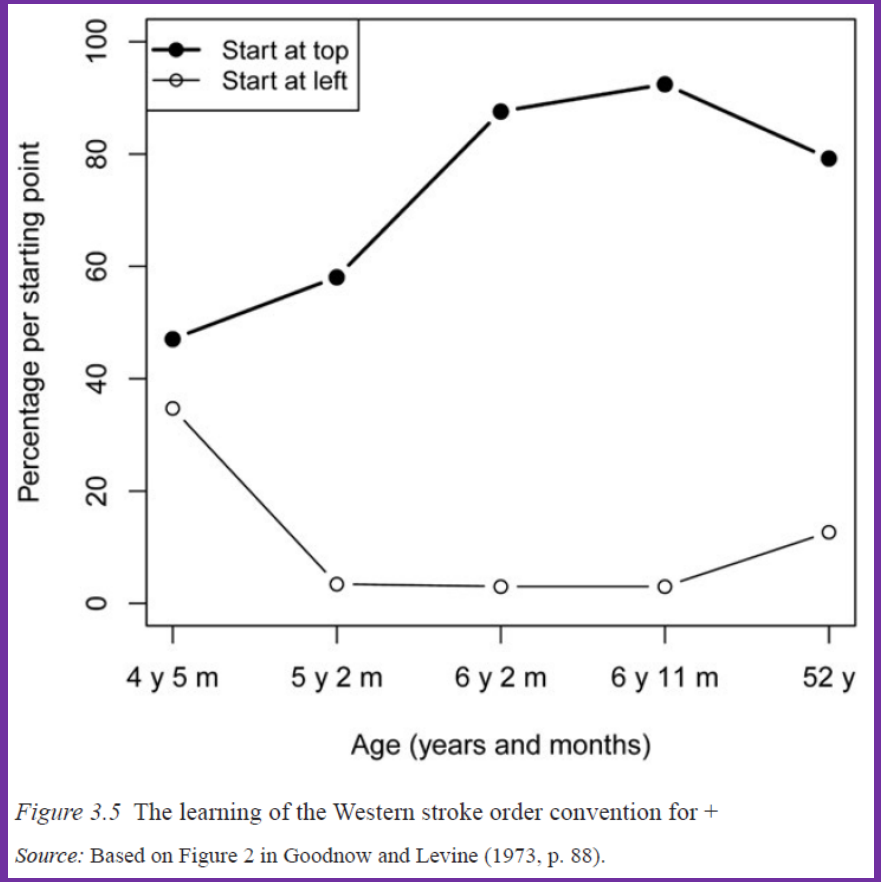
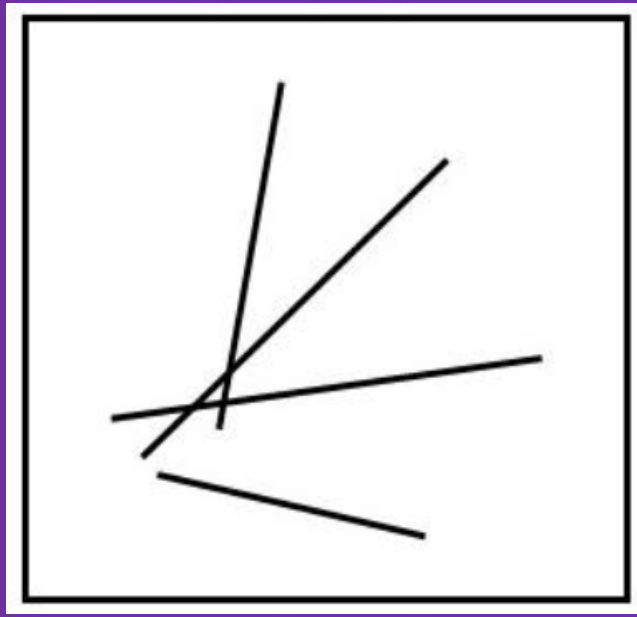


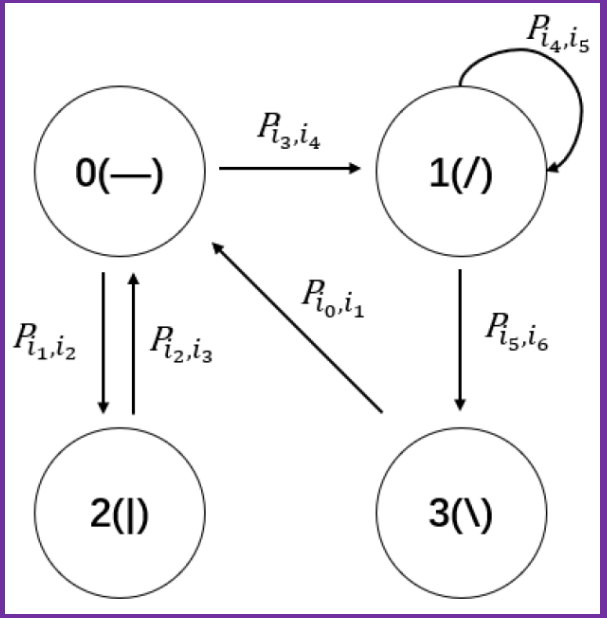
Figure 3.5 The learning of the Western stroke order convention for +

Source: Based on Figure 2 in Goodnow and Levine (1973, p. 88).

