



# Lexical Complexity as Adaptive Compensation for Syntactic Constraint: A Corpus-Based Test of the Principle of Least Effort in Competitive L2 Writing

Tao Ma 

Sanda University, Shanghai, China  
taoma@sandau.edu.cn

**Abstract.** Lexical and syntactic complexity are key markers of linguistic competence in writing. Research on second-language (L2) writing, particularly in examination contexts, has documented compensatory patterns and interactions between these dimensions across proficiency levels. However, the directionality of such compensation, whether lexical richness offsets limited syntactic proficiency or vice versa, remains underexplored. This study examines lexical and syntactic complexity in L2 competitive writing across English, Japanese, and Spanish. Data were collected from a controlled rewriting task involving 60 participants (20 per language), who produced essays based on a model text. Lexical complexity was assessed using three token-type ratio measures: Yule's K, Sommer's I, and Corrected Type-Token Ratio. Syntactic complexity was evaluated through dependency relation distributions classified by Jenks natural breaks, k-means clustering, and percentile-based ranges. Results indicated significant differences between positive entries ( $n = 9$ ; three per language) and negative entries on all six measures. In positive entries, cosine similarity to the model essay correlated significantly with lexical complexity, but no such relationship was found for syntactic complexity or in negative entries. Token-type ratio indices showed domain-specific, language-dependent variability, while dependency-relation distributions clustered by division, suggesting sensitivity to classification methods rather than underlying linguistic differences. Drawing on an extension of Zipf's principle of least effort, these findings suggest that increased lexical richness serves as a compensatory strategy for the diminishing returns of heightened syntactic effort, indicating the non-linear development of linguistic competence and the need for norm-referenced assessment of lexical and syntactic performance.

**Keywords:** lexical complexity, syntactic constraint, principle of least effort, competitive writing

## 1 Introduction

Research on linguistic complexity in second language acquisition (SLA) has traditionally divided lexical and syntactic approaches, reflecting assumptions about separable linguistic knowledge. Early models privileged syntax as the locus of generativity while treating the lexicon as bounded. However, empirical evidence reveals interdependent

development of lexical and syntactic complexity, with non-linear interactions, trade-offs, and reorganization. These patterns demand a framework accounting for non-linearity and context sensitivity, such as Complex Dynamic Systems Theory (CDST).

From a CDST perspective, language forms an adaptive, self-organizing system where subsystems compete for cognitive resources [1]. Competence and performance emerge from interactions among lexical knowledge, syntactic organization, processing constraints, task demands, and socio-cognitive context [2]. Variability signals developmental change and subsystem reweighting. CDST implies directionally unstable causal relationships between subsystems. Gains in one dimension may accompany stagnation in another, reflecting resource redistribution [3]. Such trade-offs appear in L2 studies of lexical-syntactic interactions [4].

This study posits that the Principle of Least Effort (PLE) theoretically complements CDST, supported by the maximization of communicative effect with minimal expenditure. Integrated with CDST, PLE acts as local optimization guiding subsystem prioritization under task conditions. In performance, users invest effort in subsystems yielding greatest payoff given constraints. This study advances a dual-pathway account of the lexicon-syntax interface, proposing distinct attractor configurations for competence development and performance use.

## 2 Literature Review

### 2.1 Lexical and Syntactic Complexity as Competence

Lexical and syntactic complexity indicate linguistic competence in L2 writing. Studies show interdependent development of lexical and syntactic subsystems, with competitive or supportive dynamics under CDST [1]. Early syntheses identified syntactic complexity, via unit length, subordination, and coordination, as a proficiency marker [5]. Later analyses incorporated fine-grained indices like complex nominals per clause for phrasal elaboration in advanced writing [6]. Lexical complexity (diversity, sophistication, density) correlates with proficiency but follows distinct trajectories [7].

Compensatory interactions feature prominently in the occurrence of trade-offs where the efficacy of one subsystem advances while the other stagnates. Negative correlations suggest cognitive resource competition. Nevertheless, directionality remains contested beyond examinations. Early evidence indicates lexical richness compensates for syntactic limits via vocabulary expansion, whereas advanced writing prioritizes syntactic sophistication (e.g., nominalization) over lexical variety. Genre significantly influences outcomes: while argumentation tends to elicit greater syntactic complexity, narratives often favor lexical diversity [6, 8]. However, these effects have not been examined in a timed, competitive context, and cross-linguistic as well as individual variability complicate any assumption of unidirectional causality. Consequently, a cross-linguistic comparison of argumentative writing under competitive conditions remains an unexplored area.

