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Learning the Manchu Writing System: The Role of Intra-Symbol Processing in Orthography Acquisition

Bai Li[1] | Victoria Murphy[2] | Sonali Nag[2]

[1]University International College, Macau University of Science and Technology, Taipa, Macao, China | [2]Department of Education, University of Oxford, Oxford, UK

Correspondence: Bai Li (libai@must.edu.mo) | Sonali Nag (sonali.nag@education.ox.ac.uk)

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ABSTRACT

Characteristics of the Manchu writing system provide an excellent testing ground for current theorizing about orthography acquisition. Using traditionally demarcated orthographic units called *uju hergen*—symbol blocks representing phonological syllables—we investigated the role of visual features and phonological representations in learning the Manchu symbol set. Novice Manchu learners ($n = 196$; 89.8% female; $M_{age} = 18.79$) participated in two experiments. Experiment 1 focused on visual complexity effects and Experiment 2 on mapping complexity effects and switching costs. Among visual characteristics, the number of connected points was found to make a unique contribution to uju hergen recognition. Naming error rate was lower for a list of uju hergen with single (one-to-one) mapping between a phoneme marker and sound compared to a matched list but with multiple (one-to-many) mapping. No switching cost was observed between lists with low- and high-switching-demand. Established explanatory constructs of grain size, orthographic depth, and orthographic breadth, referenced together as the construct of orthographic scale, explain the results. But reading uju symbol blocks also requires processing within symbol blocks: at the visual level, connected points provide the sub-symbol cues to decompose discrete simple features and recompose them into phoneme markers; and at the level of phonological representation, the resultant markers must be read by appropriate symbol-to-sound mapping. Together, our study expands theorizing on orthography acquisition by bringing focus on the under-studied construct of intra-symbol processing.

Learning to read fundamentally involves the acquisition of orthography—the grasping of basic written symbols and their mapping principles with sounds. This process can be varying in nature due to the inherent diversity in orthographic characteristics across languages. For example, orthographies such as Devanagari, Mandarin, and Thai exhibit higher visual complexity because symbols intricately connect and combine in words, requiring attention to visual patterns at a level of detail not necessary for visually simple orthographies like Hebrew and Russian with less intricate features (for a multi-dimensional comparison of visual features, see Chang et al. 2018). A single symbol corresponding to multiple sounds, another orthographic feature, poses a different learning demand (e.g., the English letters "o" [as in *women*], "i" and "e" can all be pronounced as /ɪ/). Depending on the orthography, the nature of visual complexity and symbol–sound mapping complexity can thus potentially complicate reading acquisition. Yet, current reading theories overly rely on a small number of orthographic features, placing limits for us to truly build a nuanced account of reading acquisition (Share 2025). To expand the scope of research on orthographic features, we present a study on learning to read the Manchu language. Manchu is a critically endangered yet under-investigated language in northeast China with unique orthographic features of visual and symbol–sound mapping complexity. In this paper, we report a first-time analysis of Manchu symbol level factors to advance our understanding of the mechanisms underlying orthography acquisition.

1 | The Manchu Writing System

Manchu is written vertically with text arranged in columns beginning at the top left of the page. The basic orthographic unit in Manchu is called *uju hergen*—a symbol block representing one of the six syllables of V, VV, VC, CV, CVV, and CVC. For example, the word *manju* comprises two uju hergen from top to bottom— /mɑn/ and /dʒu/. Uju hergen like these were traditionally organized in a syllabary. The first section in the syllabary comprising 131 uju hergen (V = 6; CV = 125) is considered fundamental, with syllable sets in the remaining 11 sections formed by attaching <-I>, <-R>, <-N>, <-NG>, <-K>, <-S>, <-T>, <-B>, <-O>, <-L> and <-M> to these 131 base symbols (see Appendix A for annotation). Although the traditional syllabary runs to a total of approximately 1400 uju hergen, the full count is estimated at around 5600 due to substantial allography. For example, the uju hergen /mɑn/ has three positional variants (, , and) depending on their location at the beginning, middle, and end of a word. Importantly, the uju hergen can be further divided into vowels and consonants, and we refer to these sub-syllabic symbols as *phoneme markers*. For example, /mɑn/ can be subdivided into /m/, /ɑ/, and /n/. Drawing on earlier descriptions of the Manchu orthography, we identified 83 graphically distinct phoneme markers (Li and Nag in press). Unlike the Latin alphabet, but like the Arabic and Indic systems, phoneme markers within a Manchu word are written without spaces at the phonemic boundaries. Also similar to the Arabic and Indic systems, phoneme markers may also have allographs with different orthographic forms representing the same phoneme. For instance, the three phoneme markers , , and all represent /ɑ/ and are used at the beginning, middle, and end of a word. Despite this form of allography, the Manchu orthography is considered transparent to the extent that the form for a position is invariant. In addition, and of particular interest to this study, one phoneme marker may map on to more than one sound, adding a layer of opacity to an otherwise transparent system (e.g., – /ɑ/, /ə/, /n/).

In summary, symbol units in Manchu can map onto sounds in grain sizes of syllables and phonemes, and apart from the one-to-one symbol–sound mapping, there are instances of many-to-one and one-to-many mapping due to allography.

2 | Orthography Acquisition

2.1 | The Visual Form

At the most basic level, learning an orthography is to learn details about the visual form of the written symbol set. Two aspects have been studied: the overall visual complexity of the symbol and particular visual features.

