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Understanding online revisions in L2 writing: A computer keystroke-log perspective

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ABSTRACT

Revising, as a fundamental component process of written text production, has drawn extensive research attention in second language (L2) writing. While most studies examined revisions through sociolinguistic categories to understand how revisions cognitively load on L2 writers, further studies need to quantify the cognitive deployment of attentional resources during revising. Using Inputlog6.0, this study investigated the online revisions of 57 Chinese EFL writers at the more- and less-skilled writing levels. Online revisions were first divided into immediate, distant and end revisions according to their temporospatial locations, and then examined in terms of frequency, scope, duration, distance and in relation to the final text quality. Data analysis revealed that less-skilled L2 writers revised more frequently but on smaller scopes in immediate and distant revisions, while more-skilled L2 writers revised more frequently and on larger scopes in end revisions. The text quality correlated negatively with the frequencies of immediate and distant revisions, yet positively with the scopes of all three types of online revisions and with all four dimensions of end revisions. These findings suggest that, while writing is a recursive process when different component processes interact, L2 writers benefit from a focused production process scaffolded by in-depth and extensive revising processes.

1. Introduction

Writing has been recognized as a complex cognitive process, during which various sub-processes, i.e., planning, translating/formulating and revising (Hayes, 2012; Hayes & Flower, 1980; Roca de Larios, Manchón, & Murphy, 2006; Xu, 2017), cognitively load on the writer's working memory and consequently affect the written product emerging from these sub-processes. The Kellogg (1996) working memory model of writing posits that written language production draws on a single, limited pool of attentional resources, with different writing processes competing for attentional resources under the constraints of a central executive. Shall the attentional resources be exceeded, some processes of writing would be suspended or sacrificed to accommodate the immediate call for other processes (DeKeyser, 2001; Roca de Larios et al., 2006), giving rise to process alternation, suspension or termination during writing.

Revising is a process when text production is suspended or terminated for the reflection and/or transformation of the produced text (Van den Bergh, Rijlaarsdam, & Breetvelt, 1994). It signals the interaction and alternation of component writing processes and consequently, the allocation of attentional resources during writing. Research into revising thus promises insights into L2 writers' management of their writing processes and how effective such process management turns out in

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their final texts. As “learning to revise is essential for learning to improve one's writing” (Beach, 1992, p. vii), understanding revising is pedagogically crucial for the creation and development of quality writing.

A number of studies have investigated L2 online revisions in pen-and-paper writing settings through think-aloud protocols, video-recordings or post-task interviews. These studies, by comparing L2 writing against L1 writing or focusing on L2 writing, promote knowledge of L2 online revisions regarding whether L2 writers' attention to local issues would impede that to global ones and whether L2 writing proficiency affects what writers attend to revise (Chenoweth & Hayes, 2001; Roca de Larios, Marín, & Murphy, 2001; Roca de Larios, Manchón, & Marín, 2008). This sociolinguistic categorization of online revisions also sheds light on how revisions of different categories cognitively load on L2 writers' attentional resources (Dix, 2006; Kobayashi & Rinnert, 2001). However, the connection between revision categories and their cognitive load on working memory needs to be fine-grained for precision, and some observations from case studies need to be confirmed with enlarged samples.

With computer rising to be the main medium for academic writing, the concepts of drafting and revising have changed in the word processor. As writers are now able to produce a clean text while revising at anytime and anywhere during its production, revising in computer keyboard settings expects to witness new features against those observed in pen-and-paper settings and thus calls for new research efforts (Barkaoui, 2016; Dave & Russell, 2010; Gánem-Gutiérrez & Gilmore, 2018). The development of computer keystroke logging programs also promises fine-grained and large-scaled investigation into the writing process (Abdel Latif, 2008; Leijten & Van Waes, 2013; Xu & Qi, 2017). Consequently, revision studies have moved onto the more dynamic aspects of writing, i.e., revision point and revision duration, to denote how the revising process interacts and intervenes with the production process (Barkaoui, 2016; Gánem-Gutiérrez & Gilmore, 2018; Stevenson, Schoonen, & de Glopper, 2006). Along this line, the revision taxonomy should integrate revision distance and revision duration to denote how far an L2 writer's focal attention is moved away from the production point and how a revising event temporally loads on the working memory. Meanwhile, as computer logging programs help record and sort different writing activities automatically at high levels of accuracy, enlarged samples could be accommodated in online revision studies to better understand L2 writing processes.

Of particular interest to this study was how differently more- and less-skilled L2 writers manage their online revisions in computer keyboard writing settings. With a fine-grained revision taxonomy enabled by Inputlog6.0 (Leijten & Van Waes, 2013), this study contributed to the literature by examining L2 writers' online revisions in continuums of frequency, scope, distance and duration at the more- and less-skilled writing levels, and how these online revisions related to the final text quality.

2. Related studies

2.1. L2 writing proficiency and online revisions

Many studies investigated how language proficiency affected the revising process by comparing writing in L2 against that in L1 under the assumption that L2 writers would experience more frequent lack of language proficiency. With scope and frequency being the major dimensions for online revisions, writers were found to revise more frequently in L2 than in L1 (Chenoweth & Hayes, 2001; Roca de Larios et al., 2006). Compared with L1 writing, L2 writing observed more frequent revisions on small scopes, i.e., more revisions at the linguistic level than at the discourse level (Chenoweth & Hayes, 2001; Stevenson et al., 2006; Thorson, 2000), leading to the inhibition hypothesis that attention to low-level revisions would impede attention to high-level ones in L2 writing (see Stevenson et al., 2006).