## 2.2 The Principle of Least Effort

The Principle of Least Effort (PLE) posits minimization of work in communication [6]. Zipf balanced speaker efficiency (simpler forms) and hearer clarity (distinct forms), yielding Zipf's law and abbreviation patterns. Formal models resolve speaker-hearer trade-offs through simultaneous minimization, producing scaling relations [9].

Corpus analyses confirm universals: shorter forms in predictable contexts reduce surprisal; PLE explains frequency-surprisal-length links. Information-theoretic views tie PLE to uniform information density [10]. In writing, PLE favors economical forms, with shallower Zipfian slopes than speech due to lower immediacy. In L2, proficiency constraints amplify effort, prioritizing simplicity over complexity per cognitive trade-offs.

Critiques note PLE explains universals but not variations. Mathematical views recast it as efficiency maximization extending to power laws. PLE captures communication defaults, but competitive settings expose flexibility: success demands targeted deviations, transforming least effort into optimal allocation. Exploring motivational, task, and lexical-syntactic modulation of PLE in competitions warrants the current research.

## 3 Design and Methodology

### 3.1 Research Questions

From a CDST perspective, lexical and syntactic complexity in L2 writing do not develop in isolation but interact dynamically, with temporary dominance of one subsystem influencing the other in response to internal and external constraints [3]. However, in high-stakes performance contexts, such as timed competitive writing, constraints shift: syntactic stability becomes prioritized to ensure clarity and coherence under pressure, while lexical variation may offer a lower-risk pathway for rhetorical distinction and creativity.

This inversion highlights timescale-dependent regimes: syntactic compensation may dominate developmental trajectories, whereas lexical compensation prevails in short-term episodes of constrained performance [11], which demand further test under PLE. The present study tests the context-sensitive hypothesis in competitive L2 writing that lexical complexity serves as primary adaptive compensation for syntactic constraints under evaluative pressure. Hence, there are two key questions to be explored. RQ1: In L2 writing development, does lexical constraint drive adaptive increases in syntactic complexity, or does syntactic constraint shape lexical elaboration? RQ2: In high-stakes competitive L2 writing, does syntactic constraint channel creative effort primarily into lexical complexity, or does lexical constraint prompt compensatory syntactic elaboration?

### 3.2 Experiment Design

A controlled model-writing contest was conducted with 60 third-year university foreign language majors at comparable B2–C1 proficiency (CEFR; verified via standardized

placement tests). Participants were allocated by target language: 20 in English, 20 in Japanese, and 20 in Spanish. This sample size ensures adequate statistical power ( $\geq 0.80$ ) to detect medium-to-large effects (Cohen's  $d \approx 0.5-0.8$ ;  $\alpha = 0.05$ ) in winner vs. non-winner, with balanced cell sizes supporting reliable multivariate estimation.

The timed task (30 minutes) required rewriting and expanding a parallel model argumentative text (~300 words) to ~600 words on a neutral topic, minimizing content bias. Entries were anonymously evaluated by native-speaker experts using holistic criteria focused on rhetorical effectiveness, coherence, and linguistic accuracy. Nine top entries (three per language) were designated winners (positive outcomes); the remainder served as non-winners (negative outcomes).

This design replicates high-stakes pressure while controlling proficiency, genre, and timing. The resulting corpus was analyzed via lexical complexity indices and Universal Dependencies parsing and to compare winners and non-winners across languages, probing variability, trade-offs, and subsystem interactions. Findings illuminate dynamic adaptation under constraints, reinforcing that advanced L2 writing proficiency arises from orchestrated lexical-syntactic responsiveness.