2.1.1 | Visual Complexity

An important factor influencing reading accuracy and speed among both beginning and skilled readers is the visual complexity of the symbol set, although the evidence currently comes from only a limited number of orthographies. In a study of the Indic Kannada, Nag et al. (2014) reported a moderate, negative correlation between visual complexity and recognition accuracy, suggesting that visual complexity poses a challenge in learning to read an akshara orthography. Using a cross-orthography paradigm, Abdelhadi et al. (2011) presented participants with Arabic and Hebrew stimuli and required them to identify the target diacritics. The Arabic stimuli were visually more complex with letters connected to each other and disconnected dots as part of the base form. By contrast, the Hebrew stimuli had no connecting letters and the dots were diacritics rather than disconnected parts of the base form. With these stimuli sets, identification of the target diacritics was slower for Arabic than for Hebrew, indicating a processing cost for the visually more complex Arabic. A similar result was reported for simplified Chinese (Yu et al. 2018), in which participants searched for target Chinese characters with varying numbers of strokes. Identification was slower for characters with more strokes, suggesting visual complexity effects in character processing. Together, the Arabic, Hebrew, and Chinese examples show the influential role of connected, disconnected, and the density of simple features. In addition, similar to Manchu, the visual complexity in these examples from the akshara, abjad, and morphosemantic writing systems co-occurred with mixed sound–symbol mapping. However, studies to date on visual complexity effects have been conducted only with orthographies laid out on a horizontal axis; allography, where present, has not been examined. Here, we examined Manchu, a visually complex orthography with mapping complexity stemming from substantial allography, that is laid out on a vertical axis.

2.1.2 | Dimensions of Visual Complexity

A range of dimensions of visual features have been found to be associated with visual word recognition. Chang et al. (2018), for example, identified four dimensions of visual complexity that contribute to word recognition across writing systems. The first dimension is simple features (SF), referring to the number of written elements that are distinct from other elements within a symbol (Pelli et al. 2006). This measure counts the number of visual features in a symbol while disregarding other properties such as length, width, and thickness. Studies on Chinese characters (Ma and Li 2015; Yu et al. 2018) and Japanese kanji (Tamaoka and Kiyama 2013) show that characters and kanji with higher SF required more time to be recognized, suggesting that more strokes within a symbol block impose a higher cognitive demand on readers. The second dimension is connected points (CP), which refers to the place within a symbol block where two or more simple features join. CP was found to be the most important visual characteristic in letter and word recognition in English (Fiset et al. 2008; Lanthier et al. 2009). However, it remains unclear whether CP also affects symbol recognition in visually more complex orthographies. The third dimension is disconnected components (DC), identified as the visual features that do not adjoin other visual features in a symbol. The final dimension is perimetric complexity (PC), referring to the ratio of the squared perimeter of the foreground to the foreground area. Although PC has the advantages of easy calculation, size-invariance and additivity, its measurement can be inconsistent with subjective human observers' judgment of visual complexity (Arnoult 1960). Instead, Nag et al. (2014) found a significantly high correlation ($r = 0.711$, $p < 0.001$) between pixel count (PX, the amount of "ink" in a printed symbol) and teachers' judgment of visual complexity, suggesting that PX is a useful index of "visual feature density" (322). The five dimensions—SF, CP, DC, PC, and PX—have been reported to be related to recognition accuracy; we add to this growing literature with a focus on the yet to be discussed Manchu orthography.

2.2 | The Mapping Principle

Orthography learning is fundamentally a process of learning to match written symbols to phonological units in a language. Thus, acquisition requires mastery of the symbol–sound mapping principles of a writing system. Several aspects of the process are important for understanding how these mappings are learned: granularity, consistency, inventory size, and for some symbol sets, within-symbol details. In what follows, we review major theoretical frameworks that address how variations in such orthographic properties shape reading acquisition.

2.2.1 | Psycholinguistic Grain Size Theory

Ziegler and Goswami (2005) argue that decoding is closely linked with granularity or the level at which the symbol maps to sound. Importantly, when this grain size is variable, it shapes decoding strategy. For example, Goswami (1986) reported that in addition to letters, children used multi-letter orthographic chunks corresponding to rimes to read novel English nonwords. Similarly, Brown and Deavers (1999) found children and adults used both small and large grain sizes (phonemes and onset-rimes) to read English nonwords, suggesting a repertoire of more than one sublexical decoding strategy.

2.2.2 | Orthographic Depth Hypothesis (ODH)

Another influential theory in reading acquisition is the orthographic depth hypothesis (Frost et al. 1987; Katz and Frost 1992). Orthographies are viewed on a continuum of varying levels of letter–sound consistency, and ODH predicts that reading an inconsistent (deep) orthography is more challenging compared to reading a consistent (shallow) orthography. In one of the first cross-linguistic studies on European orthographies, Seymour et al. (2003) confirmed that mastery was slower to develop when learning to reading in a deep orthography (e.g., English) compared to a shallow orthography (e.g., Finnish).

2.2.3 | Orthographic Breadth Hypothesis (OBH)

While ODH and the psycholinguistic grain size theory are influential frameworks, they are deeply rooted in the view of letter–sound consistency with little attention paid to features within other orthographies (Daniels and Share 2018). The orthographic breadth hypothesis (Nag 2007, 2017), on the other hand, considers orthographies along a continuum with the *contained* (fewer than 50 symbols such as English and Finnish) and the more *extensive* orthographies (hundreds and thousands of symbols, such as Mandarin, Hindi, Kannada, and Japanese). An important implication of OBH is that there may be a trade-off between cognitive demand and inventory size in orthography learning (Inoue et al. 2017; Nag 2011, 2022). The acquisition of an extensive orthography has higher memory demand due to a larger symbol set, although symbol-to-sound mapping may be less ambiguous. In contrast, acquiring a contained orthography has lower memory demand for symbol learning, but mapping between symbols and sounds may get more complex and consume more cognitive resources.

2.2.4 | Intra-Symbol Processing

This construct captures the learning implicated in visually complex and extensive writing systems (Nag 2022). Architectural principles of the orthography, including visual distinctiveness, positional sensitivity, and decomposability of symbol blocks, drive intra-symbol processing (Nag 2021). These design principles make symbol blocks analyzable and decoding efficiency is arguably dependent on mastering these principles. One important aspect in intra-symbol processing is related to the visuo-spatial characteristics of symbols (Nag 2022), including vowel markers or diacritics positioned above, below, before, after, around, or to either side of the consonant base (e.g., Winskel 2009). Some nonlinear visuo-spatial arrangements have a greater processing cost than others (Nag 2014; Vaid and Gupta 2002). Intra-symbol processing is also related to degree of (in)consistency at the level of within-symbol markers, with predictions from the ODH applicable here.