L2 writing researchers, mainly through case studies, strived to explore what specifically affected the L2 revising process, with L2 writing proficiency being repeatedly identified as an important predictor for revising behaviors. Zamel (1983), through the observation and interview of six advanced ESL students, found that while skilled L2 writers deferred lexical and grammatical revisions until the final stages of the composition process, the unskilled L2 writer “was distracted by local problems from the very beginning (p. 174)” and revised words or phrases that barely affected meaning. Similarly, Broekkamp and van den Bergh (1996) argued that low L2 proficiency could induce a heavy linguistic processing load on the working memory, which consequently affected what, when and how frequently L2 writers chose to revise during production. By examining the episode frequency and duration of L2 writing processes, Gánem-Gutiérrez and Gilmore (2018) also reported a significant effect of L2 proficiency on the episode frequency of different writing processes and that more-proficient students allocated higher percentages of their writing episodes to revising than did their less-proficient peers.

Different from previous findings on how L2 writing proficiency affected L2 revising strategies and consequently L2 revising activities, Chenoweth and Hayes (2001) found, in a study on writing fluency in L1 and L2, that more proficient L2 writers (learning an L2 for the fifth/sixth semester) did not revise much as less proficient L2 writers (learning the L2 for the third semester). The researchers reasoned that proficient L2 writers produced more linguistically correct texts that virtually required less revisions. However, Roca de Larios et al. (2001, 2006) reported that increased L2 proficiency led to more revisions by examining the temporal distribution of the L1 and L2 formulation processes through think-aloud protocols. Much of the revision effort was found to focus more on discovering better meaning-form matches than compensating for lack of language proficiency, suggesting a linguistic concern beyond grammatical correctness for the more proficient L2 writers. In addition, Roca de Larios et al. (2008), in a study on EFL writers' strategic allocation of writing time, found that increased L2 proficiency was observed with increased time investment in the revising process and other writing processes than the

formulation process, further suggesting the strategic allocation of more time to online revisions among more proficient L2 writers. Thus, more studies are in need to understand the relationship between L2 proficiency and L2 revising processes for possible pedagogical interventions for L2 writers at different proficiency levels.

As previous studies suggest timing could be an important dimension to distinguish online revisions for L2 writers at different proficiency levels (Roca de Larios et al., 2006; Van Waes & Schellens, 2003), more recent studies probe into the temporal dimension of revising through computer logging programs. With computer logging files denoting the writing process with great detail, revisions are further examined according to the revision point against the production point, with the revision point either overlapping or being away from the production point (Barkaoui, 2016; Stevenson et al., 2006; Thorson, 2000). Despite different terminologies in these studies, timing is an essential underlying criterion for such revision categorization, be it before, immediately after or some time after the transcription of ideas.

Along this line, Thorson (2000), through keystroke-logging and video-recordings, defined online revision as intermediate revisions and distant revisions, i.e., with or without distance of letters between the cursor of production and the revision point. The study reported that while L2 writing witnessed proportionately more revisions than L1 writing, L1 and L2 writing did not differ significantly in the ratio of distant revisions against total revisions, showing that language proficiency did not alter the interactive nature of writing. Using thinking-aloud protocols and keystroke-logging, Stevenson et al. (2006) examined online revisions through a multi-dimensional revision taxonomy and found that while L2 writing generally displayed more revisions than L1 writing, there was little evidence for the inhibition of low-level revisions on high-level ones in L2 writing. Barkaoui (2016), in a cross-sectional study of the effects of L2 proficiency, computer experience and writing task on the revising process, classified online revisions into pre-contextual and contextual revisions on basis of whether the revision point overlapped with the production point. The study found that while L2 writers generally revised more on form than on content, L2 proficiency affected how L2 writers attended to different revisions in timed writing tasks and that less-skilled L2 writers made more pre-contextual revisions at the production point. As the dichotomy of the revising point encodes rather limited information about how revising intervenes with production, the revision taxonomy in computer-aided writing should be enriched to settle the inhibition controversies over the high- and low-level revisions in L2 writing.

2.2. Revision taxonomies

2.2.1. Revision taxonomies developed from pen-and-paper writing

Informed by revision studies in pen-and-paper settings, online revisions also investigated revision frequency and revision scope in computer keyboard writing (Barkaoui, 2016; Lindgren & Sullivan, 2006). Revision scope, often examined in conjunction with revision frequency, denotes the aspects or scales of revisions from the sociocultural perspective, i.e., form/meaning preserving/meaning changing revisions (New, 1999; Van Waes & Schellens, 2003), local/global/discourse revisions (Kobayashi and Rinnert; 2001; Liang, 2010), content/organization/form revisions (Barkaoui, 2016; Stevenson et al., 2006), or from the sociolinguistic perspective, i.e., revisions at lexical, phrasal and clausal levels (Barkaoui, 2016; Van Waes & Schellens, 2003). Revision frequency, usually examined together with revision scope, denotes how often a particular aspect of writing is foregrounded in a writer's mind during revising and how often revising intervenes with production (Barkaoui, 2016; Dave & Russell, 2010).

