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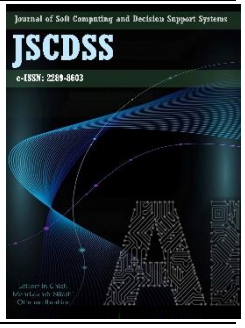

Exploring Second Language Writers' Usage Behavior of Automatic Speech Recognition: A Focus on Lexical Diversity in Narrative Texts

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Abstract

Strategies are techniques for making tasks easier to complete. While strategy use in writing research has been widely investigated, little is known about the strategies that second language (L2) writers might employ when producing text using automatic speech recognition (ASR), and whether there is an association between the strategy used and the lexical diversity of the produced text. This study adopts an exploratory approach with a one-sample design involving 30 nonnative English writers to examine what strategies L2 writers adopt when producing narrative texts with ASR and how these strategies affect the diversity of lexical items in their texts. While the absence of a control group limits causal inferences, the study provides preliminary insights into the role of ASR in shaping L2 writing behaviors and lexical diversity, emphasizing the unique affordances of ASR technology for process-based writing. The findings reveal that L2 writers mostly used four general strategies when composing with ASR and that the exclusive use of ASR does not necessarily lead to a higher lexical diversity of narrative texts. Our discussion highlights the importance of these findings and proposes lines of inquiry for future research on the use of ASR-based writing strategies and their potential effect on lexical diversity in texts.

Keywords: Automatic speech recognition, writing strategies, narrative writing, lexical diversity, input modalities

1. Introduction

While speaking is a natural mode of communication that doesn't require external tools such as keyboards or pen and paper, writing, on the other hand, is an activity that relies on the use of external tools. Thus far, different input methods (e.g., typewriters, ballpoint pens, keyboards) have been developed for writing purposes. One of the technological innovations in the development of writing (the "voice evolution"; Enge, 2020) is automatic speech recognition (ASR), an accessible and ubiquitous technology that converts users' speech to text, which can be found in many current devices (e.g., laptops, smartphones) and in word-processing and communication software (e.g., Google Docs, Microsoft Office Suite, text messaging applications). As such, ASR has the potential to revolutionize the way individuals can effortlessly transform their spoken language into written form, expanding the possibilities of written communication (a more detailed discussion of ASR is provided under the 'ASR-Assisted Writing' section).

Despite the ongoing increase in the use of voice as an input tool in mobile human-computer interaction (Enge, 2020), as well as the extensive use of ASR in the second language (L2) pronunciation research, ASR-assisted writing has not received the attention it deserves. Although research shows the efficacy of ASR technology in improving L2 pronunciation (Liakin et al., 2015) and describes the strategies that L2 learners adopt when practicing pronunciation with the technology (Dillon & Wells, 2021; Van Lieshout & Cardoso, 2022), the exploration of ASR-assisted writing remains relatively limited, with only a small number of studies delving into this area. Moreover, the majority of these studies have focused on individuals with learning difficulties (Leijten & van Waes, 2005; MacArthur, 1999). Importantly, very few studies have investigated (1) how writers interact with ASR to produce text, regarding their behaviors; and (2) whether there is a relationship between the writers' choice of behavior and the lexical diversity of their final text.

To address these research gaps, this study employed an exploratory sequential design to identify the behaviors that participants employ when writing narrative texts via ASR (e.g., exclusive use of ASR, combining keyboarding with ASR) and to provide a preliminary examination of the relationship between the behaviors used and the diversity of lexical items in their texts. An exploratory sequential design, a mixed methods research approach, involves initially collecting and analyzing qualitative data. The results then inform the development of subsequent quantitative research, allowing for a comprehensive and iterative understanding of research questions (Johnson & Onwuegbuzie, 2004). To contextualize and provide motivation for the study, the component skills in writing and the significance of learner

behavior for learning (and writing) are briefly reviewed below.