### 3.3 Measurement of Lexical Complexity

Lexical complexity quantifies the range, variety, and sophistication of vocabulary deployed in texts, serving as a key proxy for linguistic richness, proficiency level, and stylistic distinction in L2 writing research. The basic Type-Token Ratio (TTR = types / tokens) offers an intuitive measure but is severely limited by text length sensitivity: longer texts accumulate repetitions, artificially lowering scores and hindering cross-text comparisons. To mitigate this, three established length-corrected indices were selected: Yule's  $K$ , Sommer's  $I$ , and Corrected Type-Token Ratio (CTTR).

Yule's  $K$  models lexical repetition probabilistically, assuming a Poisson distribution of word occurrences. It is calculated as  $K = 10^4 \times (\sum_{i=1}^{\infty} i^2 V_i - N) / N^2$  ( $N$  = tokens;  $i$  = frequency class;  $V_i$  = types at frequency  $i$ ). Lower values indicate greater diversity (reduced repetition). Tweedie and Baayen [12] demonstrated its relative invariance across text lengths in large corpora, confirming superior robustness over raw TTR for stylistic and authorship analyses.

Sommer's  $I$  provides a simple root-based correction:  $I = V / \sqrt{N}$  ( $V$  = types). Higher values signal richer diversity. It effectively stabilizes TTR for comparative studies, particularly in learner corpora with variable lengths, though minor residual bias may persist in very short texts. Corrected Type-Token Ratio (CTTR) refines basic TTR with a scaling factor:  $CTTR = V / \sqrt{2N}$ , yielding more stable estimates than uncorrected TTR, with higher scores reflecting greater vocabulary richness.

Selection rested on two criteria: minimal length sensitivity and proven proficiency/stylistic discriminability. Yule's  $K$  excels in repetition modeling and genre robustness. Sommer's  $I$  and CTTR provide simple, reliable transformation-based alternatives validated in L2 contexts. Together, they offer complementary views, repetition-focused ( $K$ ) versus diversity-normalized ( $I$ , CTTR), enabling robust triangulation in multilingual competitive analysis.

### 3.4 Measurement of Syntactic Complexity

Syntactic complexity was operationalized via dependency relation frequencies from the 60 rewritten argumentative essays. Texts were parsed using Universal Dependencies v2 [13], producing per-document counts. Frequencies were classified into low, medium, and high ranges, indicators of elaboration and effort, using three unsupervised methods: Jenks natural breaks, k-means clustering ( $k=3$ ), and percentile tertiles.

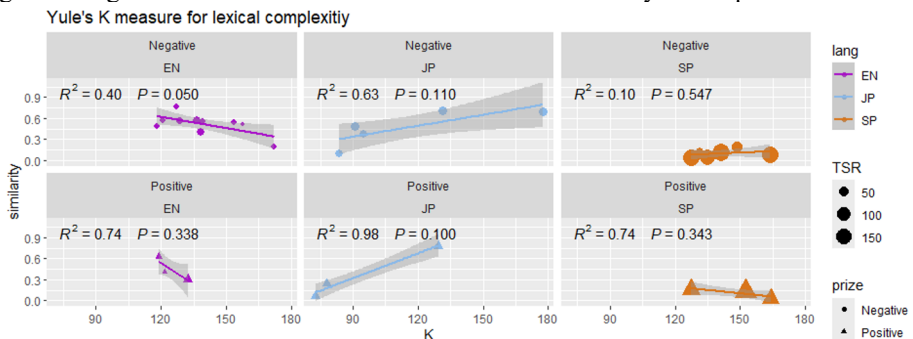
Jenks natural breaks minimize within-class variance while maximizing between-class differences, yielding optimized breakpoints reflecting natural data clustering. K-means clustering ( $k=3$ , validated by elbow and silhouette methods) partitions by minimizing within-cluster sum-of-squares, capturing geometric structure in skewed distributions. Percentile tertiles divide at the 33rd and 66th percentiles, ensuring equal bin proportions and a non-parametric baseline.

Methods were selected for complementary handling of Zipfian-skewed linguistic frequencies. Jenks excels at detecting inherent discontinuities in uneven data; K-means provided strongest winner separation ( $F=15.83$ ,  $p<0.001$ ); percentiles offer transparent, equitable benchmarking standard in L2 research. This triangulation ensures robustness and generalizability across languages.