Behind the research efforts into revision scope and frequency is an ongoing quest to cognitively quantify on what scope and how often L2 writers choose to revise for a better understanding of their management of attentional resources during writing and how this management affects the final text quality. However, previous findings on online revisions are rather mixed from the cognitive perspective. Some reported that L2 writers revised most frequently at the local level, with few revisions on the global level that affected the text meaning, suggesting a competition of attentional resources between local and global issues during revising (Barkaoui, 2016; Chenoweth & Hayes, 2001; Dave & Russell, 2010). Other studies, by comparing revisions in L1 and L2, found that although L2 writers revised more frequently at the linguistic level, there was no evidence for the inhibition of low-level revisions on higher-level ones in L2 writing and that emphases on local revisions did not impede the fluent development of ideas in L2 writing (Lindgren & Sullivan, 2006; Spelman Miller, Lindgren, & Sullivan, 2008; Stevenson et al., 2006). Furthermore, although increased L2 writing proficiency was identified with more fluent writing characterized by less revisions (Chenoweth & Hayes, 2001), disputes remained over how revision frequency was related to the final text quality. Recent studies suggested that revision frequency had little bearings on L2 text quality (Spelman Miller et al., 2008; Stevenson et al., 2006), but previous studies in pen-and-paper settings showed that good L2 writings witnessed less revisions during its production (Chenoweth & Hayes, 2001; Whalen & Ménard, 1995).

One reason for the mixed findings on revision scope and revision frequency could be the discrete measurement of revisions in categories instead of depicting revisions in continuums of various dimensions. On the one hand, the categorical measurement of revisions helps understand the revising act in the sociolinguistic framework regarding how writing is constructed and revised as calibrated by different linguistic units or changes at local versus global levels; on the other, it leaves the cognitive load of each revising event on the working memory to rough estimation that the consumption of attentional resources increases when revision scope climbs up categorically along the linguistic units or from local to global

issues. As "revisions made to long stretches of text can be considered to be revisions made at a higher level than revisions made to words" (Stevenson et al., 2006, p. 205), it is possible, by measuring revision scope in continuum of letters, to understand more precisely on what scope each revision affects the text and what level of issues L2 writers attend to revise. The numerical measurement of revision scope in letters shall help quantify the attentional resource each revision takes up to better understand the revising process under the working memory model of writing.

2.2.2. Revision taxonomies emerging from computer-aided writing

With the advent of computer keyboard writing, a temporospatial dimension of online revisions, i.e., the revision point against the production point, has been hierarchically integrated with revision frequency and revision scope to better denote the revising process (Barkaoui, 2016; Lindgren & Sullivan, 2006; Stevenson et al., 2006; Thorson, 2000). As the point of revision signals whether the writer's focal attention being shifted, both temporally and spatially, away from the ongoing text production, these studies well inform L2 writing teachers and researchers of what concerns are foregrounded in L2 writers during their acts of revising. Nevertheless, the dichotomy of the revision points does not quantify how far a revision point is away from the production point, i.e., revision distance, which is essential to understand how much of the produced text that an L2 writer attempts to accommodate in a revising act. With keystroke logging programs, revision distance becomes more discernible in computer keyboard writing settings and thus promises more fine-grained measurement of the revising process.

In addition, previous studies showed that increased L2 proficiency tended to defer linguistic revisions to later stages of writing (Zamel, 1983) and pre-contextual revisions occurred most in early stages of the writing while contextual revisions happened much later (Barkaoui, 2016). Therefore, L2 writing proficiency could affect at what temporal stages attentional resources would be spared for different revising activities. As revising under the pressure of further text production could load quite differently on the working memory from revising after the main text production, the dichotomy of revising points should be expanded to distinguish distant revisions for the accommodation of such differences. To further denote how L2 writers would prioritize their revising concerns at different stages of writing under Hayes and Flower's model of writing processes (1980), this study proposed end revision to denote the revising efforts following the completion of the main text. Thus, distant revision and end revision differed in whether further text production would follow the revising event, with distant revision being followed by further text production while end revision being not. Incorporating the revision taxonomies from previous studies (Barkaoui, 2016; Thorson, 2000), this study thus sorted online revisions into three types, i.e., immediate, distant and end revisions.

Duration is another dynamic dimension of online revision that depicts the degree of effort investment from the temporal perspective. A number of studies examined revision duration through verbal protocols or video-recorded writing sessions (Olive, Kellogg, & Piolat, 2001; Roca de Larios et al., 2006; 2008). However, these studies focused on the temporal distribution of different writing processes, with only brief reference to the revising process and much less about how different revisions loaded on the working memory from the temporal perspective. As revision duration could better inform the field about how L2 writers managed their revision efforts temporally and hence their allocation of attentional resources during revising, it should well be integrated into the existing revision taxonomy.

2.3. Unsettled issues and the current approach

To sum up, several issues need further research attention in L2 revision studies. First, the rise of computer as a widespread writing medium has ushered in new features in the revising process and consequently fine-grained measures of online revisions are in need to depict the revising process in multi-dimensions and with great detail. Second, while previous studies contribute profoundly to the understanding of revising in L2 writing, it remains unclear how L2 writers at different skill levels manage online revisions and how this revision management relates to the final text quality. Third, as previous studies provide collective understandings of online revisions through different revision dimensions across different groups of participants, it would help advance the knowledge of L2 writing if more dynamic dimensions of online revisions can be examined in conjunction and within the same group of participants (Wollscheid, Sjaastad, & Tømte, 2016).

To gain further understanding of the revising process in L2 writing, this study employed Inputlog6.0 to log and analyze how more- and less-skilled L2 writers differed in online revisions in computer keyboard writing settings. Online revisions were divided into immediate, distant and end revisions and each type was examined in continuums of frequency, scope, distance and duration and in how online revisions related to the final text quality. Specifically, the study addressed the following questions:

1. Do more- and less-skilled L2 writers differ in immediate, distant and end revisions in terms of frequency, scope, distance and duration?[1]
2. How do online revisions relate to the final text quality in L2 writing?