2. Background

2.2 Importance and Challenges of Writing

Effective writing skills are key to fostering literacy and communicative competence and are often assessed in high-stakes exams to validate academic and professional capabilities (Weigle, 2010). However, research has demonstrated that learners' writing skill is deteriorating (Healey & Gardner, 2021). As Silva (1993) explains, L2 writing is often more restricted, challenging, and less successful than L1 writing, as L2 writers "plan less, revise for content less, and write less fluently and accurately than first language writers" (Weigle, 2010).

Challenges in L2 writing can be explained through the developmental model of writing process (Berninger & Winn, 2006). This model highlights three interconnected skills involved in working memory during text production: *text generation*, *transcription skills*, and *executive functions* (see Fig. 1). Text generation is described as the cognitive process of utilizing vocabulary and grammar to translate ideas into linguistic representations (i.e., language) at the word, sentence, and discourse level (Berninger et al., 1992). Text generation refers to the writer's cognitive ability to formulate and organize ideas into coherent, structured language. Transcription skills are defined as "the translating of … language representations in working memory into written symbols on the printed page" (Berninger et al., 1996). Transcription focuses on the physical execution of writing, such as typing or handwriting ideas into text. Finally, executive functions refer to the writer's ability to self-regulate the cognitive and metacognitive processes in writing (Berninger & Amtmann, 2003). Executive functions comprise "conscious attention, planning, reviewing [or monitoring], revising, [and] strategies for self-regulation" (Berninger & Amtmann, 2003).

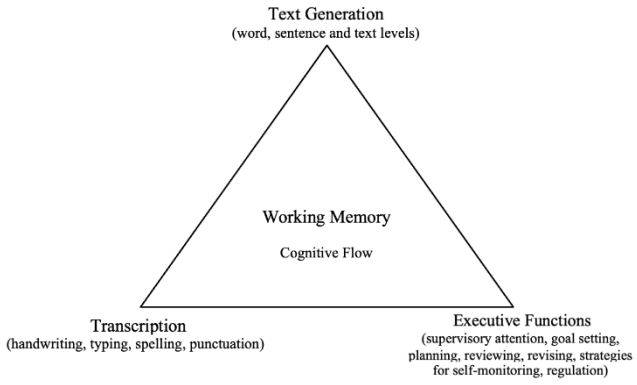

Fig. 1. Developmental Model of Writing (Adopted from Berninger et al., 2009)

These skills can constrain the composing process, thus prompting the writer to develop strategies to ease writing. This study first focuses on learner behaviors associated with *executive functions* (research question 1). So, let us begin by defining 'learner behavior'.

2.3 Learner Behavior

Learner behavior refers to the various actions, strategies, and processes that language learners use when acquiring a second language (Griffiths, 2007). Some key aspects of learner behavior include learning *strategies*, which will be the focus of this study. Griffiths (2007) describes strategies as specific actions that learners deliberately take to simplify task completion (e.g., rehearsing, memorizing vocabulary). Oxford (1999) defines the concept as "specific actions taken by the learner to make learning easier, faster, more enjoyable, more self-directed, more effective, and more transferable to new situations" (p. 8). In this research, learner behavior refers to the range of strategies and processes language learners employ in acquiring a second language. It includes diverse approaches and cognitive mechanisms. Strategy use, a key aspect, represents the intentional, goal-driven methods learners apply, especially during early stages of navigating new tasks or technological tools. When used frequently, these strategies can become automatic (Chamot, 2005).

Learning strategies can be divided into four major interrelated types: Cognitive, metacognitive, affective, and social. According to Stewner-Manzanares et al. (1984), *cognitive* strategies refer to "the direct manipulation or transformation of learning materials in order to enhance learning and retention" (p. 9). In ASR writing, cognitive strategies include vocabulary selection (i.e., choosing words and phrases for accurate ASR recognition) and syntax monitoring (i.e., structuring spoken sentences to match written grammar and punctuation). *Metacognitive* strategies involve learners' reflection on their thought processes. ASR writers apply these strategies to regulate their writing by planning (setting clear goals), self-monitoring (assessing transcription quality), and problem-solving (addressing transcription errors) (Stewner-Manzanares et al., 1984). *Affective* strategies are "emotional or attitude-related" such as identifying and using a method to lower anxiety during the writing process (Oxford, 1986). In ASR writing, affective strategies encompass motivation (staying positive and motivated to utilize ASR for writing), self-efficacy (confidence in using ASR), and emotional regulation (managing frustration when the technology falters) (Oxford, 1999). Finally, *social* strategies in ASR-based writing refer to learning with and from others, such as collaborating with peers or editors to review and improve ASR-generated text, and seeking feedback from teachers to hone transcription quality (Ma & Oxford, 2014; Oxford, 1986).