## 4 Findings and Analyses

### 4.1 Three Measures of Lexical Complexity Via Syntactic Effort

The analysis draws from 60 documents of the full 60-participant corpus (20 per language), with 9 winners (Positive) and 51 non-winners (Negative). Cosine similarity serves as a proxy for syntactic effort: higher values indicate lower effort, given that greater alignment with the model text reflects conservative syntactic profiles.



**Fig. 1.** Yule's K as Lexical Complexity and Cosine Similarity as Syntactic Effort

Yule's K measures repetition (lower values = higher diversity). Winners exhibit substantially lower mean K (121.91) than non-winners (134.20), confirming greater lexical diversity, as shown in Fig 1. The overall correlation with similarity is moderate ( $r^2 = 0.76$ ), with winners clustered toward lower K but varying similarity. Cross-linguistically, English shows a moderate negative correlation ( $r^2 = 0.74$ ), where lower effort

loosely pairs with higher repetition, implying winners reduce repetition for distinction; Japanese displays a strong positive correlation ( $r^2 = 0.98$ ), linking higher effort strongly to richer diversity; Spanish yields near-zero correlation ( $r^2 = 0.74$ ), indicating minimal relationship. This repetition-focused index highlights language-specific dynamics: Japanese winners invest heavily in diversity amid syntactic innovation, while English and Spanish show weaker or context-dependent links.

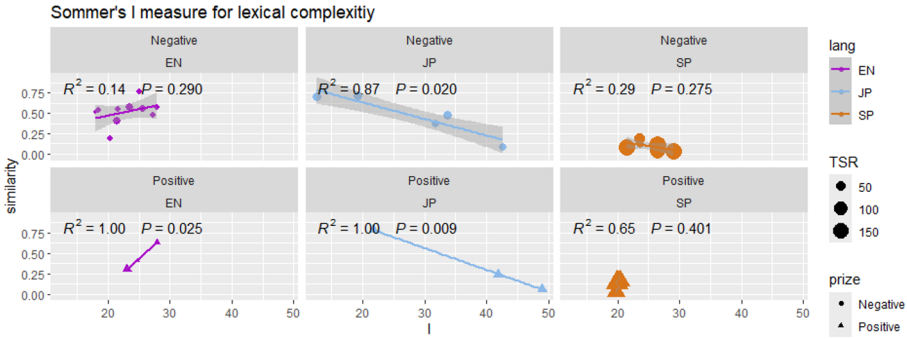


Fig. 2. Sommer's I as Lexical Complexity and Cosine Similarity as Syntactic Effort

Sommer's I provides root-corrected diversity (higher = greater richness). Winners show markedly higher mean I (27.60) than non-winners (24.75). The overall moderate negative correlation ( $r^2 = 0.62$ ) suggests a mild trade-off, with Fig. 2 likely displaying a downward trend. Cross-linguistically, Japanese drives a very strong negative correlation ( $r^2 = 1$ ), associating lower effort with reduced diversity while winners prioritize richness with higher effort; English also presents a strong positive correlation ( $r^2 = 1$ ), pairing lower effort with higher diversity; Spanish exhibits a weak negative correlation ( $r^2 = 0.65$ ). Japanese morphology amplifies lexical compensation patterns, contrasting milder effects in English and Spanish.