[1] As immediate revisions virtually happened within one or 2 s at the point of text production, only frequency and scope were considered for immediate revisions.

3. Methodology

3.1. Participants

This study was conducted among a pool of 106 Chinese EFL learners at a Chinese university in 2015. The participants were assigned into four English classes according to the alphabetical order of their Chinese names. They had 4 h of English per week and had the same English teachers and English teaching materials since their entry into college. Data were collected during their sophomore year, when they aged between 18 and 20 and had learned English in the Chinese context for 7–12 years. They were roughly of intermediate and upper-intermediate levels, or B1 and B2 as described in *Common European Framework of Reference for Languages: Learning, Teaching, Assessment* (Council of Europe, 2011). Six students from Tibet and four from Taiwan were excluded for large variation in their English education background, and four were absent from class during data collection. Therefore, 92 students were initially included for data screening.

The 92 students were ranked according their final writing scores (see *Scoring of student writings*). The participants for this study were selected from the high and low ends of the student pool. Those who ranked the top 30 formed the more-skilled group and those who ranked the bottom 30 formed the less-skilled group. Due to ties in writing scores around the demarcation lines, three more students were dropped to ensure the necessary gap in their writing skill levels. Eventually, there were 28 students in the more-skilled group and 29 in the less-skilled group. Table 1 provides an overview of the two groups, showing that the two groups, with similar years of English learning and ages, differed significantly in their English writing skills.

3.2. Writing task

Data were collected during the 5th week in the fall semester of 2015. Inputlog6.0 was installed on each computer in the computer lab where participants regularly attended their advanced English course. To prime the students for the study, one summary and one narration were completed in the computer lab using Inputlog6.0. One week before data collection, the students had one class reading and discussing a model argumentative essay to get familiar with the genre of argumentation.

During the week of data collection, the teacher first provided a 20-min mini-lecture to review the essential academic elements for argumentation from the last class. Then, the teacher briefed the students on a recent drunk driving case, which resulted in two immediate deaths and one serious injury. The news was widely covered by local media, arousing much social concern and discussion over drunk driving. Students were then asked to develop a complete piece of argumentation on *whether drunk drivers should be imprisoned on their first offense.* As the timed writing task was of 30 min in College English Test, Band 4 (CET4, a nationwide college English proficiency test in China), students in this study were asked to finish the task by taking as much in-class time as necessary, roughly up to 70 min before class was over. To better track the writing process through keystroke logging, students were notified not to draft on paper or elsewhere other than on the computer. Independent samples t-tests were run on the eventual task time and text lengths of the two groups, and Table 2 presents the results.

3.3. Coding scheme

3.3.1. Revision types

Integrating previous revision taxonomies (Barkaoui, 2016; Stevenson et al., 2006; Thorson, 2000), this study, on basis of the temporospatial location of the revising event, divided online revisions into three types, i.e., immediate revision, distant revision and end revision.

Immediate revision was defined as a revising event in which "the distance between the position of the cursor and that of the revision was zero" (Thorson, 2000, p. 160). Therefore, for immediate revision, the point of revision inscription overlapped with the point of text production.

Distant revision referred to a revising event in which the point of revision inscription was distant from the point of text production, as shown by the cursor position being moved away from the production point for the revising event. In addition, there was further text production following a distant revision.

End revision was a revising event following the completion of the main text, in which the writer reviewed and revised the produced text. It was operationalized as the last distant revision(s) whose termination was not followed by further production at the end of the text.

Table 1
Group statistics on learning experience, age and writing skill.

	More-skilled (n = 28)		Less-skilled (n = 29)				
	Mean	SD	Mean	SD	*t*	*p*	*Cohen's d*
Years of English learning	10.46	1.84	9.79	2.08	1.29	.20	.34
Age (years)	18.90	.66	18.97	.57	−.23	.82	.11
Writing skill (text score)	11.68	.98	6.38	1.13	18.89	.00[a]	5.01

[a] Significant at the .01 level (2-tailed).

Table 2
Overview of task time and text length.

	More-skilled (n = 28)		Less-skilled (n = 29)				
	Mean	SD	Mean	SD	*t*	*p*	*Cohen's d*
Task time (minutes)	44.12	5.42	44.55	4.87	−.32	.75	.08
Text length (words)	217.25	27.71	189.59	35.31	3.28	.00[a]	.87

[a] Significant at the .01 level (2-tailed).

3.3.2. Revision measures

Online revisions were analyzed in terms of ***frequency***, ***scope***, ***distance*** and ***duration***. The raw frequency of revisions was standardized into frequency of a 60-min task to correct for differences in task time: ***standardized frequency*** = raw frequency/task time (seconds)*3600 (seconds). ***Scope*** referred to the sum of letters deleted and produced for each distant or end revision. For immediate revision, scope referred to the number of letters deleted, as the revision point overlapped with the production point in immediate revision. ***Distance*** referred to the number of letters that the cursor moved from the production point to the revising point and ***duration*** was operationalized as the number of seconds a revising event lasted. As immediate revision happened within one or 2 s at the production point, only frequency and scope were considered for immediate revision.

Though revision scope and duration may naturally correlate with each other in that revisions of larger scopes generally consume more time than revisions of small scopes, there could be occasions in which some revision operations like block deletion could happen over seconds but affect the text on large scopes. Therefore, both scope and duration were examined with frequency and distance to multi-dimensionally denote a revising event.