2.4 Writing Behaviors and Individual Differences

Writing behaviors (WBs), guided by the abovementioned definitions, are actions the writer takes to overcome constraints from component skills (e.g., text generation, transcriptions) to facilitate the writing process. Traditional

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writing activities involve behaviors enhancing the writing process. These behaviors include strategies such as brainstorming, mind-mapping, drafting, revising, and using resources (e.g., thesauruses, dictionaries). However, the factors influencing writers' strategy choices are often unclear beyond teacher and textbook instruction. What is clear, though, is that the choices made by L2 writers are likely influenced by their individual differences (for similar claims, see Dörnyei, 2005; Pawlak & Kruk, 2022). According to Dörnyei (2005) and Pawlak & Kruk (2022), individual differences refer to the unique characteristics, abilities, preferences, and needs of language learners, which can influence their interactions with technology and their overall language learning outcomes. Dörnyei (2005) categorizes these differences into three main categories: Language Aptitude (cognitive abilities such as working memory and analytical skills), Motivation (the degree of desire, effort, and commitment towards obtaining a learning goal), and Personality Traits (characteristics that shape an individual's behavior and preferences).

This study also draws on theories of cognition and multimedia learning to conceptualize L2 WBs, including *cognitive flexibility*—the ability to transition between cognitive processes or tasks. This theory probes how individuals adapt their thinking and behavior to new conditions, tasks, or expectations (Spiro et al., 1991). L2 learners' use of WBs can also be conceptualized using Sweller's (1988) *cognitive load theory*. This theory is concerned with how the cognitive demands of a writing task affect learners' ability to successfully produce text. It implies that employing WBs such as planning and chunking information to manage cognitive load can enhance L2 writing performance. Finally, this study uses the concept of "linearity" to justify the adoption of specific WBs (Papert, 1980). The term linearity refers to a sequential progression from one tool to another, such as transitioning from exclusive use of ASR to exclusive use of keyboarding while composing texts.

In the context of ASR-assisted L2 writing, exploration of WBs is essential for two main reasons: First, it provides us with insight into the cognitive, metacognitive, affective, and social processes that ASR writers are usually involved with during the speak-to-write process. For instance, the cognitive processes include idea generation and language production from spoken language, while metacognitive processes involve planning, monitoring, and evaluating the accuracy of the ASR output. Affective processes are also present as learners manage their emotional states, such as reducing anxiety and increasing confidence when speaking. Social processes are apparent when writers interact with ASR, receive feedback from it, or co-author with peers to improve their work. All these processes offer a holistic approach to explaining how writers engage with ASR for the speak-to-write task. Second, the exploration enables us to impart new WBs (i.e., introducing novel strategies) to less competent or novice ASR writers to improve their writing skills (Ardasheva & Tretter, 2013; Grenfell & Harris, 1999). Research indicates that higher strategy use leads to improved L2 proficiency (Ardasheva & Tretter, 2013; Lan & Oxford, 2003), enhanced academic achievement in areas like language arts (Chamot, 2007), and improved cognitive and behavioral performance (Magogwe & Oliver, 2007). Another focus of this study is to examine whether participants' writing behaviors with ASR affect the lexical diversity of their final text (research question 2).

