Online supplementary material S2

The Interaction of Central and Peripheral Processing in L2 Handwritten Production: Evidence from Cross-linguistic Variations

Supporting Information: Individual differences in L2 linguistic proficiency

Introduction

Individual differences related to second-language (L2) linguistic proficiency have been studied in L2 spoken word production (Casillas, 2020; Collentine et al., 2004; Segalowitz & Freed, 2004). For this reason, it is important to understand how individual writing behavior varies in grouping level effects as a function of their L2 proficiency levels. In this section, we propose that variability in the degree to which writers with divergent L1 backgrounds rely on different dual-route procedures in L2 handwriting will be ascribed to the individual level of mastery attained in L2. Grabe (2008) stated that *bilinguals with weak L2 proficiency use all of their L1 academic reading skills to carry out L2 academic reading tasks successfully* (p.141). The aspects of this proposal resonate with the framework of computational models of bilingualism that in late sequential L2 acquisition, the L2 self-organizing networks tend to parasitize on the structure of L1 components to access the L2-specific representations (Li, 2009, 2013; Li & Zhao, 2013). Relatedly, in Cuppini et al. (2013)'s model, such parasitism attenuates as L2 proficiency increases, and direct connections between the L2 word-forms and the corresponding linguistic information are established. These predictions are also compatible with models of the bilingual lexicon that propose the functional role of increased L2 proficiency in a strengthening of the automaticity in the L2 processes (RHM, Kroll & Stewart, 1994) and the rest activation levels of L2 linguistic components (BIA+, Dijkstra & Van Heuven, 2002). In parallel, Chung, Chen, and Geva (2019) defined cross-language transfer from an interactive perspective. In their theoretical work, the effect of L1 orthographic features on bilingual learning is weakened by a higher level of L2 proficiency or extended instruction of L2 literacy (Berghoff et al., 2021; see also Chung, Chen, Commissaire, et al., 2019). Therefore, inspired by models of reading and learning, understanding the modulation of individual differences in L2 proficiency can provide us additional information regarding how sensitivity to different levels of dual processing develops in the bilingual spelling system. With this in mind, we estimate the posterior distribution of individual intercepts from the hierarchical models (see the main text) to explore the correlation between each participant's sensitivity to Lexical frequency/P-O consistency effect and their L2 proficiency levels.

It is not easy to make predictions concerning L2 linguistic proficiency for central and peripheral levels of processing in Spanish and Chinese groups respectively, as there is no direct evidence on the handwritten production of L2 word-forms. In writing research, individual differences in L1 experience, such as vocabulary sizes (Bonin et al., 2013) or the slope estimates of different variables (Bonin et al., 2015), make a unique contribution to the degree of involvement of dual-route procedures during the orthographic access (i.e., central level of processing). Likewise, because the orthography of English is overall deeper than that of Spanish but shallower than Chinese, at the central level we may see increased L2 proficiency in Spanish bilinguals associated with heightened sensitivity to lexical frequency effect, whereas higher proficient Chinese bilinguals are prone to using the combination of both lexical and sublexical processes. It is yet unknown whether individual differences in language experience can be observed during motor execution. This will be tested in the current study.

Method

To estimate individual-level effects, the Bayesian approach offers the benefit of obtaining a range of plausible parameter estimates in the form of a posterior distribution. In this sense, the random effect structures fitted in hierarchical models (see the main text, *Session: Statistical Modeling*) along with the corresponding posterior predictive distributions were assessed to explore individual variations in sensitivity to P-O consistency and lexical frequency. Thus, each participant had one posterior median (i.e., random slope estimate) that quantifies the effect of P-O consistency and one that indexes reliance on lexical frequency. Note that since the intercept in each omnibus model represented the grand average across conditions, the posterior distribution of each participant in response to P-O consistency and lexical frequency was coded as how much they differ from the constant levels of these two predictors at 0. Therefore, a posterior median *farther* away from 0 indicates *more* sensitivity to P-O consistency, in the same direction as the slope estimate reflecting sensitivity to lexical frequency. The resulting posterior medians were then submitted to exploratory Bayesian correlation analyses, examining whether individual differences in L2 linguistic proficiency were related to their reliance on P-O consistency and lexical frequency respectively during L2 handwritten production. Since there was a highly significant correlation between the LHQ 3.0 and the LexTALE scores (rho = 0.86, 95%