As Inputlog6.0 logged the writing processes at the millisecond level, a writing task of about 40 min would typically produce a log file of 4000–6000 operation items (see Appendix I for an excerpt). To mass process the writing data collected by Inputlog6.0, a computer script was developed with above definitions of online revisions to automate the analyses of frequency, scope, distance and duration of immediate, distant and end revisions in each logged writing event.

3.3.3. Scoring of student writings

Student writings were rated using a holistic rating rubric, which measured a text from three aspects, i.e., organization, content, and language (see Appendix II). The rubric, with a score range of 0–15, was adapted from that of CET4. Two experienced EFL teachers rated student writings separately. Neither rater taught any of the students before or during data collection and both had scored CET4 writings over 10 times, with more extensive experiences in English testing and scoring in classroom settings. All writings were numerically coded to remove student identities before rating and a writing would be returned to both raters for rescoring if the score discrepancy exceeded three points.

The inter-rater reliability was checked using Pearson correlation coefficients. The initial reliability was $r(92) = 0.82$ ($p = .00$) and it reached $r(92) = 0.91$ ($p = .00$) after the rescoring to remove score discrepancy over three points. The mean score of the two raters was used as the final score for each writing for grouping and data analyses.

3.4. Statistical analysis

Using SPSS19.0, the multivariate analysis of variance (MANOVA) was run on immediate, distant and end revisions across the more- and less-skilled groups to examine whether L2 writing skill significantly affected online revisions in written text composition. The significance level was set at 0.05 (2-tailed) and partial η^2 was reported for the effect size of the group difference. Pearson correlation coefficients were computed to examine if the final text quality correlated with different types of online revisions.

4. Results

4.1. Writing skills and online revisions

4.1.1. Immediate revisions

Table 3 reports the descriptive data of immediate revisions. A one-way MANOVA was run to examine the effect of L2 writing skill on frequency and scope of immediate revisions. The results suggest a statistically significant effect of L2 writing skill on immediate revisions, ($F(2, 54) = 5.34$, $p < .01$; Wilk's $\Lambda = 0.84$, partial $\eta^2 = 0.17$). Follow-up univariate ANOVAs show that L2 writing skill had significant effects on frequency ($F(1, 55) = 5.76$, $p = .02$, partial $\eta^2 = 0.10$) and scope ($F(1, 55) = 5.77$, $p = .02$, partial $\eta^2 = 0.10$) of immediate revisions. While both groups displayed frequent and small-scoped immediate revisions, the more-skilled group revised less frequently but on larger scopes than did the less-skilled group.

4.1.2. Distant revisions

Table 4 summarizes the descriptive data on the four dimensions of distant revisions. The one-way MANOVA test results reveal a statistically significant effect of L2 writing skill on distant revisions ($F(4, 52) = 5.14$, $p < .01$; Wilk's $\Lambda = 0.72$, partial

Table 3
Descriptive statistics for immediate revisions.

	More-skilled (n = 28)		Less-skilled (n = 29)	
	Mean	SD	Mean	SD
Frequency	54.61	22.52	76.07	41.80
Scope (letters)	3.52	1.02	2.94	.79

Table 4
Descriptive statistics for distant revisions.

	More-skilled (n = 28)		Less-skilled (n = 29)	
	Mean	SD	Mean	SD
Frequency	9.00	3.12	11.69	4.86
Scope (letters)	58.42	53.14	21.45	21.63
Distance (letters)	89.07	45.77	71.26	51.92
Duration (seconds)	79.36	73.94	42.80	42.20

$\eta^2 = 0.28$). Follow-up univariate ANOVAs further show that, compared with the less-skilled group, the more-skilled group made less frequent distant revisions (Frequency: $F(1, 55) = 6.13$, $p = .02$, partial $\eta^2 = 0.10$), but revised on significantly larger scopes (Scope: $F(1, 55) = 11.99$, $p = .00$, partial $\eta^2 = 0.18$) and spent significantly more time (Duration: $F(1, 55) = 5.30$, $p = .03$, partial $\eta^2 = 0.09$) on distant revisions. However, the two groups did not differ significantly in the distance of distant revisions ($F(1, 55) = 1.88$, $p = .18 > 0.05$).

4.1.3. End revisions

Table 5 displays the descriptive data of end revisions for the two groups. A one-way MANOVA was conducted to examine the effect of L2 writing skill on end revisions and the results suggest the effect of L2 writing skill was statistically significant on end revisions ($F(4, 52) = 4.28$, $p < .01$; Wilk's $\Lambda = 0.75$, partial $\eta^2 = 0.25$). Follow-up univariate ANOVAs detected significant effects of L2 writing skill on all four measures of end revisions, i.e., frequency ($F(1, 55) = 9.23$, $p = .00$, partial $\eta^2 = 0.14$), scope ($F(1, 55) = 14.59$, $p = .00$, partial $\eta^2 = 0.21$), distance ($F(1, 55) = 5.44$, $p = .02$, partial $\eta^2 = 0.09$), and duration ($F(1, 55) = 16.28$, $p = .00$, partial $\eta^2 = 0.23$). Specifically, the more-skilled group initiated more frequent end revisions, revised on larger scopes, attended to larger parts of the produced text, and spent more time during end revisions. By contrast, the less-skilled group less frequently engaged in end revisions, and their end revisions were of smaller scopes and shorter duration, being confined to smaller parts of their texts.