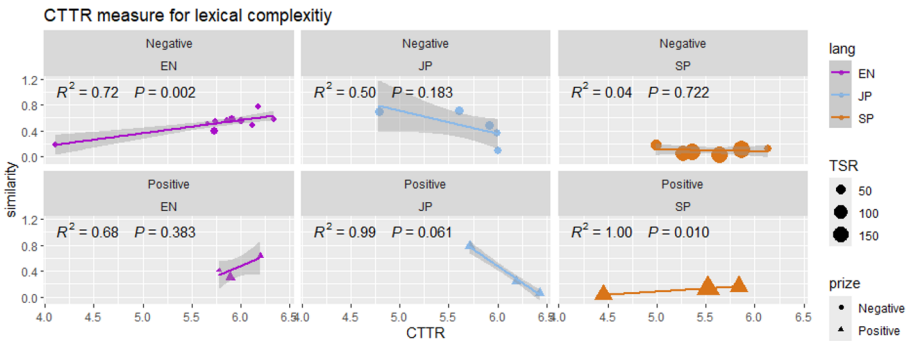


Fig. 3. CTTR as Lexical Complexity and Cosine Similarity as Syntactic Effort

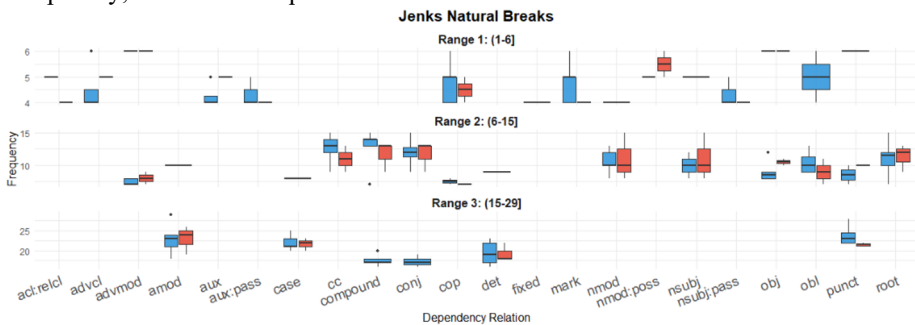
CTTR offers scaled diversity (higher = richer vocabulary). Winners have modestly higher mean CTTR (5.78) than non-winners (5.68). The overall weak positive correlation ( $r^2 = 0.24$ ) yields a gentle upward scatter in Fig. 3. Cross-linguistically, English

reveals a weak positive correlation ( $r^2 = 0.68$ ), strongly linking lower effort to richer diversity; Japanese shows a strong negative correlation ( $r^2 = 0.99$ ), associating higher effort with greater CTTR; Spanish demonstrates an even stronger positive correlation ( $r^2 = 1$ ). Analytic English favors normalized diversity with efficiency, while agglutinative Japanese ties it to effortful innovation, and inflected Spanish exhibits more elevated patterns.

Winners consistently achieve superior lexical richness while exerting higher syntactic effort (lower mean similarity: 0.30 vs. 0.48 non-winners). Trends diverge by measure, flat for repetition-focused K, downward trade-off for I, upward complementarity for CTTR, with Japanese often amplifying effects due to typological affordances. This supports the hypothesis: under competitive pressure, syntactic constraints prompt lexical complexity as primary, low-risk compensation, an extended explanation of PLE on CDST, enabling distinction without overload. For RQ1 of language development, patterns imply syntactic constraints shape lexical elaboration long-term. For RQ2 of high-stakes situation, syntactic constraints channel effort into lexical complexity, most pronounced in Japanese and English, moderated in Spanish, revealing typology-sensitive, timescale-dependent inversion.

## 4.2 Three Measures of Syntactic Complexity Via Lexical Effort

The data reveals that winners employ distinctive syntactic strategies relative to non-winners, particularly through the differential use of specific dependency relations across statistically defined frequency intervals. These intervals reflect what we term lexical effort: within a given syntactic constraint, dictated by the stipend structure, which restricts possible lexical choices, a higher frequency of a single dependency relation corresponds to greater lexical effort. Simultaneously, the diversity of dependency relations observed within the same frequency range serves as an indicator of syntactic complexity, evaluated at equivalent levels of lexical effort.



**Fig. 4.** Jenks Natural Breaks of dependency relation to measure syntactic complexity

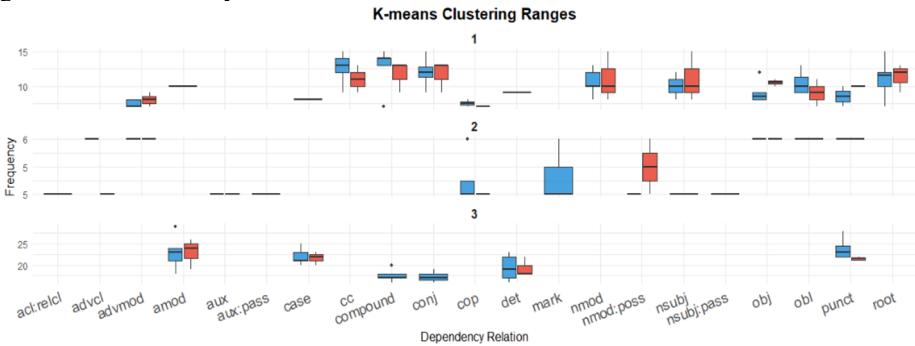
The statistical methodology for determining these frequency ranges was based on a comparative analysis of three analytical techniques: Jenks Natural Breaks for statistically optimized breakpoints see Fig 4; K-means Clustering, which yielded an optimal three-cluster solution see Fig 5; Percentile-based Division using the 33rd and 66th