HDI[0.83, 0.92]), the latter was chosen as an index of participants' proficiency for the subsequent analyses. We considered the LexTALE test as a more objective measure that evaluates participants' vocabulary knowledge. Also of note is that the reliability of random slope estimates is subject to inter-individual variability in response accuracy. Individuals with either extremely high or low accuracy rates are likely to have less reliable estimates compared to those with a balanced number of correct and incorrect trials. This variability in reliability could potentially bias the correlation between posterior medians and L2 proficiency in a systematic manner. Therefore, we did not conduct individual-level analysis that involved predicting accuracy data.

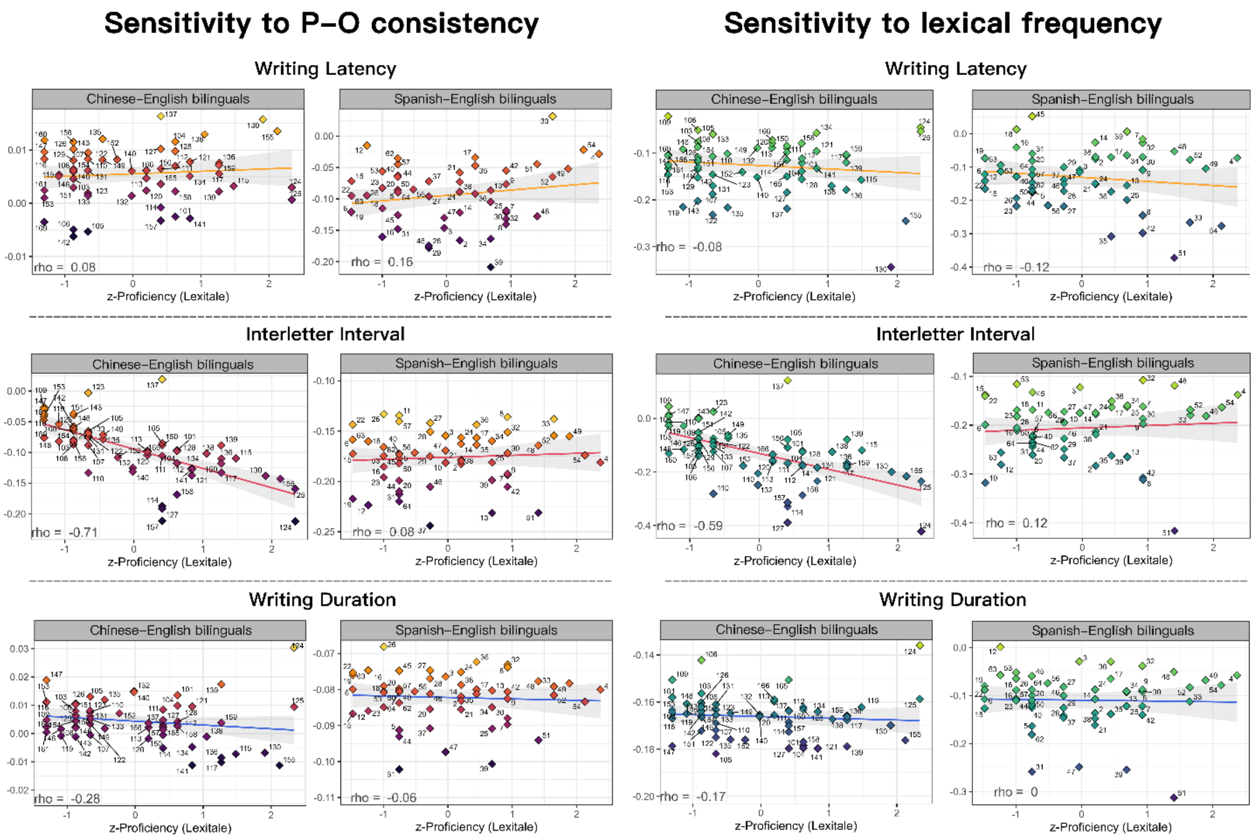
Results

This portion of the analysis focused on whether individual differences in L2 proficiency correlated with sensitivity to P-O consistency and lexical frequency effects during L2 handwritten production. Tables S1 and S2 provide the posterior correlation medians for temporal metrics in each task along with the 95% highest density credible intervals.

Figure S1 displays scatter plots of the posterior medians as a function of standardized P-O consistency and lexical frequency estimates respectively in the spelling-to-dictation task. The analysis showed that Chinese-English individuals with higher L2 proficiency tended to exhibit a larger magnitude of sensitivity to P-O consistency during motor execution (interletter interval: rho = -0.71, 95% HDI [-0.85, -0.56]; writing duration: rho = -0.28, 95% HDI [-0.55, -0.01]). Similarly, a negative correlation between L2 proficiency and sensitivity to lexical frequency (interletter interval: rho = -0.59, 95% HDI [-0.75, -0.39]) indicated that higher proficiency levels were associated with greater sensitivity to frequency effect during execution. No relevant patterns were found in the Spanish group.

Figure S1

Spelling-to-dictation Task: Scatter plots of individual posterior medians as a function of standardized P-O consistency and lexical frequency estimates. Values farther away from 0 (darker colors) indicate greater sensitivity to the given effect.