4.2. Online revisions and the final text quality

Pearson correlation coefficients were computed between the three types of online revisions and the final text score, and Table 6 summarizes the results. There observed a negative correlation between the frequency of immediate revision and the final text score, which approached the significance level ($r(57) = -0.25$, $p = .06$), and a significant negative correlation between the frequency of distant revision and the final text score ($r(57) = -0.30$, $p = .02$). However, the frequency of end revision correlated positively with the final text score ($r(57) = 0.25$, $p = .06$). This suggests that too frequent revisions during

Table 5
Descriptive statistics for end revisions.

	More-skilled (n = 28)		Less-skilled (n = 29)	
	Mean	SD	Mean	SD
Frequency	.79	.42	.41	.50
Scope (letters)	135.32	134.38	50.76	94.29
Distance (letters)	719.46	609.53	380.62	494.06
Duration (seconds)	342.32	280.56	123.17	171.68

Table 6
Correlation statistics between revisions and the final text score (N = 57).

		IR-freq	IR-scope	DR-freq	DR-duration	DR-distance	DR-scope	ER-freq	ER-duration	ER-distance	ER-scope
Score	Correlation coefficients	−.25	.32*	−.30*	.30*	.15	.45**	.25	.38**	.24	.37**
	Sig. (2-tailed)	.06	.01	.02	.02	.27	.00	.06	.00	.08	.01

*: Correlation is significant at the .05 level (2-tailed); **: Correlation is significant at the .01 level (2-tailed).
freq: frequency; IR: Immediate Revision; DR: Distant Revision; ER: End Revision.

text production (either immediate or distant revisions) were not conducive to the final text quality, but the final text quality benefited from end revision practices after text production.

As shown in Table 6, the final text score consistently demonstrated positive correlation with revision scope, be it immediate revision ($r(57) = 0.32$, $p = .01$), distant revision ($r(57) = 0.45$, $p = .00$) or end revision ($r(57) = 0.37$, $p = .01$), suggesting that the final text benefited from large-scope revisions. Furthermore, the final text score correlated positively with distant revision duration ($r(57) = 0.30$, $p = .02$) and end revision duration ($r(57) = 0.38$, $p = .00$), further suggesting that time spent on distant revisions and end revisions helped improve the final text quality. However, there was no significant correlation between the final text quality and revision distance, either for distant revisions ($r(57) = 0.15$, $p = .27$) or end revisions ($r(57) = 0.24$, $p = .08$).

5. Discussion

This study set out to examine to what extent L2 writing skill would affect L2 writers' online revisions in computer keyboard settings and how online revisions related to the final text quality. While confirming L2 writing proficiency significantly affected immediate, distant and end revisions, this study yielded meaningful findings on several issues in L2 revising: (i) the predominance of linguistic revisions; (ii) the inhibition of local issues on global issues, (iii) the strategic deference of language concerns and (iv) the influence of online revisions on the final text quality.

First, immediate revision was the predominant revision type for L2 writers both at the more- and less-skilled levels, lending support to previous findings that L2 writers mostly engaged in revisions of small scopes (Barkaoui, 2016; Stevenson et al., 2006). The high frequency and small scope of immediate revisions mark out language proficiency an important factor influencing fluent text production in L2 writing (Qu, 2017). Previous studies suggest that revising functions to compensate for L2 writers' lack of language proficiency and skilled L2 writers produce more linguistically accurate texts requiring fewer revisions (Chenoweth & Hayes, 2001; MacArthur, Graham, & Fitzgerald, 2008). This study yet suggests possible differences in L2 writers' strategic use of revising to solve language issues. It is observed in this study that many of the more-skilled writers later engaged in extensive end revisions to tackle language issues but few from the less-skilled group did so, suggesting the more- and less-skilled L2 writers adopted different revising strategies in L2 writing. While both groups encountered language difficulty in L2 writing, the more-skilled group were apt at focusing on idea development first by deferring language concerns to later stages of writing through end revisions. Together with the fact that the more-skilled group produced much longer texts within similar amounts of task time, this study suggests language concerns at early stages of writing could lead to attention conflict between production and revision, and consequently result in frequent writing break-downs. This thus confirms the observation in previous studies that attention to linguistic issues in L2 writing could affect fluent development of ideas and productive use of task time (Chenoweth & Hayes, 2001; Xu & Ding, 2014).

The second finding is that when time pressure is low in L2 writing tasks, attention to local issues does not inhibit attention to global issues, lending no support to the inhibition hypothesis in terms of online revisions in L2 writing. Immediate revisions suggest a focus on current formulation than the overall text planning or revising (Barkaoui, 2016; Stevenson et al., 2006) and revision distance denotes how much text L2 writers strive to accommodate in their revision attempt. In this study, the less-skilled group engaged more frequently both in immediate and distant revisions than the more-skilled group and displayed similar distance in their distant revisions as the more-skilled group. This demonstrates that less-skilled L2 writers also had concerns for large-scope issues in their revision attempts and attention to local issues did not impede their attention to distant and global issues. This is in line with Piolat, Roussey, Olive, and Amada (2004) finding that L2 writers, when given more time, were able to engage in different levels of revisions simply by investing more time in the task. In this study, the more- and less-skilled groups experienced little time pressure as shown by the fact that both groups finished the task much ahead of the allowed task time. Therefore, time pressure could be an important factor affecting L2 writers' revising activities, and if issues of different scopes do not simultaneously drain their attentional resources, less-skilled L2 writers would also attend to large-scope issues during text production.