How productive are these patterns?

- Xin and Lyu (2021). Experimental measurement and Markov chain modelling of stroke order intuition. *Journal of Physics: Conference Series, 2289*, 012015.
  - Chinese writers copied random stroke patterns (to avoid lexical biases) ✓
  - Results analyzed using Markov chain models (as used for "real" phonetics) ✓



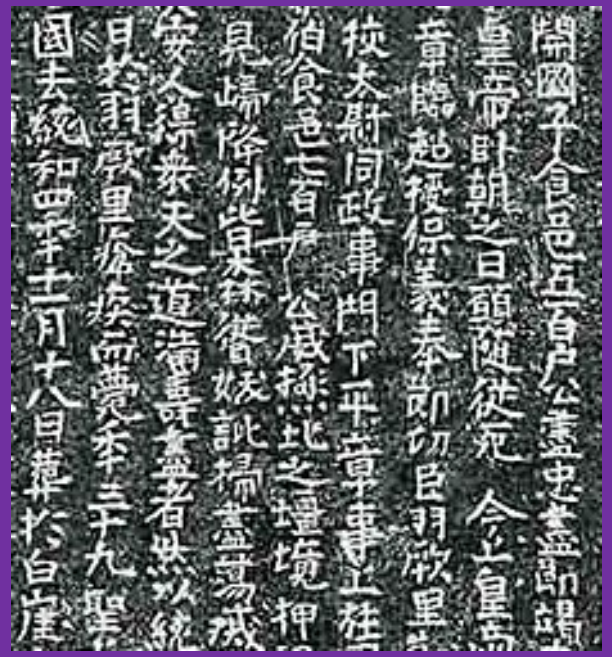


But a random bunch of lines doesn't look like a Chinese character...

We need “real” fake Chinese characters

- Khitan (契丹語): Non-Sinitic language of NE Asia (died ca. 1200 CE)
- Writing system heavily influenced by Chinese characters

Large script (logographic)

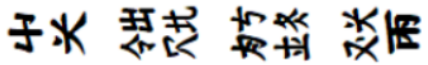


https://commons.wikimedia.org/wiki/File:Yanningmuzhi.jpg

Small script (semi-syllables in blocks)

https://commons.wikimedia.org/wiki/File:Khitan_mirror_from_Korea.jpg

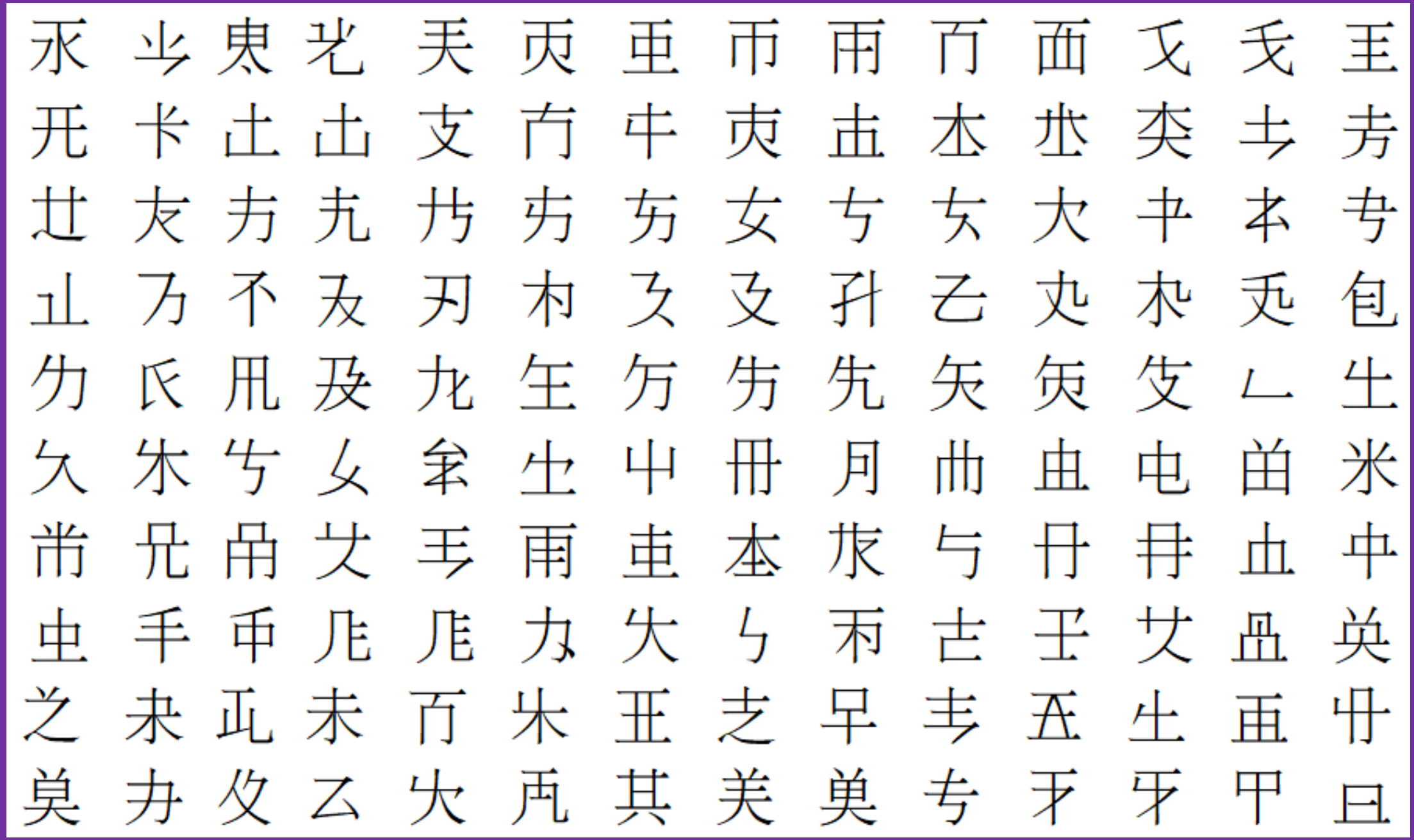
Unicode Khitan fonts in modern Ming style