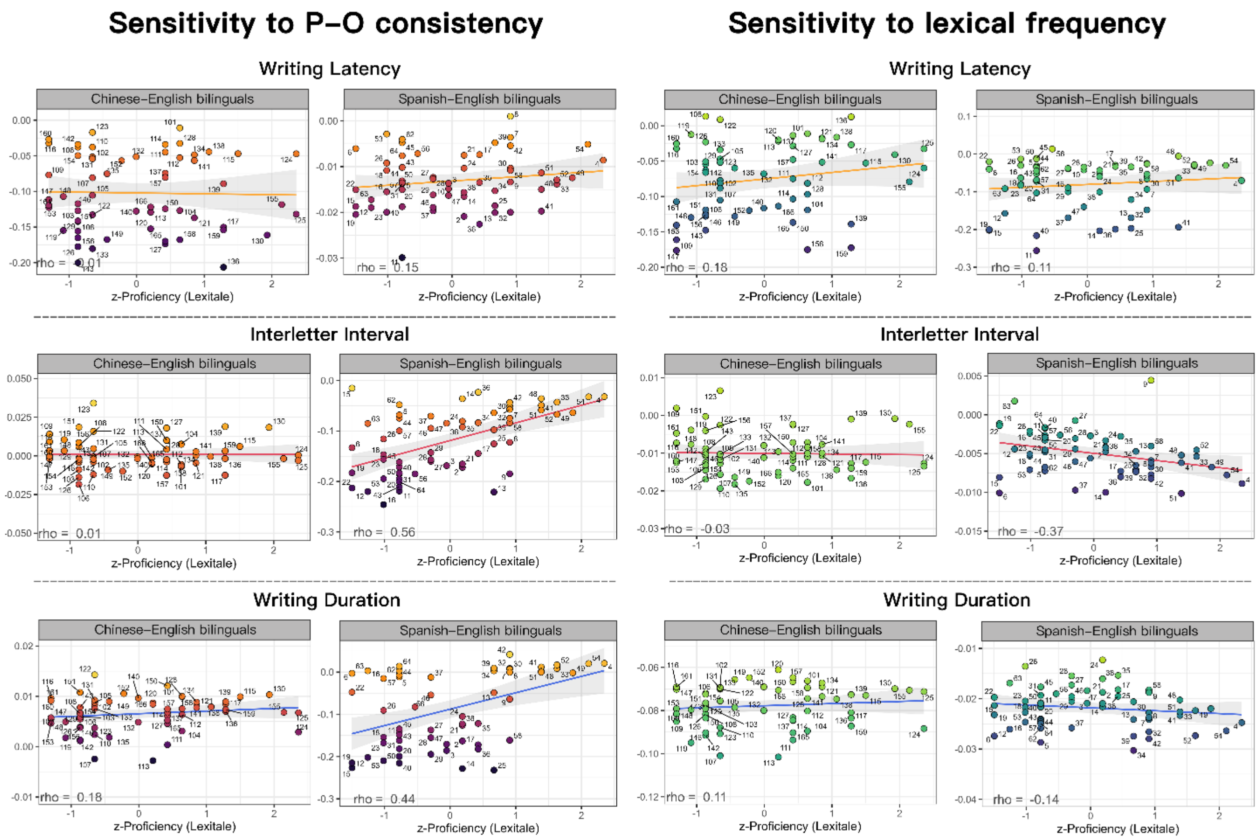


Note. Median posterior estimates of rho are provided in the lower left-hand corner of each plot.

Conversely, in the immediate copying task, as shown in Figure S2, individual posterior medians in response to sensitivity to P-O consistency showed a positive correlation with L2 proficiency, which importantly, was only observed in the Spanish group (interletter interval: rho = 0.56, 95% HDI [0.36, 0.74]; writing duration: rho = 0.44, 95% HDI [0.21, 0.64]). Individuals that reported lower levels of L2 proficiency tended to be more sensitive to the consistency effect during writing execution. In contrast, higher proficient Spanish-English bilinguals were more prone to lexical frequency effect during writing production (interletter interval: rho = -0.37, 95% HDI [-0.61, -0.12]). Also note that no correlation was observed in terms of the central measure.

Figure S2

Immediate Copying Task: Scatter plots of individual posterior medians as a function of standardized P-O consistency and lexical frequency estimates. Values farther away from 0 (darker colors) indicate greater sensitivity to the given effect.



Note. Median posterior estimates of rho are provided in the lower left-hand corner of each plot.

Discussion

In relation to individual differences in L2 proficiency, our findings indicate that the variance of peripheral processes in reliance on the lexical and sublexical routes is modulated by within-group variability in L2 linguistic proficiency. For Chinese-English bilinguals in the spelling-to-dictation task, sensitivity to P-O consistency exhibited a negative correlation with proficiency levels, while in the case of Spanish bilinguals, a positive correlation was observed during the word copying task. In parallel, the influence of lexical frequency on motor execution in the spelling-to-dictation task increased with proficiency for Chinese bilinguals, with a similar pattern observed for Spanish individuals in the immediate copy task. These results corroborate the previous L2 word recognition research (Blumenfeld & Marian, 2007; Giezen et al., 2015; Hamada & Koda, 2008), indicating that proficiency levels contribute to the adjustment and refinement of L2 literacy-related skills to accommodate the orthographic properties specific to the target language. Nevertheless, the observed variation in patterns across tasks and bilingual groups implies that the underlying mechanism of proficiency-driven modulation cannot be deemed as a context- or language-free measure of an individual's susceptibility to lexical and/or sublexical levels of processing.