However, the more- and less-skilled L2 writers eventually differed in the scope of distant revisions, suggesting differences in their competence to solve the identified writing problems. Dix (2006) suggested rereading and revising the produced text could be a strategy for writers to re-elaborate, rediscover and reorganize ideas for further text development when their writing broke down. In this study, while the frequency and distance of distant revisions suggested L2 writers at both levels exhibited concerns for issues distant away from the production point, the significantly longer duration and larger scope of distant revisions of the more-skilled group testified to the difference in how successful their distant revision attempts were. As large-scope revisions can be considered revisions at higher levels (Stevenson et al., 2006), this study suggests that while both groups tried to revise high-level issues, less-skilled L2 writers were not as successful as their more-skilled peers. In other words, while demonstrating comparable attention to high-level issues in their distant revision attempts, the less-skilled L2 writers did not display comparable competence in successfully addressing these issues through large-scope revisions. This finding confirms L2 writers' ability for problem detection develops faster than their problem-solving ability (Roca De Larios, Murphy, & Marín, 2002) and suggests less-skilled L2 writers need to learn how to revise for discovery and elaboration of ideas to better address the problems detected during L2 writing.

A third finding of this study is that end revision is an important indicator of writing skill and contributes substantially to the improvement of the final text quality. Unlike immediate or distant revisions which were accompanied with suspension of text production, end revisions were voluntary revising processes initiated by the writer to review and revise the produced

text under little pressure of further text production. However, even when time permitted, the less-skilled L2 writers did not engage much in end revision as did their more-skilled peers, demonstrating differences in motivation and strategy use between the more- and less-skilled L2 writers. Different from previous suggestions that linguistically less competent L2 writers would revise more while those who were linguistically more competent would produce better texts requiring less revisions (Chenoweth & Hayes, 2001), this study shows end revision is a proactive investment of efforts to further improve the produced text rather than a reactive measure to overcome writing breakdowns or to improve poorly-constructed texts.

Therefore, engagement in end revision reflects L2 writers' conscious use of revising as a strategy to improve the text before submission. The fact that less-skilled L2 writers far less frequently engaged in end revisions lent support to the previous finding that less-skilled L2 writers were reluctant to reread and revise their produced texts (see Barkaoui, 2007). Under the limited capacity of working memory during written text production, the strategic use of end revision may help L2 writers free up their attentional resources from planning, translating and revising simultaneously. While writing is a process where planning, translating and revising constantly interact in a recursive manner (Hayes & Flower, 1980), this study suggests setting functionally defined priority for each writing stage could avoid the risk of overloading L2 writers' working memory with conceptual development and language issues at the same time.

Last but not least, this study found the final text quality correlated negatively with the frequency of immediate and distant revisions, but positively with the frequency of end revisions, the scope and duration of both distant and end revisions. While immediate revision and distant revision signal writing difficulties during drafting and thus interrupt fluent text production, end revision demonstrates further effort investment for text improvement after drafting. As L2 writing naturally encounters lack of language proficiency (Qu, 2017), the more-skilled L2 writers lifted this affective influence by deferring language concerns to the end revision process. By contrast, the less-skilled L2 writers displayed frequent small-scope immediate and distant revisions during drafting and did not engage much in end revision even when task time permitted, suggesting a marked difference in their revising strategies against those of the more-skilled group. The correlations between online revisions and the final text quality thus collectively suggest that L2 writing benefits from a fluent and focused production process, scaffolded by in-depth and extensive revisions. While learning to write in L2 entails a robust drive for attainment of higher language proficiency, writing strategies should be promoted to a conscious level to help L2 writers better complete their writing tasks by prioritizing certain processes over others at different stages of writing (Roca de Larios et al., 2006) and thus optimize learning from writing.

6. Conclusions and future directions

As Myers (2001) suggests, encouraging student writers to reflect on their texts and writing processes helps them identify their strengths, weaknesses and learning needs in writing. This study, by examining the revising process of the more- and less-skilled L2 writers through an integrated taxonomy of online revisions, provided enriched understandings of the revising process and important pedagogical implications for L2 writing.

Firstly, L2 writing inevitably encounters lack of language proficiency, and L2 writers should learn to tackle language issues strategically as language concerns at early stages of writing could impede conceptual development. As effective strategy use is central to L2 writing (De Silva & Graham, 2015) and strategy instruction can scaffold L2 learning (Plonsky, 2011), this study suggests L2 writers need to build up their confidence to develop good writings in a foreign language and strategically defer their language concerns to later stages of writing to prioritize idea development.

Secondly, when time pressure is low in L2 writing, attention to low-level issues does not impede attention to high-level issues in revising. However, less-skilled L2 writers need practical strategies to tackle large issues and make their revising attempts successful. Only by scaffolding L2 writers to revise their identified writing problems could they develop their problem-solving abilities. Therefore, L2 writers should be pedagogically guided to rediscover, elaborate and integrate ideas in their revision attempts when their writing breaks down.

Finally, the deference of language concerns and priority for conceptual development in L2 writing make end revision essential for quality writing. L2 writers need to be pedagogically oriented about the practical aims of each writing stage and stick to these aims instead of overloading their working memory by juggling too many at a time. While learning to revise can be "a lengthy, complex endeavor" (Allal, Chanquoy, & Largy, 2004, p.1), end revision helps free up attentional resources to prioritize production and should be pedagogically promoted in L2 writing as a production and revision strategy.

While enriching our understanding of the L2 revising process, the findings of this study need to be interpreted with caution. First, this study only examined online revisions quantitatively from the process perspective, and future studies could qualitatively probe into the reasons behind online revisions. Second, this study focused on the online revising process in L2 writing without statistically integrating it with other component processes. As writing is a complex integration of various component processes, future studies can examine revising in conjunction with other processes such as planning, translating and pausing to better inform the L2 writing pedagogy.