Khitan Large Script (PUA mapped)	BabelStone Khitan Large Glyphs	Version 1.012		歪夫万丌北此来沓
	BabelStone Khitan Seal Glyphs	Version 1.004	OPEN FONT LICENSE	
	BabelStone Khitan Seals	Version 1.004	OPEN FONT LICENSE	
Khitan Small Script (Unicode mapped)	BabelStone Khitan Small Linear	Version 16.000		屮关 令出冗北 为亏业冬 又关雨
	BabelStone Khitan Small Seal	Version 13.000	OPEN FONT LICENSE	冗尺夜互玑礼突互关
	Khitan Small Linear	Version 16.000		屮关 令出冗北 为亏业冬 又关雨
	Khitan Small Rotated	Version 16.000		
	Khitan Small Vertical	Version 16.000		屮 令出 为亏 又关 关 冗北 业冬 雨

BabelStone Khitan Large Glyphs
(we used 32 characters, including 2 for practice)

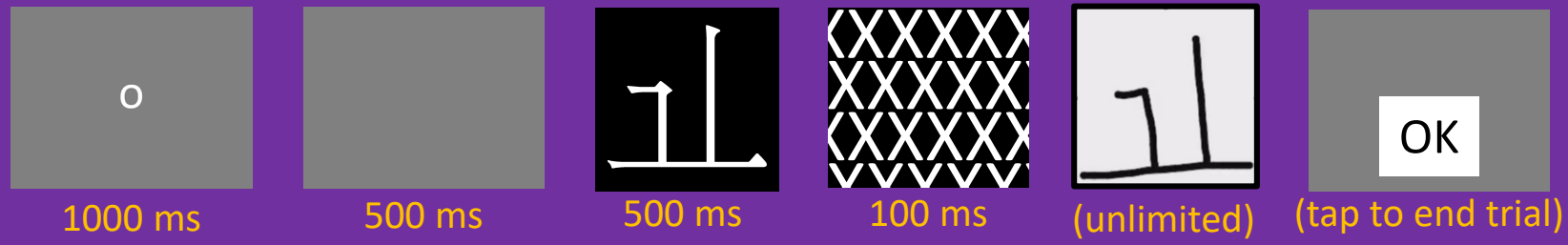
BabelStone Khitan Small Linear
(we used 108 characters, including 2 for practice)

(created and maintained by Andrew West)
https://www.babelstone.co.uk/Fonts/index.html



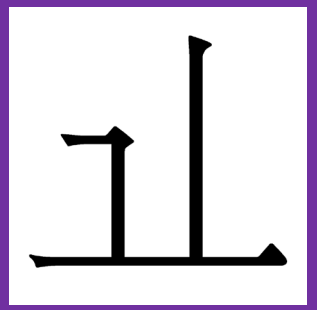
Methods

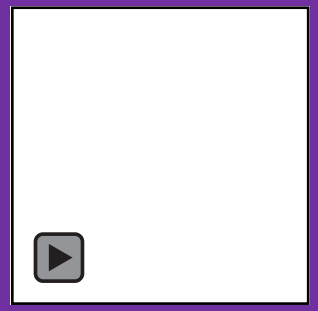
- 136 experimental items
- 43 college students in Southern Taiwan (5 left-handed)
- Wacom® One tablet and digital pen
- PsychoPy (https://www.psychopy.org)
  - Pen treated like a mouse (contact = holding down mouse button)
  - Strokes and their properties derived via scripts in R (R Core Team, 2024)
  - For details, see Myers (2023). Nonstatistical things that linguists can do with R. *NACCL-34 Proceedings*. Indiana University Bloomington.
- Procedure:

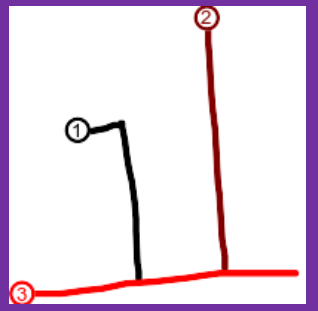


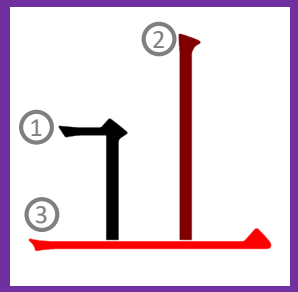
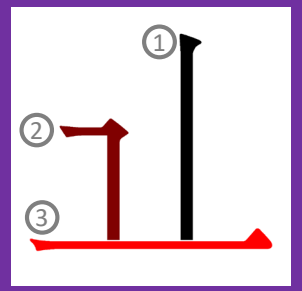
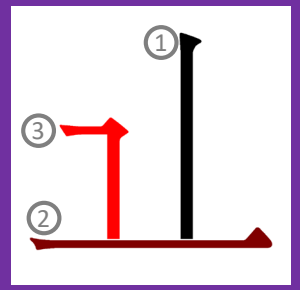
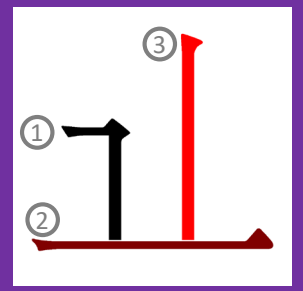
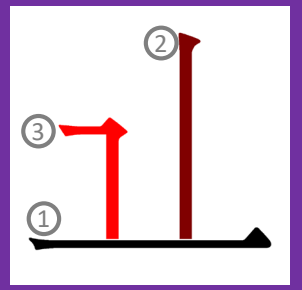
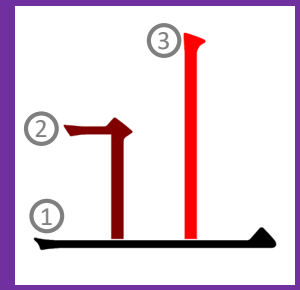
Quantifying stroke order acceptability

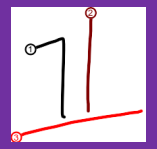
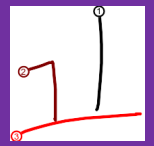
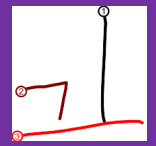
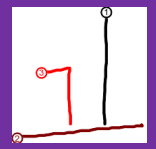
- Five lab assistants judged each stroke order as good vs. bad
- There was lots of variability
  - Judges disagreed about the correctness of any given stroke order
  - Individual judges often gave different judgments for the same order in the same character
  - Characters differed in the judged correctness of their stroke orders
- E.g. this character has *no* stroke order acceptable to all of the judges:



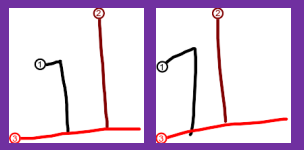


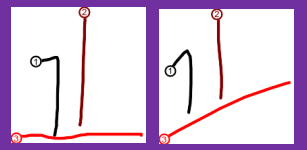


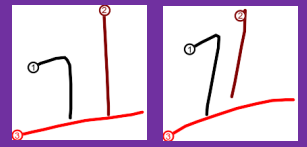







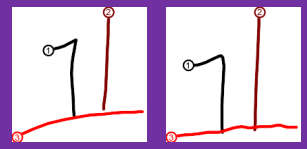





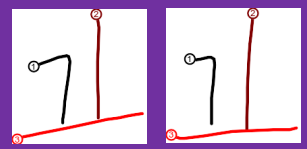
Right-handers



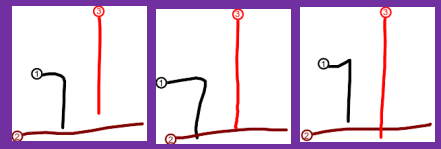
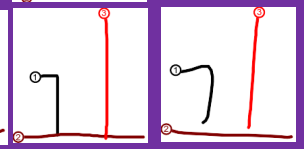


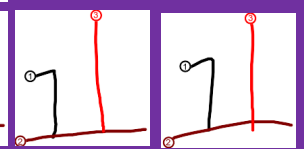
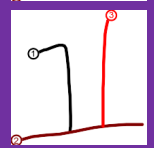
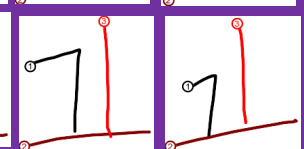