One possible explanation for the differences in the organization of the writing system of bilinguals is linked to the nature of English orthography in response to specific task demands. Turning to the spelling-to-dictation task, the selection of the English graphemes unavoidably prompts the computation of orthographic codes by means of sublexical conversion procedure, thus activating the corresponding phonemes stored in the phonological output lexicon of the to-be-used language. Consequently, the presence of P-O consistency effect for Spanish-English bilinguals, irrespective of their L2 proficiency, could be associated with a mutual pattern of phonological mediation originating from both Spanish and English orthographies that compete for the selection and execution of graphemes. Unlike the alphabetic structure, Mandarin Chinese is likely the most distant language from English in terms of the letter-to-sound mapping system. In such a perspective, as proficiency increased, the more Chinese bilinguals became sensitive to L2 linguistic features, the better they would be able to allocate sufficient cognitive resources to assemble sublexical units for graphomotor production, resulting in stronger connectivity between L2 proficiency and cascaded functioning. In the immediate copying task, however, the quasi-regular letter-to-sound conversion in the English writing system tends to drive the spelling of words via lexical access and the impact of phonological mediation is rather limited. This would account for no significant correlations observed in the Chinese group in this task, as lexical mappings between orthography and phonology are favored over sublexical ones in both Chinese and English orthography (Seidenberg & McClelland, 1989; Yang et al., 2009; Ziegler & Goswami, 2005). Moreover, it also supports the view that the degree of L2 proficiency shapes the strength of lexical involvement among Spanish-English bilinguals. Should these interpretations hold, a general observation derived from the exploratory analysis suggests that the spelling-motor interaction is affected by the inter-individual variabilities in the L2 language experience. Future investigation may validate the current results either by replicating L2 proficiency in diverse writing contexts or utilizing it as a population-level effect.

Table S1

Summary of the Bayesian correlation analyses (P-O consistency effects in immediate copying and spelling-to-dictation tasks). For each dependent variable, the table provides the median rho estimate, *along with the 95% highest density credible intervals (HDI). Bold typefaces signify a substantial correlation.*

Tasks	Language Groups	Measures	rho	95% HDI
Immediate copying	Chinese-English	Interletter Interval	0.01	[-0.25, 0.27]
		Writing Duration	0.18	[-0.08, 0.43]
		Writing Latency	-0.01	[-0.27, 0.25]
	Spanish-English	Interletter Interval	**0.56**	**[0.36, 0.74]**
		Writing Duration	**0.44**	**[0.21, 0.64]**
		Writing Latency	0.15	[-0.11, 0.4]
Spelling-to-dictation	Chinese-English	Interletter Interval	**-0.71**	**[-0.85, -0.56]**
		Writing Duration	**-0.28**	**[-0.55, -0.01]**
		Writing Latency	0.08	[-0.24, 0.11]
	Spanish-English	Interletter Interval	0.08	[-0.19, 0.34]
		Writing Duration	-0.06	[-0.33, 0.21]
		Writing Latency	0.16	[-0.12, 0.41]

Table S2

Summary of the Bayesian correlation analyses (Lexical frequency effects in immediate copying and spelling-to-dictation tasks). For each dependent variable, the table provides the median rho estimate, along with the 95% highest density credible intervals (HD. Bold typefaces signify a substantial correlation.

Tasks	Language Groups	Measures	rho	95% HDI
Immediate copying	Chinese-English	Interletter Interval	-0.03	[-0.3, 0.23]
		Writing Duration	0.11	[-0.15, 0.36]
		Writing Latency	0.18	[-0.09, 0.42]
	Spanish-English	Interletter Interval	**-0.37**	**[-0.61, -0.12]**
		Writing Duration	-0.14	[-0.39, 0.13]
		Writing Latency	0.11	[-0.16, 0.35]
Spelling-to-dictation	Chinese-English	Interletter Interval	**-0.59**	**[-0.75, -0.39]**
		Writing Duration	-0.17	[-0.43, 0.12]
		Writing Latency	-0.08	[-0.36, 0.2]
	Spanish-English	Interletter Interval	0.12	[-0.16, 0.4]
		Writing Duration	0	[-0.27, 0.27]
		Writing Latency	-0.12	[-0.38, 0.18]

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