2.3 | The Present Study

Our behavioral study goes beyond existing research in several important ways. To the best of our knowledge, this is the first empirical investigation into orthography acquisition in the Manchu writing system. We focused on novice Manchu learners and examined two key parameters of the writing system: visual complexity and mapping complexity of uju hergen. To investigate the reading process, we posed two sets of research questions (RQs). With respect to visual complexity, we asked:

> RQ1a: What is the association between the visual complexity of uju hergen and recognition errors among novice Manchu learners?
>
> RQ1b: What are the dimensions of visual complexity of uju hergen that predict recognition errors among novice learners?

We also asked questions about mapping complexity of phoneme markers:

> RQ2a: Is there a difference in novice learners' performance in uju hergen reading for lists with one-to-one compared to one-to-many mapping?

RQ2b: Is there a switching cost for novice learners when lists have low-switching demand compared to high-switching demand?

2.4 | Participants

A sample of 196 first-year Mandarin-speaking university students (89.8% female) with a mean age of 18.79 (SD = 0.59 years) was recruited from a population of 1851 students taking a university-wide introductory Manchu course offered as part of a revitalization effort for the "critically endangered" Manchu language (United Nations Educational, Scientific and Cultural Organization 2025). Participants earned academic credits for taking the course. None of them reported any prior experience learning Manchu. A substantial focus in Manchu instruction was on demonstrating the ways in which phonology is mapped onto orthography through teacher-led chanting, transliteration, and in particular, segmentation of symbol blocks (for an ethnographic description of the pedagogical practices followed at the research site, see Li et al. 2025). At the time of the study, the participants had completed 10 sessions of 45 min each and were thus considered novice learners of Manchu. Informed consent was obtained from all participants before their involvement in the study. The study received ethical approval from the Department of Education, University of Oxford (ED-CIA-18-243) and conformed to the recognized standards presented in the Declaration of Helsinki.

2.5 | Procedure

Each participant was seen individually in a quiet room by the first author or by one of three research assistants who were fluent in Manchu and Mandarin and had 6 h of training in data collection. The task involved naming uju hergen items presented on a desktop computer with a 21.5-in. monitor of 1920 × 1080 resolution. Participants had the option to skip an item by explicitly stating "pass". The task began with 12 practice items. In Experiment 1, participants were presented with 18 uju hergen items one at a time manipulated for their visual complexity. In Experiment 2, they were shown uju hergen in List 1 (8 items characterized by one-to-one mapping) and List 2 (8 matched items but by one-to-many mapping, details below). In addition, the presentation condition of List 1 and List 2 was manipulated such that in the low-switching-demand order, List 1 preceded List 2, while in the high-switching-demand order, the 16 items from both lists were brought together and the presentation order was randomized. The order of Experiments 1 and 2 was counterbalanced across the sample, with List 1 and List 2 also counterbalanced within and across mapping and presentation conditions.

2.6 | Measures

The uju hergen items in Experiments 1 and 2 were in font style Daicing H11, font size 140, and image size 20 kb in a 300 × 400 pixels PNG image, with black foreground (i.e., the uju items) against a white background. The ImageJ software (version 1.52 k) for macOS was used to calculate the pixel value statistics of the foreground area.

2.6.1 | Visual Complexity

The uju items presented in Experiment 1 were measured for visual complexity on five dimensions—SF, CP, DC, PC (Chang et al. 2018) and PX (Nag et al. 2014). The SF measure was a count of distinct Manchu strokes in an uju hergen. These strokes are locally identified as the crest, tail, tooth, circle, dot, falling, belly, curve, horizontal, and vertical stroke (Li and Nag in press). CP and DC were manually counted for each item. PX was measured by the value of filled pixels (i.e., the "ink" area) of the foreground in an image. The formula for computing PC is $PC = P^2/A4\pi$, where P is the summation of the inside and outside perimeters of a foreground and A is the foreground area, with 4π as the nominalizing constant (Pelli et al. 2006; Watson 2012). For example, the uju hergen item <JE> comprises four SFs: a slanted horizontal, a vertical, a tail, and a dot. Both CP and DC in is 2. It's PX is 8651 pixels and PC 8.72.

2.6.2 | Symbol–Sound Mapping Complexity

In Experiment 2, symbol–sound mapping complexity was indexed based on the mapping relationship between a *target* phoneme marker and its corresponding sound. For example, in <TI>, the target phoneme marker <-I> only represents the sound /i/, while in the pair-matched <TE>, the target phoneme marker <-E>can map onto three sounds /ɑ/, /ə/, and /n/. Therefore, the mapping complexity is assigned a value of 1 for <TI> and 3 for <TE>. *Non-target* phoneme markers in the presented uju hergen item in both lists always had a one-to-one mapping with sound. In addition, two manipulations were made on items: eight uju hergen pairs differed in mapping between the target phoneme marker and sound (one-to-one and one-to-many mapping) but they were matched for syllable structures (CV = 6, CVC = 2).

2.6.3 | Uju Hergen Recognition

In both experiments, the error rate in naming each uju hergen item was computed. The error rate for an item was the ratio of the total number of incorrect responses to the total number of attempted responses across the sample. The resulting error rate for an item was thus a value between 0 (indicating accurate recognition across the whole sample) and 1.

2.7 | Control Measures

2.7.1 | Instruction Frequency

Symbol frequency accounts for reading accuracy in a variety of orthographies (Carreiras et al. 1993; Frost et al. 1987; Liversedge et al. 2014; Nag et al. 2014; Simpson and Kang 2004; Tamaoka and Kiyama 2013). For developing symbol frequency metrics for our purposes, instruction frequency was the more appropriate approach since exposure to Manchu print outside the classroom was minimal or completely absent. A mini corpus was created based on orthography instruction in the participating classes. This corpus included all taught uju hergen and individual phoneme markers across instructional sessions. Frequency counting was determined by instruction for students' *sustained attention* on an orthographic unit. For example, uninterrupted engagement with an orthographic unit (e.g., choral reading of  <JE> during class) resulted in a frequency count of 1 for this uju hergen, as attention remained continuously focused on it. However, if instruction focus shifted and later returned (e.g., reviewing a previously taught uju hergen), the frequency of the repeated uju hergen was counted as 2, reflecting two distinct instances of directed attention. This frequency counting method was also applied to phoneme markers. In Experiment 1, instruction frequency was a control variable when computing correlations between item and dimensions of visual complexity. In Experiment 2, instruction frequency was matched for each uju hergen pair across List 1 and List 2 ($t(7) = -0.552$, $p = 0.598$, MD $= -0.125$).