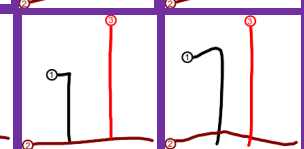
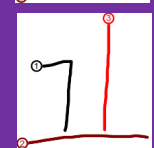
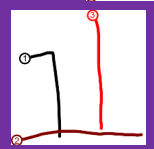
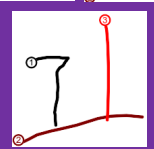
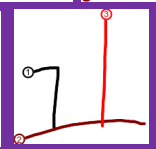
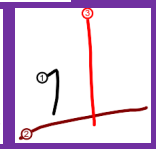
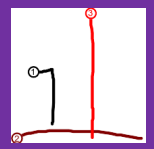
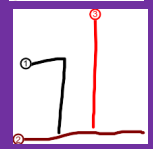
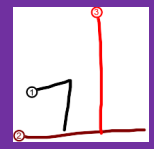
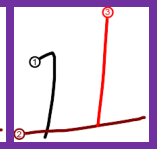


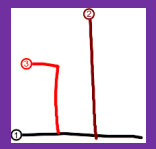


Lefties are in here,
just like righties

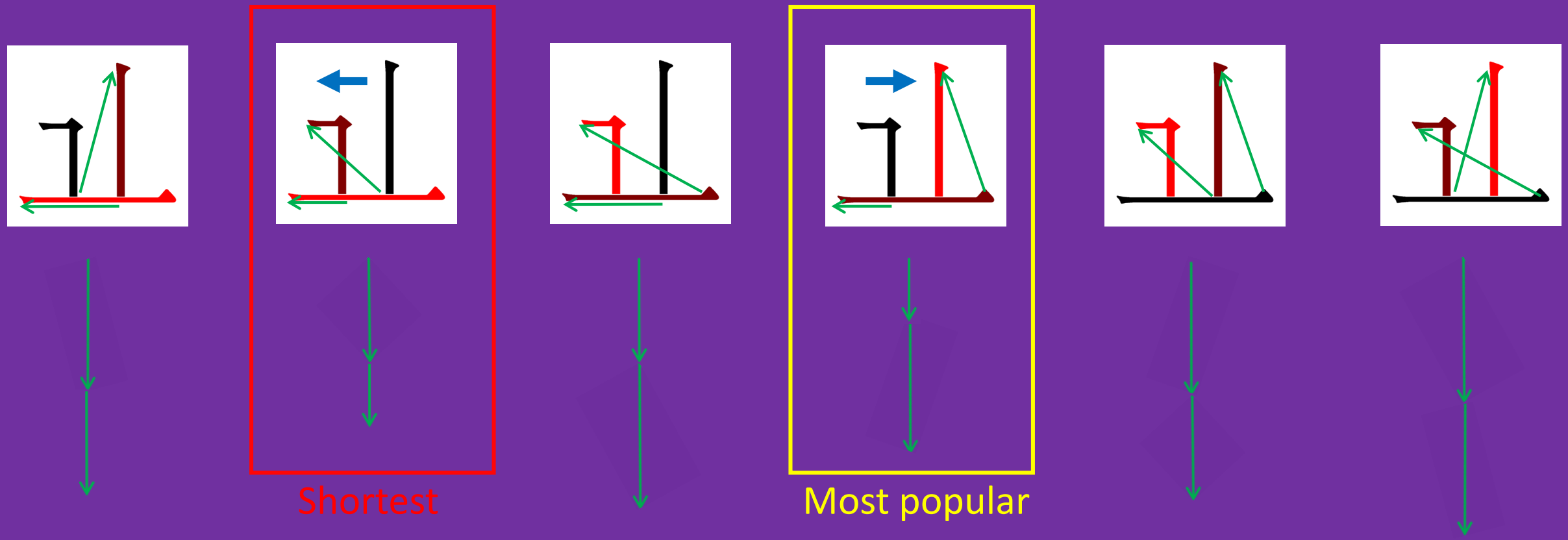













Ditto

Why this pattern?