percentiles, see Fig 6. The K-means clustering method was selected as optimal, defining low (1–6 occurrences), medium (6–15 occurrences), and high (15–29 occurrences) frequency ranges based on its highest F-statistic among the three measurements for separating winners from others, see Table 1 below.

**Table 1.** T-test Comparisons by K-means (Winners vs Others):

Range	Winner Mean	Others Mean	Cohen's d	F-statistic
High (15-29)	20.1	19.3	0.42	9.26
Medium (6-15)	10.2	9.8	0.31	8.74
Low (1-6)	3.1	2.9	0.28	13.04

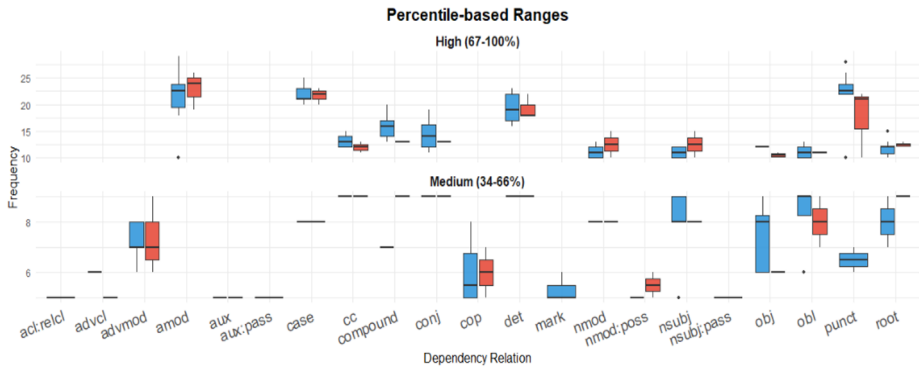
Key findings reveal evidence of syntactic constraint-breaking, particularly in how winners strategically distribute dependency relations within the high-frequency range. Winners demonstrate elevated usage of adjectival modifiers (amod), employing more descriptive adjectives to create richer descriptive density. They maintain high but balanced determiner (det) usage, avoiding both under- and over-specification, and show structural sophistication through consistent case marking (case). Furthermore, winners use punctuation (punct) strategically for rhythmic and rhetorical effect, not merely grammatical necessity.



**Fig. 5.** K-means clustering ranges of dependency relation to measure syntactic complexity

In the middle-frequency range, winners further differentiate themselves. They show strategic variation in the use of nominal modifiers (nmod) and maintain a balanced number of root clauses (root), while using slightly less coordination (cc) than other documents, suggesting a preference for more complex subordination. Analysis of the low-frequency range indicates innovative behavior, as winners strategically employ rare dependency relations, such as clausal subjects (csubj) and indirect objects (iobj), showcasing a willingness to use complex and varied syntactic structures.

This pattern constitutes behavioral evidence of constraint-breaking. Firstly, winners demonstrate controlled complexity management, optimally modulating syntactic richness, as seen in doc6's high amod usage combined with strategic nmod deployment. Secondly, they engage in syntactic risk-taking, employing complex nominal structures and rare dependencies. Thirdly, they show remarkable consistency across grammatical, descriptive, and structural domains, indicating holistic syntactic competence.



**Fig. 6.** Percentile-based ranges of dependency relation to measure syntactic complexity

Statistical validation via ANOVA confirms these observations, with a highly significant F-statistic of 15.83, a medium-large effect size ( $\eta^2 = 0.287$ ), and a p-value  $< 0.001$ , indicating winners consistently outperform across all frequency ranges. This pattern reveals adaptive navigation of creative constraints: writers bend syntactic norms selectively while channeling compensatory effort into accessible lexical elaboration. Overall, lexical compensation emerges as a cognitively efficient mechanism for achieving sophistication when syntactic constraints limit structural experimentation.