2.7.2 | Visual Complexity

In Experiment 2, visual complexity of the pair-matched uju hergen items was controlled across five dimensions (SF, CP, DC, PC, and PX). Each uju item pair had an identical number of DC. Additionally, the item pairs were not significantly different on SF ($t(7) = 0.753$, $p = 0.476$), CP ($t(7) = -1.183$, $p = 0.275$), or PC ($t(7) = -0.604$, $p = 0.565$), but the item pairs were less effectively controlled for PX ($t(7) = -2.725$, $p = 0.030$).

2.7.3 | Allographs

The uju hergen items in both experiments were in their independent form rather than initial, medial, or final form.

2.7.4 | Ligatures

Many Manchu phoneme markers can be nested within each other or connected without a short vertical linking line (e.g.,  <BO>and  <BI>respectively). No such ligature forms were used and all target phoneme markers in the uju hergen item set were connected with a line (e.g.,  <NI>).

2.8 | Analytic Plan

In Experiment 1, the association between dimensions of visual complexity (SF, CP, DC, PC, and PX) and participants' naming performance was examined, controlling for instruction frequency. Next, a multiple linear regression with the five measures as predictors was conducted to develop a model for predicting error rate in recognizing uju hergen. In Experiment 2, a two-way repeated measures ANOVA was performed to examine the main effects of item mapping condition (one-to-one and one-to-many) and item presentation condition (low- and high-switching-demand orders) on naming error rates.

The percentage of missing values in item naming in Experiments 1 and 2 was 14.51% and 18.69%, respectively. Data were primarily missing due to nonresponse (opting to say "pass"). We used the multiple imputation technique to create and analyze 20 multiply imputed datasets, which ensures a less than 1% tolerance for power falloff (Graham et al. 2007). Missing values in the naming data were imputed using predictive mean matching and fully conditional specification (Van Buuren 2018). Variables SF, CP, DC, PC, and PX were used as predictors, and the item error rate was estimated in each imputed dataset separately and pooled together according to Rubin's rules (Rubin 1987):

$$\bar{\theta} = \frac{1}{m} \sum_{t=1}^{m} \hat{\theta}_t$$

where $\hat{\theta}_t$ is the parameter estimates from data set t and $\bar{\theta}$ is the pooled estimate. For comparison, we also performed the analysis on the observed values and obtained similar results.

3 | Results

3.1 | Experiment 1: Visual Complexity of Manchu Uju Hergen

The visual complexity metrics and instruction frequency of the uju hergen in Experiment 1 are presented in Table 1. The symbol-level measures of SF, CP, PC, and PX were significantly correlated with each other, except for DC (see Table 2). Participants' mean error rate for naming the 18 uju hergen was 0.656 (SD $= 0.192$).

3.1.1 | Association Between Uju Hergen Visual Complexity and Naming Error Rate

To answer our RQ1a, we examined the inter-correlations between the five measures of visual complexity (SF, CP, DC, PC, and PX) and the error rate of naming the uju hergen. The error rate has a strong positive correlation with CP ($r = 0.777$, $p < 0.001$), along with moderate correlations with SF ($r = 0.688$, $p = 0.002$), PX ($r = 0.588$, $p = 0.010$), and PC ($r = 0.533$, $p = 0.023$). However, after controlling for uju hergen instruction frequency, only CP emerged as the symbol-level measure exhibiting a significantly moderate correlation with error rate ($r = 0.688$, $p = 0.002$).

3.1.2 | Predictors of Error Rate in Uju Hergen Naming

To address RQ1b, we first performed a multiple linear regression analysis. The resulting regression model, which incorporated a combination of five independent variables (SF, CP, DC, PX, and PC), significantly predicted the uju hergen naming error rate ($R^2 = 0.649$, $F(5, 12) = 4.447$, $p = 0.016$). However, among the five

TABLE 1 | Symbol-level measures of visual complexity for uju hergen ($n = 18$) in Experiment 1.

Uju hergen		Syllable structures	Measures					Instruction frequency
Traditional script	**Latin transliteration**		**PX**	**PC**	**SF**	**CP**	**DC**	
ᠠ	*a*	V	8292	7.61	3	2	1	12
ᡝ	*e*	V	8871	9.24	4	2	1	3
ᡳ	*i*	V	6622	7.22	4	2	1	10
ᡠ	*u*	V	7740	8.10	4	3	2	7
ᡡ	*ū*	V	8661	8.15	5	4	1	4
ᠴᠠ	*ca*	CV	9933	8.69	6	4	1	1
ᡩᡠ	*du*	CV	10,034	9.28	7	6	2	1
ᡥᠠ	*ha*	CV	12,678	12.49	7	3	2	1
ᠵᡝ	*je*	CV	8651	8.72	4	2	2	0
ᠮᡝ	*me*	CV	10,384	10.60	5	3	2	0
ᠨᡳ	*ni*	CV	7559	8.49	5	2	2	2
ᠰᠣ	*so*	CV	8320	7.78	6	5	1	0
ᡨᠣ	*to*	CV	8096	7.98	5	5	1	1
ᡴᡳᠪ	*kib*	CVC	15,804	15.90	8	6	1	0
ᠯᠠᠨ	*lan*	CVC	11,663	10.87	7	5	1	0
ᠰᡝᡴ	*sek*	CVC	13,923	14.02	12	7	2	0

(Continues)

TABLE 1 | (Continued)

Uju hergen		Syllable structures	Measures					Instruction frequency
Traditional script	Latin transliteration		PX	PC	SF	CP	DC	
	*sun*	CVC	14,982	13.49	9	6	2	0
	*yor*	CVC	14,858	13.19	9	8	1	0

dimensions of visual complexity, only CP emerged as a significant unique predictor ($p = 0.045$).