Pen path length



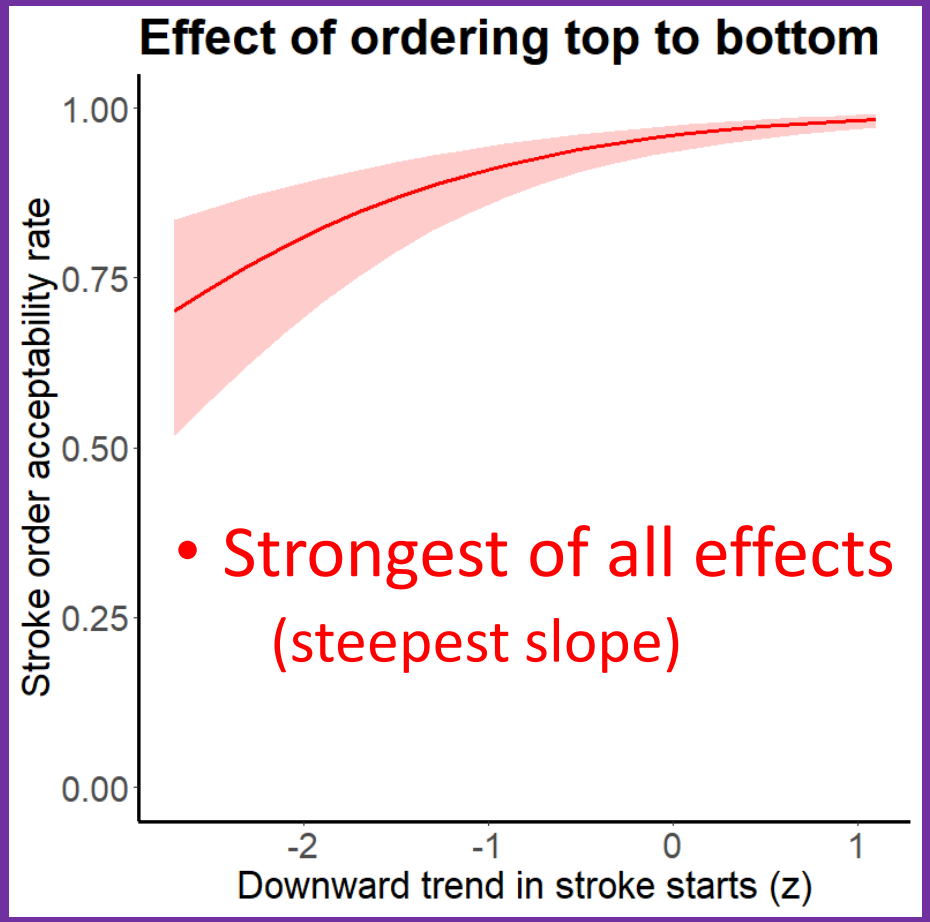
Preparing a larger analysis

- Drop items with just one stroke
- Drop written characters that are visually wrong (ignoring order)
  - Wrong number of strokes … and/or …
  - At least one of the five lab assistants said it didn’t look enough like the target
- Drop left-handed writers
  - (Regretfully and maybe unnecessarily)
- Final data set
  - 38 participants
  - 132 items
  - 5,710 trials

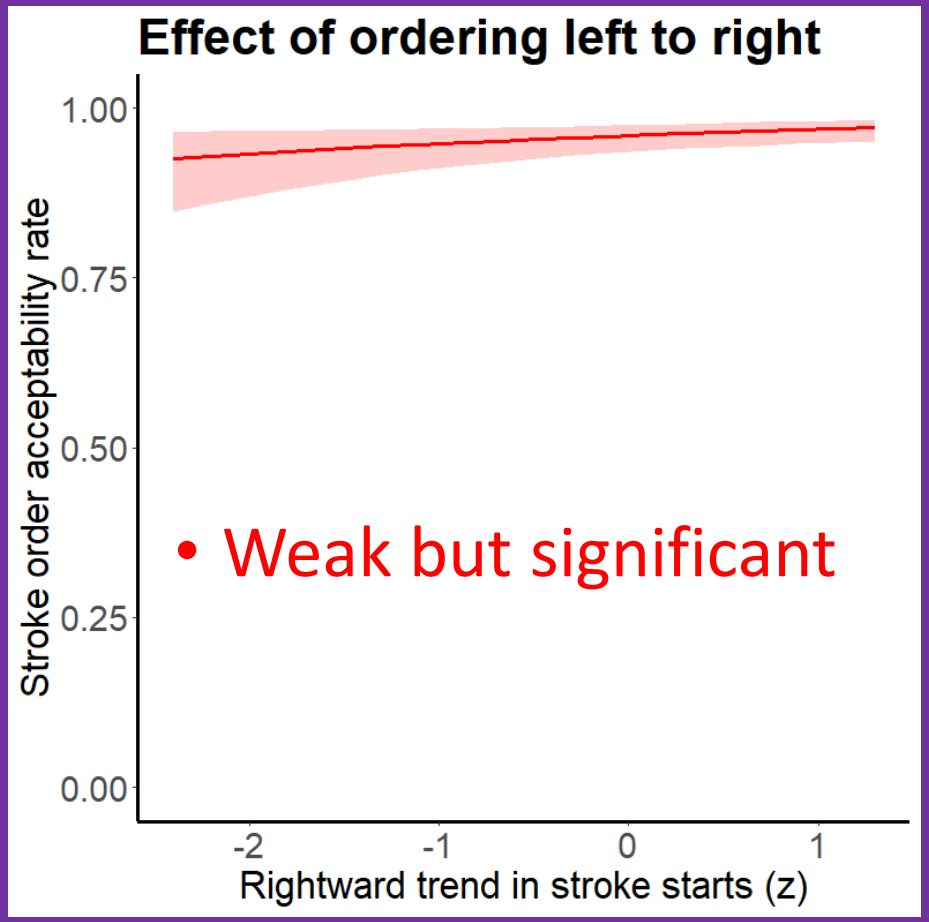
Predicting stroke order acceptability

- Production variables
  - **Direction**: Ordering downward and rightward should be better
    (nonlinear correlations between order and x or y coordinates of stroke starts)
  - **Path distance**: Longer paths should produce worse orders
    (proportion of total pen path that is between strokes)
  - **Axis**: Horizontal before vertical, left-falling diagonal before right-falling
    (nonlinear correlation between order and slopes of best-fit line through each stroke: slope between 0 and 1 means horizontal or left-falling, else vertical or right-falling)
- Perceptual variable
  - **Stroke size**: Larger strokes should come earlier to establish overall layout
    (nonlinear correlation between order and area of rectangle defined by each stroke)
- All put into mixed-effects logistic regression with *z*-scored predictors
  (1 = most of the five assistants said order is good, 0 = most said bad)