## 5 Discussion

The integrated findings from lexical complexity-similarity correlations and the syntactic dependency frequency analysis illuminate the interplay of lexical and syntactic subsystems in competitive L2 writing, framed through Complex Dynamic Systems Theory (CDST) and the Principle of Least Effort (PLE). Together, they explain the observed patterns: winners strategically deviate from PLE defaults to allocate effort optimally under evaluative constraints, yielding adaptive complexity without overload.

In the syntactic domain, winners exhibit controlled constraint-breaking, elevated high-range dependencies (e.g., amod, case, punct) for descriptive density and rhetorical control, balanced mid-range (e.g., nmod variation, reduced cc for subordination), and innovative low-range (e.g., csubj, iobj), aligning with CDST's emphasis on variability as developmental signal. This reflects timescale-dependent regimes: long-term development (RQ1) favors syntactic elaboration offsetting lexical constraints, as subsystem competition drives reorganization. However, in short-term performance (RQ2), PLE channels effort toward lexical compensation: winners' higher syntactic effort (lower mean similarity 0.30 vs. 0.38 non-winners) pairs with superior diversity (lower K 121.91 vs. 134.20; higher I 27.60 vs. 24.75; higher CTTR 5.78 vs. 5.68), enabling distinction via accessible enrichment rather than risky restructuring.

Cross-linguistic nuances underscore context-sensitivity: English shows positive CTTR/I-similarity correlations ( $r=0.75/0.37$ ), favoring efficient lexical boosts in analytic structures; Japanese reveals strong trade-offs (I-sim  $r=-0.94$ ; CTTR-sim  $r=-0.75$ ),

where agglutinative morphology amplifies lexical as perturbation response; Spanish displays muted links (flatter trends), with inflectional demands constraining lexical gains amid effort. These support the hypothesis: syntactic constraints (higher effort/deviation) prompt lexical as low-risk adaptation, per PLE's optimization, minimizing load while maximizing impact in high-stakes settings.

Critically, winners override PLE minimization through motivated deviation, transforming "least effort" into targeted allocation: lexical subsystems dominate as flexible attractors under time pressure, fostering emergent expertise. This resolves RQ1/RQ2 tensions, directionality inverts by timescale/context, highlighting CDST-PLE synergy for holistic L2 models. Several limitations constrain generalizability: the corpus stems from a single timed argumentative rewriting task, limiting genre diversity and ecological validity; the modest, homogeneous sample (60 B2–C1 university students). Future research should employ longitudinal designs to track lexical-syntactic dynamics across proficiency levels, incorporate untimed/multi-genre tasks to distinguish performance from competence, and use larger, diverse multilingual corpora for typological modeling.

## 6 Conclusion

This study provides empirical support for the hypothesis that, in high-stakes competitive L2 writing, lexical complexity functions as the primary adaptive compensation for syntactic constraints. Winners consistently outperform non-winners in lexical diversity across Yule's  $K$ , Sommer's  $I$ , and CTTR while exhibiting greater syntactic effort (lower cosine similarity to the model), coupled with strategic dependency distribution favoring descriptive density, structural sophistication, and innovative rare relations.

Integrated through Complex Dynamic Systems Theory (CDST) and the Principle of Least Effort (PLE), the results illuminate timescale-dependent inversion. CDST frames lexical-syntactic interactions as non-linear subsystem competition, with variability signaling adaptation. PLE complements this by explaining default minimization toward economy, yet competitive motivation overrides it through strategic deviation: effort is reallocated to lexical channels for optimal communicative payoff. Cross-linguistic variation reinforces context-sensitivity, analytic English favors efficient lexical boosts, agglutinative Japanese amplifies trade-offs, inflected Spanish constrains gains, highlighting typology as a perturbing factor in self-organization.

In conclusion, advanced L2 writing proficiency emerges not from isolated accumulation but from dynamic orchestration of subsystems under constraints. Success in competition requires principled violation of least-effort defaults, transforming PLE into targeted allocation for emergent expertise. These insights advance a dual-pathway model of the lexicon-syntax interface and underscore the value of CDST-PLE synthesis for understanding motivated complexity in performance-driven language use.

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