Multicollinearity was detected in the dataset. Specifically, SF showed high collinearity with PX ($r = 0.842$) and PC ($r = 0.819$), with both correlation coefficients surpassing the threshold value of 0.8 (Young 2018). PX and PC also exhibited collinearity, with their variance inflation factor (VIF, $\text{VIF}_{\text{PX}} = 27.99$; $\text{VIF}_{\text{PC}} = 25.27$) exceeding the critical value of 10 (Vittinghoff et al. 2012). To mitigate these issues, we followed the recommendation to drop highly correlated independent variables that may measure the same underlying construct (O'Brien 2007). In our case, PX and PC were related as they both use the "area" of items to assess visual complexity, and both were closely associated with SF (Nag et al. 2014; Pelli et al. 2006). This suggests that SF, PX, and PC may all measure the underlying construct of symbol visual density (Nag et al. 2014). We thus entered PX, PC, and SF separately, along with CP and DC as the other two independent variables, into three regression models to predict uju hergen naming error rate. While all three models significantly predicted participants' reading error rate, only CP emerged as a significant predictor in every model. These models are presented in Table 3. We next conducted a final univariate regression with CP as the sole predictor for uju hergen naming error rate (see Table 4). CP accounted for approximately 60% of the variance in the naming error rate ($R^2 = 0.603$). Due to the small number of items ($n = 18$) in Experiment 1, we further conducted a post hoc power analysis using G*Power (version 3.1.9.6; Faul et al. 2009) for the multiple linear regression model. With a calculated effect size of $f^2 = 1.519$, a sample size of $N = 18$, one predictor, and an alpha level of $\alpha = 0.01$ (Cohen 1988), the achieved power was approximately 0.981.

3.2 | Experiment 2: Symbol–Sound Mapping Complexity of Manchu Uju Hergen

Details of the uju hergen used in Experiment 2 are provided in Table 5. In the blocked presentation order (i.e., low-switching-demand order), the mean naming error rate was 0.633 (SD = 0.135) for List 1 items (featuring one-to-one mapping) and 0.791 (SD = 0.096) for List 2 items (featuring one-to-many mapping). In comparison, performance of the same items when shown in the mixed presentation order (i.e., high-switching-demand order), the mean error rate was 0.624 (SD = 0.123) for List 1 items and 0.780 (SD = 0.072) for List 2 items. Figure 1 compares the error rates in Lists 1 and 2 under blocked and mixed presentation orders.

3.2.1 | Naming Error Rates Across Item Mapping and Item Presentation Conditions

To answer RQ2a and RQ2b, a two-way repeated measures ANOVA was conducted to examine the main effects of item mapping characteristics (one-to-one and one-to-many) and item presentation order (blocked and mixed) on uju hergen naming error rates. Assumption of normality was met (all Shapiro–Wilk tests $p > 0.05$). The results revealed a significant main effect of mapping characteristics on naming error rate ($F(1, 7) = 18.312$, $p = 0.004$, $\eta^2 = 0.723$). Specifically, lower error rate was observed for naming uju hergen with single (one-to-one) mapping ($M = 0.629$, SD = 0.125) compared to multiple (one-to-many) mapping ($M = 0.786$, SD = 0.082). However, no significant main effect was found for item presentation order ($F(1, 7) = 1.510$, $p = 0.259$, $\eta^2 = 0.177$). There was no interaction effect between the mapping and presentation conditions ($F(1, 7) = 0.005$, $p = 0.946$, $\eta^2 = 0.001$). Due to the small number of items ($n = 16$) in Experiment 2, a post hoc power analysis was conducted using G*Power (version 3.1.9.6; Faul et al. 2009) for the main effect of mapping characteristics on naming error rate. Based on a calculated effect size of $f = 1.616$, a sample size of $N = 16$, and an alpha level of $\alpha = 0.01$ (Cohen 1988), the achieved power was approximately 0.998. These results suggest a mapping complexity effect on reading performance—novice Manchu learners were more prone to make errors when naming uju hergen comprising phoneme markers in the opaque one-to-many mapping with sound. However, no switching cost was shown when the novice learners read the uju hergen presented in the blocked order with its low switching demand and when there was the high switching demand of the mixed order.

4 | Discussion

We examined the effects of visual complexity and symbol–sound mapping complexity of uju hergen—a written symbol block representing phonological syllables in Manchu—on novice readers' reading performance. Our findings highlight the unique contribution of connected points in uju hergen recognition. In addition, novice readers made more errors when reading uju hergen comprising phoneme markers in the opaque one-to-many mapping with sound compared to those with one-to-one mapping. However, performance did not differ when reading the same uju hergen presented in contexts with low- and high-switching demand.

TABLE 2 | Correlation among symbol-level measures of uju hergen in Experiment 1.

Measures	PX	PC	SF	CP	DC
PX	—				
PC	0.970***	—			
SF	0.842***	0.819***	—		
CP	0.733***	0.641**	0.850***	—	
DC	0.112	0.192	0.206	−0.080	—

**$p < 0.01$.
***$p < 0.001$.

4.1 | The Dual Function Connected Points: Decomposition and Recomposition

4.1.1 | The Decomposition Function

An interesting finding from Experiment 1 is that the number of connected points, rather than the more intuitive metrics of the number of simple features or visual feature density, emerged as the only predictor for naming accuracy, demonstrating inhibitory effects on uju hergen visual processing. This finding aligns with previous research highlighting the critical function of connected points in the visual recognition of objects, letters and words (Biederman 1987; Lanthier et al. 2009; Szwed et al. 2009). Connected points are junctions where two or more simple features adjoin. For instance, in the Manchu phoneme marker , the connect point (indicated as 4 in Figure 2) is at the intersection of the vertical line and the short "tooth". We posit that connected points serve as sub-symbol visual cues that guide readers in decomposing uju hergen and provide critical signals about visual identity. Specifically, connected points introduce local discontinuities in key geometric properties—changes in relative orientation, lengths, and shapes of simple features

TABLE 3 | Multiple linear regression (enter) models of uju hergen naming error rates in Experiment 1.