Downward & rightward (especially downward)

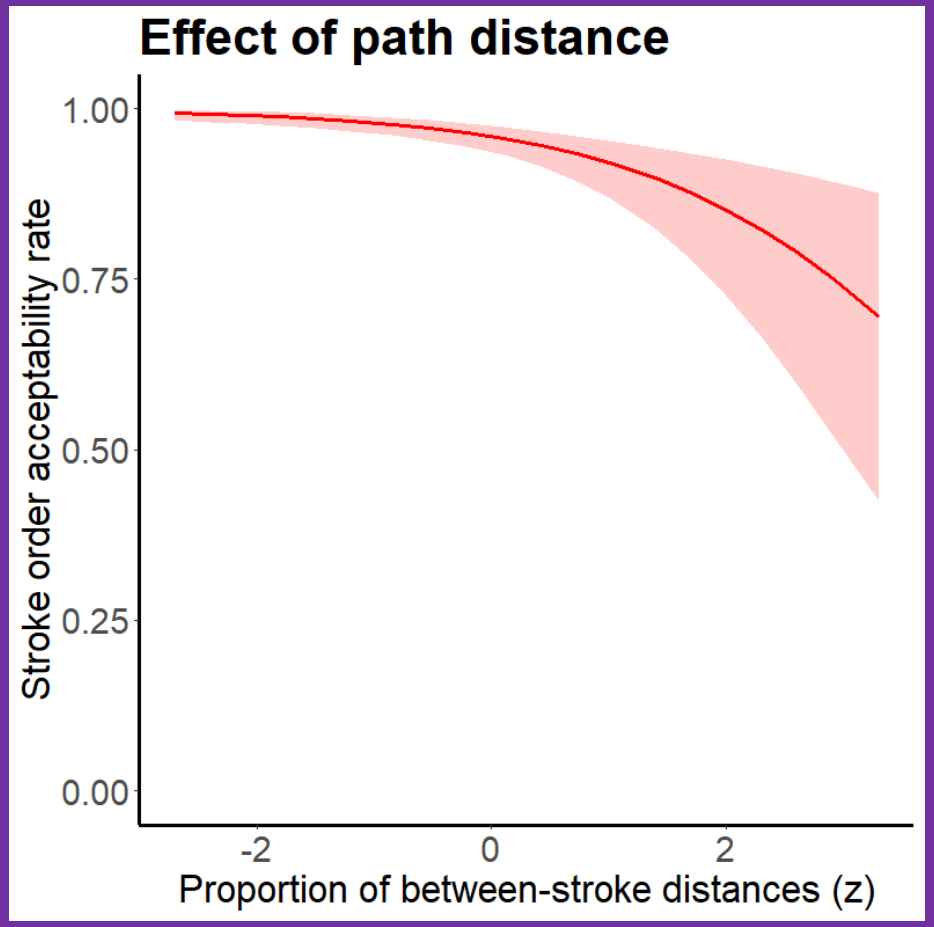


- Strongest of all effects (steepest slope)