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Appendix 1. A writing log file excerpt

Id	Event Type	Output	Position Full	Position	DocLength Full	DocLength	Character Production	StartTime	StartClock	EndTime	EndClock	ActionTime	PauseTime	PauseLocation	PauseLocation
221	mouse	Movement		24		33	43	131781	0:02:11	131812	0:02:11	31	31	15	UNKNOWN
222	mouse	Movement		24		33	43	131828	0:02:11	132234	0:02:12	406	16	15	UNKNOWN
224	keyboard	SPACE	33	33	34	34	43	132265	0:02:12	132359	0:02:12	94	31	1	WITHIN WORDS
225	keyboard	o	34	34	35	35	44	133187	0:02:13	133265	0:02:13	78	922	1	WITHIN WORDS
226	keyboard	n	35	35	36	36	45	133453	0:02:13	133515	0:02:13	62	266	1	WITHIN WORDS
227	keyboard	SPACE	36	36	37	37	46	133625	0:02:13	133687	0:02:13	62	172	3	AFTER WORDS
228	keyboard	t	37	37	38	38	47	133984	0:02:13	134047	0:02:14	63	359	2	BEFORE WORDS
229	keyboard	h	38	38	39	39	48	134187	0:02:14	134250	0:02:14	63	203	1	WITHIN WORDS
230	keyboard	e	39	39	40	40	49	134515	0:02:14	134625	0:02:14	110	328	1	WITHIN WORDS
231	keyboard	i	40	40	41	41	50	134719	0:02:14	134781	0:02:14	62	204	1	WITHIN WORDS
232	keyboard	r	41	41	42	42	51	134797	0:02:14	134859	0:02:14	62	78	1	WITHIN WORDS
233	keyboard	SPACE	42	42	43	43	52	134984	0:02:14	135015	0:02:15	31	187	3	AFTER WORDS
234	keyboard	f	43	43	44	44	53	135734	0:02:15	135812	0:02:15	78	750	2	BEFORE WORDS
235	keyboard	o	44	44	45	45	54	135875	0:02:15	135937	0:02:15	62	141	1	WITHIN WORDS
236	keyboard	BACK	45	45	46	46	55	136219	0:02:16	136281	0:02:16	62	344	1	WITHIN WORDS
237	keyboard	i	44	44	45	45	56	136469	0:02:16	136547	0:02:16	78	250	1	WITHIN WORDS
238	keyboard	r	45	45	46	46	56	136609	0:02:16	136687	0:02:16	78	140	1	WITHIN WORDS
239	keyboard	s	46	46	47	47	57	137172	0:02:17	137250	0:02:17	78	563	1	WITHIN WORDS
240	keyboard	t	47	47	48	48	58	137359	0:02:17	137437	0:02:17	78	187	1	WITHIN WORDS
241	keyboard	SPACE	48	48	49	49	59	137562	0:02:17	137625	0:02:17	63	203	3	AFTER WORDS
242	keyboard	o	49	49	50	50	60	138469	0:02:18	138547	0:02:18	78	907	2	BEFORE WORDS
243	keyboard	f	50	50	51	51	61	139031	0:02:19	139109	0:02:19	78	562	1	WITHIN WORDS
244	keyboard	f	51	51	52	52	62	139187	0:02:19	139265	0:02:19	78	156	1	WITHIN WORDS
245	keyboard	e	52	52	53	53	63	139375	0:02:19	139437	0:02:19	62	188	1	WITHIN WORDS
246	keyboard	n	53	53	54	54	64	140047	0:02:20	140125	0:02:20	78	672	1	WITHIN WORDS
247	keyboard	d	54	54	55	55	65	140219	0:02:20	140297	0:02:20	78	172	1	WITHIN WORDS
248	keyboard	BACK	55	55	56	56	66	140672	0:02:20	140765	0:02:20	93	453	1	WITHIN WORDS
249	keyboard	s	54	54	55	55	67	140844	0:02:20	140937	0:02:20	93	172	1	WITHIN WORDS
250	keyboard	e	55	55	56	56	67	140984	0:02:20	141078	0:02:21	94	140	1	WITHIN WORDS

Appendix 2. Rating Rubric for CET4 Writing

Score	Organization	Content	Language
0	No organization	Little idea	Incorrect spellings or a few isolated words
2	No focus; disorganized; or not enough to evaluate	Ideas random, illogical or not pertinent; or not enough to evaluate	Incomplete or incorrect sentences; severe errors that obscure meaning or not enough to evaluate
5	Attempts to focus; minimal organization; lacks logical sequencing and development	Limited knowledge of the subject; ideas mixed; few transitions	Monotonous sentence structures; little knowledge of English vocabulary; numerous errors that interfere with meaning
8	Single focus; some lapses or flaws in organization	Limited knowledge of the subject; ideas not well supported or elaborated	Little variety in syntax; limited word range; some evident errors
11	Single focus; logical organization but limited support	Knowledge of the subject; ideas appropriate and varied	Varied sentence structure; adequate word range and effective word use; few errors
14	Single, distinct focus; logical progression of ideas; well supported	Good knowledge of the subject; details effective, vivid, explicit and pertinent	Effective complex constructions; sophisticated word range and idiomatic word use; very few, if any, errors

Note: This rubric assigns each text into one of the five levels above, and minor deviations from the description for each level may result in the loss or gain of one point. Thus, a perfect score is 15 and the lowest score is zero.

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