								95% CI			
Models	**Predictors**	***R***	***R^2***	***F* (3, 14)**	***p***	**Estimate**	**SE**	**LL**	**UL**	***t* (14)**	***p***
1		0.803	0.645	8.486	0.002						
	Constant					0.226	0.136	−0.066	0.517	1.659	0.119
	PX					−2.542E−6	0.000	0.000	0.000	−0.153	0.881
	CP					0.082	0.024	0.030	0.134	3.403	0.004
	DC					0.079	0.062	−0.054	0.212	1.275	0.223
2		0.803	0.645	8.480	0.002						
	Constant					0.224	0.138	−0.071	0.520	1.629	0.126
	PC					−0.002	0.016	−0.036	0.032	−0.128	0.900
	CP					0.081	0.022	0.035	0.127	3.767	0.002
	DC					0.079	0.063	−0.056	0.215	1.252	0.231
3		0.805	0.648	8.606	0.002						
	Constant					0.215	0.117	−0.035	0.465	1.842	0.087
	SF					−0.011	0.029	−0.074	0.052	−0.388	0.704
	CP					0.091	0.035	0.017	0.165	2.637	0.020
	DC					0.091	0.070	−0.059	0.240	1.298	0.215

Abbreviations: CI, confidence interval; LL, lower limit; UL, upper limit.

TABLE 4 | Multiple linear regression (enter) model of uju hergen naming error rates with CP as the only predictor.

				95% CI		
Models	**Predictors**	**Estimate**	**SE**	**LL**	**UL**	***p***
	Constant	0.322	0.072	0.180	0.485	< 0.001
	CP	0.078	0.016	0.044	0.111	< 0.001

Abbreviations: CI, confidence interval; LL, lower limit; UL, upper limit.

TABLE 5 | Measures of symbol–sound mapping relations, visual complexity, and frequency for the uju hergen ($n = 16$) in Experiment 2.

Lists of uju hergen		Visual complexity					
Traditional script	**Latin transliteration**	**PX**	**PC**	**SF**	**CP**	**DC**	**Instruction frequency**
List 1 (Item $n = 8$)							
	*sū*	9940	9.06	8	6	1	0
	*ce*	10,663	9.85	7	4	2	0
	*di*	8897	9.86	7	4	2	1
	*nū*	9120	9.05	6	4	2	2
	*ti*	8163	8.64	6	4	1	1
	*cū*	9760	8.73	8	6	1	0
	*jūs*	14,224	13.47	9	7	1	0
	*tib*	17,265	17.32	10	8	1	0
List 2 (Item $n = 8$)							
	*tu*	9303	8.11	6	6	1	1
	*we*	11,638	10.74	5	3	2	0
	*de*	11,827	10.51	7	5	2	1
	*du*	10,034	9.27	7	6	2	1
	*te*	11,096	9.35	6	5	1	2
	*fū*	10,714	9.60	6	5	1	0

(Continues)

Lists of uju hergen		Visual complexity					
Traditional script	**Latin transliteration**	**PX**	**PC**	**SF**	**CP**	**DC**	**Instruction frequency**
	*tus*	15,372	13.38	10	9	1	0
	*teb*	17,492	16.34	11	8	1	0

Note: Target phoneme markers are underlined. In List 1, all target phoneme markers have a one-to-one mapping with sound. In List 2, the target phoneme markers in *tu*, *we*, *du*, *fū*, and *tus* have a one-to-two mapping with sound, and they have a one-to-three mapping with sound in the remaining three items.

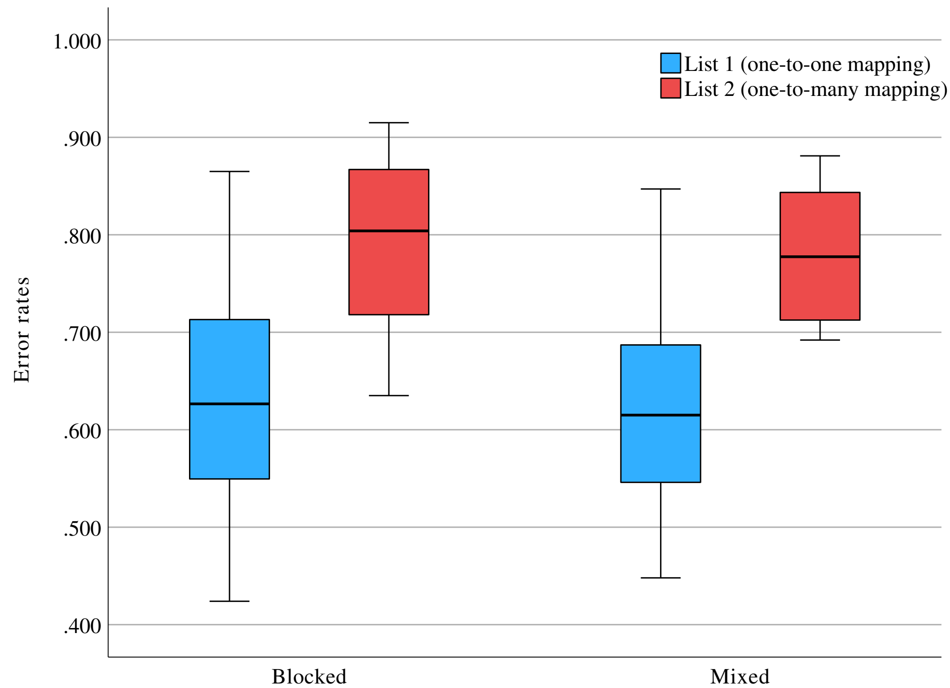


FIGURE 1 | Naming error rates of uju hergen in List 1 ($n = 8$) and List 2 ($n = 8$) presented in blocked and mixed orders in Experiment 2.

(Changizi et al. 2006)—which increase the computational demands of perceptual parsing. As the number of connected points grows, cognitive costs make symbol block harder to parse and discriminate, resulting in lower accuracy. That is, while connected points can visually cue decomposition of a complex configuration into sub-symbol features and help disambiguate confusable simple features, an excess of connected points undermines efficient visual processing. This mechanism explains why a count of simple features or gross visual density did not predict reading performance: neither capture the cognitively informative connected-point-driven discontinuities that govern segmentation and recognition in visual symbol processing.