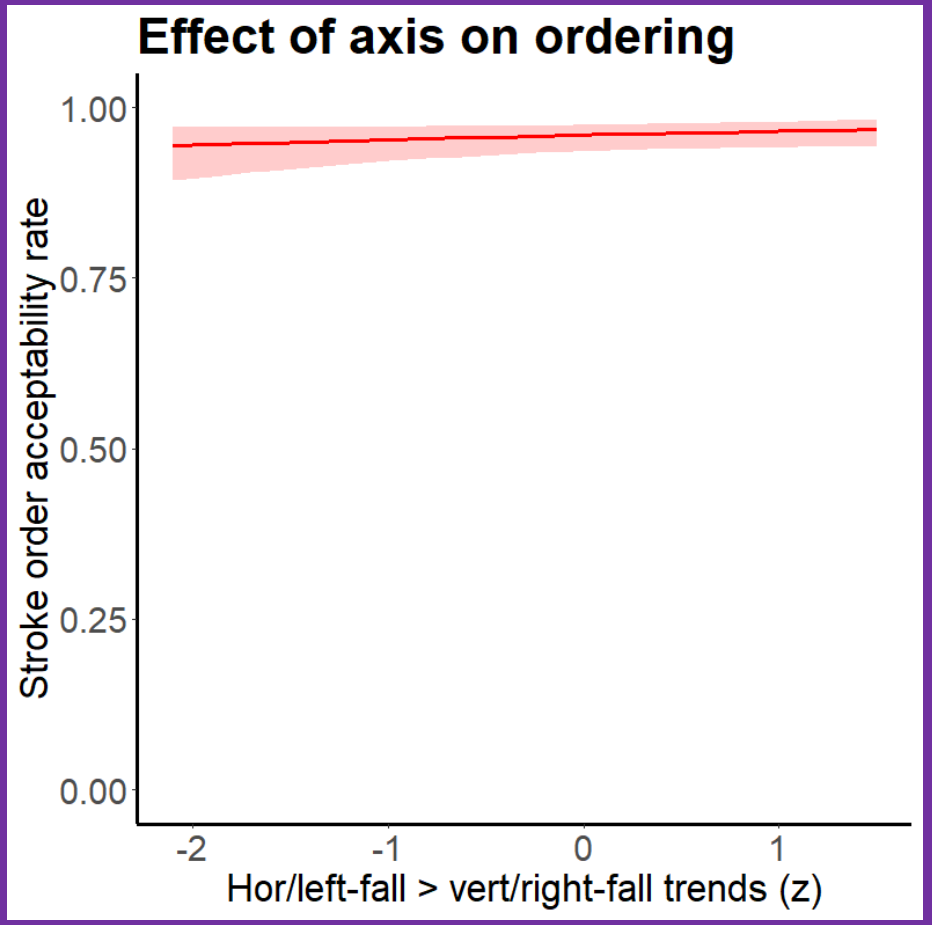
- Weak but significant

Longer pen path = worse



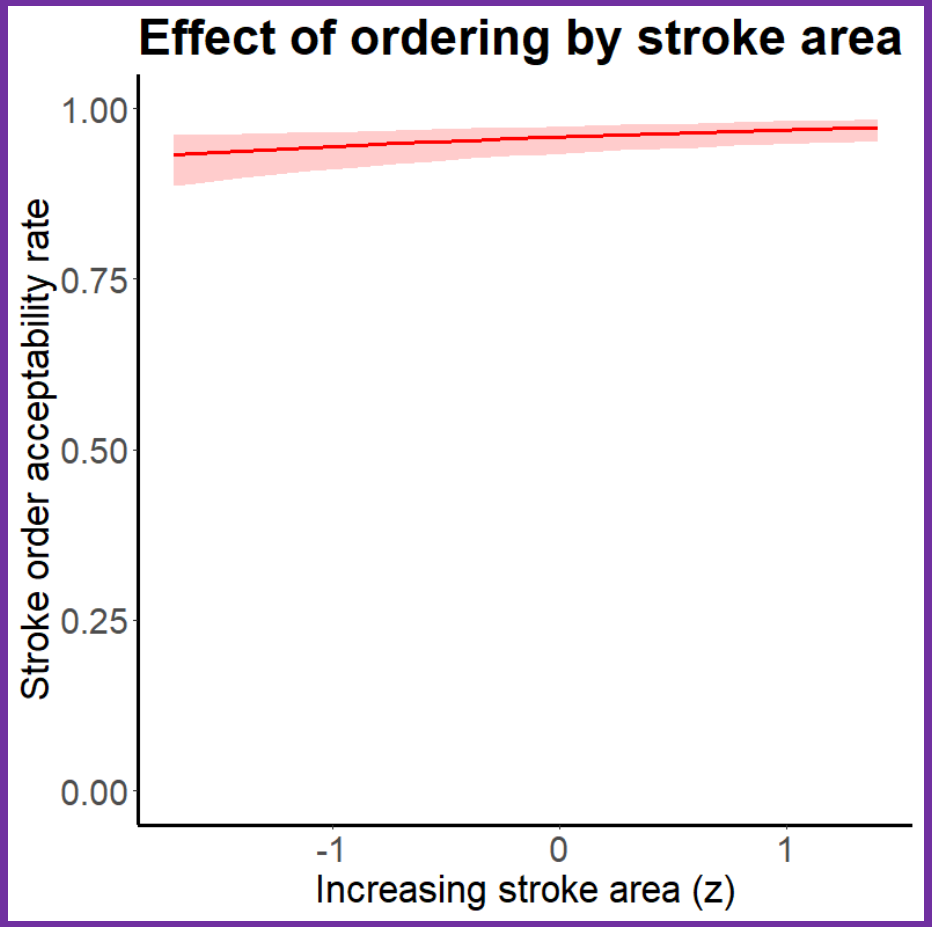
- Second-strongest effect

No hor > vert & diagonal ordering rules?



- Not significant
  - Because not quantified correctly?
  - Or because these are arbitrary conventions?

Increasing stroke size = better (?)



- Weak but significant
- May be confounded with prosody
  - Bottom/right strokes are usually written last
  - And they are also usually "stressed" (enlarged)

What next?

- More analyses
  - Quantifying symmetry?
  - Factor out target character acceptability
  - Predicting order “popularity” within the actual productions?
- More data
  - Stroke order in real characters (already have the data)
  - Judgments of “correct” ordering by a larger number of “ordinary” people
  - Recruit enough left-handers to analyze them properly
- Formal modeling
  - Build on the Markov chain approach of Xin & Lyu (2021)?
  - AI? (it’s so hot right now)
    - Will AI trained on real-character order generate human-like fake-character order?
    - What needs to be hard-wired in *untrained* AI to mimic human stroke order?

The End