4.1.2 | The Recomposition Function

In addition to *de*composing relative orientation, length and shape of simple features that adjoin at connected points, accurate naming also requires readers to *re*compose these identified features into phoneme markers, and phoneme markers into uju hergen. It is arguably during this visual–spatial processing of orthographic units that connected points serve as the nexus integrating discrete visual features into recognizable phoneme markers. For instance, in Figure 2, connected points 5, 6, and 7 link together a long "tooth", a curve, a slanted line, and a short line. Consequently, these visual features are organized into the phoneme marker  /k/.

In sum, connected points perform a dual function of decomposition and recomposition in novice Manchu reader's visual processing of uju symbol blocks. As visual cues, they arguably assist readers in breaking down the visually complex configuration of an uju hergen into discrete simple features. Additionally, readers use connected points to assemble these recognized simple features into coherent visual patterns corresponding to individual Manchu phoneme markers. What is noteworthy is that both connected points and disconnected components also predict uju hergen reading speed (Li and Nag in press), suggesting that,

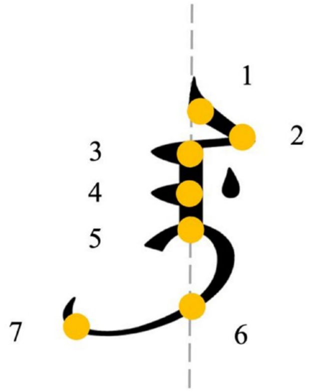


FIGURE 2 | Connected points in uju hergen <SEK>. The dotted line running through the centre of the uju symbol block indicates the "spine", an invisible vertical axis along which simple features are arranged in Manchu.

theoretically, uju hergen processing involves not only connected points but also the visual features of diacritic dots and circles positioned to the left or right of the phoneme markers. This non-linear visuo-spatial processing of the features both at connected points and spatially discontinuous point from the base architecture may collectively consume readers' cognitive resources. The nature of these processing demands remains an open question.

4.2 | Manchu Orthographic Characteristics and Uju Hergen Reading

4.2.1 | Use of Manchu Phoneme Markers in Uju Hergen Reading

Experiment 2 demonstrated that novice Manchu learners were more prone to make errors when reading uju hergen in which the target phoneme marker had a more complex one-two-many mapping with sound. Given that the uju hergen in Experiment 2 were pair-matched for visual complexity, syllabic structure, and instruction frequency, this inhibitory effect can be attributed to learners' reliance on consistent mapping at the smaller grain sizes of phoneme markers in Manchu reading. Further, the absence of switching cost between the low- and high-switching-demand orders of presenting Lists 1 and 2 also supports this interpretation. If learners had used mixed grain sizes (i.e., whole uju hergen symbol blocks alongside Manchu phoneme markers), the conflicting activation triggered by inconsistent phoneme marker–sound mapping (i.e., one-to-one in List 1 and one-to-many in List 2) in the mixed order would have increased cognitive demands, made evident by decreased reading accuracy. In fact, no such effect was observed. This interpretation is further supported by indirect evidence: the same participants read uju hergen in List 1 (phoneme markers in one-to-one mapping with sounds) faster than those in List 2 (in one-to-many mapping; Li and Nag in press). This finding suggests that novice learners process Manchu uju hergen analytically, relying on phoneme markers when reading the syllabic uju hergen.

Taken together, evidence from the mapping complexity effects but no switching cost effects indicate that novice Manchu learners use mapping details extensively for decoding while applying flexibility irrespective of which type of mapping they may encounter in contiguous uju hergen (a situation similar to real world reading of Manchu).

4.2.2 | Orthographic Scale and Manchu Symbol Blocks Reading

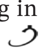
Reading Manchu uju symbol blocks is closely associated with three key characteristics of orthographic units—their granularity (small vs. large grain sizes), mapping (single vs. multiple correspondence with sounds), and repertoire (contained vs. extensive inventory sizes), which together may be considered by the construct of *orthographic scale* (for discussion see Li and Nag in press). All orthographic characteristics of orthographic scale collectively shape Manchu reading.

The selection of the smaller grain size phoneme marker in reading Manchu symbol blocks is a reasonable, if not optimal, choice for novice learners. Manchu can be considered a shallow orthography (Frost et al. 1987; Katz and Frost 1992) as a majority of its phoneme markers (75 out of 83) have a transparent one-to-one mapping with sound, despite the allography of four-to-one mapping between the four positional variants of an uju hergen and a phonological syllable. Furthermore, learning to read Manchu symbol blocks is constrained by its inventory size. Manchu can be considered an extensive orthography when the orthographic unit of uju hergen is regarded as the basic symbol (a syllabary of about 5600, including all four positional variants), but a less extensive orthography if counting phoneme markers as the basic symbols (83 in all). This difference in inventory size presents a potential trade-off between cognitive demands and the set of symbols to be learned (Nag 2011).

4.3 | Intra-Symbol Processing for Reading Uju Hergen

Our research proposes that reading uju hergen involves intra-symbol processing across at least two interlinked levels. At the sub-symbol level, readers recognize simple features and mentally organize them into phoneme markers, a cognitive process supported by connected points as visual cues. At the symbol level, readers convert the resultant phoneme markers into sounds by appropriately applying their knowledge of symbol-to-sound mapping. This construct of intra-symbol processing is central to understanding how uju symbol blocks are read.

The process of reading an uju hergen may begin with readers recognizing the simple features that are intricately interconnected within a symbol block. This sub-symbol visual processing is facilitated by connected points, which act as visual cues to decompose and subsequently recompose these elements. Specifically, connected points serve as a mechanism enabling novice readers to segment uju symbol blocks into their constituent strokes for recognition, and then to reassemble them into coherent patterns representing individual phoneme markers. A fundamental question in printed symbol identification is whether symbols are perceived by features or as a global whole (Fiset et al. 2008). Our study on novice Manchu learners suggests that uju symbol blocks are initially perceived by simple features, which are subsequently organized into phoneme markers.

In parallel, reading uju symbol blocks utilizes mapping knowledge to convert a phoneme marker into its corresponding sound. To be specific, the decoding process of an uju symbol block may begin by converting the first phoneme marker into its corresponding sound, followed by the conversion of the first two phoneme markers, and so on, until all phoneme markers are translated into sounds (after Coltheart 2005). For example, to decode the symbol block <SEK>, the first phoneme marker  is converted into /s/ based on the symbol-to-sound mapping. Next, the second phoneme marker  is converted to /ə/, resulting in /sə/. Finally, with the conversion of the phoneme marker  into /k/, the symbol block is decoded as /sək/. It is noteworthy that reading symbol blocks such as <SEK> is a nonlinear process due to the diacritic dot positioned to the right of the base symbol. The visual–spatial processing beyond the vertical axis of the word "spine" is critical, because the diacritic dot helps disambiguate the sound of a phoneme marker from  /ɑ/ to  /ə/. This decoding process enables readers to access the corresponding phonological representation encoded in the symbol and retrieve the appropriate sound associated with the symbol block. The fundamental question to answer here is whether an uju symbol block is read by assembled phonology (generated by symbol–sound mapping rules) or addressed phonology (accessed as a whole from lexicon through the presentation of the printed word; Coltheart et al. 2001; Katz and Frost 1992). Given that it is Manchu phoneme markers that are chosen as the basic orthographic unit in reading, we speculated that uju symbol blocks are decoded through assembled phonology. This speculation finds support in the successful decoding of the untaught symbol blocks in Experiment 2, which may not have been possible if the addressed phonology approach had been applied.

To summarize, reading uju symbol blocks involves intra-symbol processing. It first requires visual processing, which entails recognizing visual elements and mentally organizing them into phoneme markers. Additionally, it incorporates phonological processing, wherein readers access the corresponding phonological information encoded in the phoneme marker and retrieve the appropriate sound associated with it.

4.4 | Limitations

The syllabic structure of the symbol blocks used in experiments was limited, consisting mainly of V, CV and CVC syllables and without ligatures. While these symbol blocks aligned with the participants' proficiency as novice Manchu learners, it still remains unclear whether alternative decoding strategies, such as using large or mixed grain sizes (as shown in English by Goswami 1986) would be employed to read more complex words, such as *bontoholobumbi* <CVC.CV.CV.CV.CVC.CV>. This study is also limited in that the participants were novice learners of Manchu. For learners with more advanced proficiency levels, they may have developed flexible approaches for reading uju symbol blocks based on their increased knowledge and experience with the language. Therefore, to achieve a comprehensive understanding of the reading process in Manchu and other writing systems, future studies are needed in languages with varying levels of orthographic scale, symbol block complexity, and with both novice and expert readers.

5 | Conclusion

This study, to the best of our knowledge, is the first empirical investigation of Manchu orthography acquisition. We propose that reading uju symbol blocks requires intra-symbol processing across at least two interlinked levels. At the sub-symbol level, readers, supported by connected points as cues, visually decompose the simple features within a symbol block and mentally recompose them into Manchu phoneme markers. At the symbol level, readers appropriately apply their knowledge of symbol-to-sound mapping to convert these resultant phoneme markers into sounds.

Theoretically, this study contributes to the development of a more nuanced theory of reading by providing additional empirical evidence to the existing body of research on reading acquisition (e.g., Akshara, Nag 2022; Arabic, Abdelhadi et al. 2011; Chinese, McBride 2016; Cyrillic, Bola et al. 2017; Hebrew, Share and Bar-On 2018). It also highlights the importance of considering the constructs of orthographic scale (i.e., granularity, mapping principle, and inventory size) and intra-symbol processing in understanding orthography acquisition. Notably, although our participants were multilingual university students, not enough is known on implications when the beginning reader is a monolingual (or native) Manchu child. Studies from other orthographic breadth studies focused on monolingual children provide some insights. For example, the number of connected points in symbol blocks without diacritics, but not with diacritics, was significantly associated with accurate naming in a recent study of monolingual Sinhala-speaking children in Grades 1 (5.0–5.99 years) and 2 (6.0–6.99 years) in Sri Lankan schools (Sumanasena et al. 2025). Visual complexity effects on early-stage child acquisition are also seen in other Indic systems (e.g., Nag 2007; Nag et al. 2014). However, despite some overlap in which orthographic features are difficult to learn, more research is needed to understand the cognitive demand that underlie reading acquisition across age bands when orthographies differ in orthographic scale and intra-symbol features.

Methodologically, as part of our examination on uju hergen reading, we developed a mini corpus from observations on Manchu orthography instruction and measured frequency of the orthographic units of uju hergen and phoneme markers with reference to readers' sustained attention on them. It presents a novel contribution although such a corpus yields only a preliminary frequency metric. Creating instruction-based corpora appears to be a promising method, especially for languages without an available print corpus and should be explored in future research.

We close the paper acknowledging the International Decade of Indigenous Languages, launched to draw global attention to the critical situation faced by many indigenous languages (United Nations 2020). Pedagogically, our study has important implications for literacy instruction. For instance, the findings inform decisions regarding the reasonable, if not optimal, grain size for teaching orthographic knowledge for one endangered language. One implication is that compared to the extended class hours required to instruct the larger grain size of uju hergen (approximately 1400 independent forms and around 5600 in the entire syllabary), teaching the 83 smaller Manchu phoneme markers would enable teachers to efficiently cover fundamental orthographic knowledge within a limited period of time. In parallel, from a cognitive perspective, learning phoneme markers would be less memory intensive. This may reduce anxiety, boredom, and frustration among heritage language learners in the classroom. Given the urgency for preserving indigenous and endangered languages, our study provides important cognitive-linguistic insights to support new learners.

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Ethics Statement

Ethical clearance for the study was received from the Departmental Research Ethics Committee at the Department of Education, University of Oxford (ED-CIA-18-243).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The authors have nothing to report.

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Appendix A

Annotation of Manchu

1. Uppercase letters are used for annotating the traditional Manchu script and italicized lowercase letters for transliteration (e.g., KA and *ka*).
2. Uju hergen and Manchu phoneme markers are enclosed in angle brackets (e.g., <KA>and <M>).
3. The independent, initial, medial, and final forms of an uju hergen are denoted by (null) hyphens respectively (e.g., <KA>, <KA->, <-KA->, and <-KA>).
4. Similarly, the initial, medial, and final positions of a phoneme marker within an uju hergen are denoted by hyphens too (e.g., <M->, <-M->, and <-M>).