2.5 Lexical Diversity

Lexis (or vocabulary) is a key component of language, both spoken and written (Nation & Newton, 2008). Lexical diversity is described as a measure of the number of distinct lexical items used in a text. It is regarded as an informative determinant of learners' overall language skill (Yu, 2010) and an important indicator of their writing quality (Laufer & Nation, 1995). The significance of lexical diversity is also demonstrated in the writing scoring scale of many international language proficiency texts (e.g., IELTS, TOEFL). For example, IELTS writing band descriptors consist of four criteria by which written responses are assessed, and one of them is 'lexical resource' (i.e., 'the range of vocabulary used') that constitutes 25% of the total writing score (*IELTS Guide*, 2022). Moreover, in terms of measuring text features, lexical diversity has been found to be one of the most essential elements in automated writing assessment systems (McNamara et al., 2014).

As Laufer and Nation (1995) indicate, lexical diversity is an important factor in determining the vocabulary employed in a written text and, as a result, the holistic text quality assessment, particularly if the text is written by an L2 learner with a limited vocabulary in comparison to native speakers. For example, in a study by Linnarud (1986), the lexical diversity of texts written by L2 learners (Swedish learners of English) was lower than that of texts written by English native speakers, which has an adverse effect on the overall quality grading of learners' written texts. Due to the importance of lexical diversity in L2 writing, this study employs four indices to assess the lexical diversity of participants' texts (see Method for further details). The indices are variations of type-token ratio (TTR), which is one of the most widely employed methods for measuring lexical diversity. These indices were particularly selected to mitigate the text-length sensitivity that exists in conventional TTR to ensure a more reliable measure of lexical diversity across the collected texts. TTR is calculated by dividing the number of unique words (types) in a text by the total number of words (tokens) used. The resulting indices were used to examine whether the behaviors participants use in an ASR-assisted writing environment affect the lexical diversity of their final texts.

2.6 ASR-Assisted Writing

The term ASR-assisted writing refers to the act of producing text with speech recognition tools (e.g., Google Voice Typing, Microsoft Dictate). ASR introduces a mode of language production that bridges spoken and written communication. As such, it may result in spoken and/or simpler grammatical structures or linguistic patterns

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compared to traditional writing; however, these differences are integral to understanding how L2 writers adapt communication strategies in ASR-assisted writing. This study specifically examines ASR's impact on L2 *written communication* in narrative tasks, aiming to explore its potential to enhance both the quality of writing and the writing process without conflating it with traditional writing norms.

While there has been a substantial body of research conducted on ASR-based interventions in providing feedback and creating practice opportunities for L2 learners to improve their pronunciation skills (Inceoglu et al., 2023; Liakin et al., 2015), ASR-assisted writing remains relatively underexplored, despite several benefits it can provide to support writing. This gap in research is further amplified in the context of adult L2 learners, particularly among those with no learning and/or writing difficulties, as most ASR research in writing has focused on participants with learning difficulties or writing deficits. Below, we will describe some of the benefits that ASR-assisted writing provides.

2.7 Inclusive Writing Environment

New ASR systems afford an *inclusive* writing environment because their sensitivity to accented L2 speech is relatively low (McCrocklin & Edalatishams, 2020) and, as such, L2 learners with different pronunciation proficiency levels can conveniently use the system to input text without experiencing too many recognition errors. Further, people with learning (and writing) disabilities can easily use the system for writing purposes. Research indicates that ASR can contribute to the writing development of people with learning disabilities (Caute & Woolf, 2016). For instance, cognitively, it lessens the mental strain of transcribing, which allows writers to focus on idea development and content organization. Or, affectively, it boosts confidence and motivation by offering a more accessible and less daunting mode of producing text. Interestingly from a pedagogical standpoint, ASR does not promote one specific writing behavior, as users can maintain their planning, reviewing, or pausing behavior, developed by other input tools (e.g., keyboards) in ASR-assisted writing (Leijten & van Waes, 2005).

2.8 Speech-based Input Tool

ASR technology serves as a *speech-based input* tool, offering L2 learners a means to enhance their text production efficiency. By harnessing the natural and rapid nature of speech (Selouani et al., 2008), the technology promotes fluency in the writing process. Compared to typing, speech-based input proves to be a faster medium for language production (Quinlan, 2004). In addition, using speech as an input method reduces reliance on keyboards and mitigates challenges related to typing, such as poor spelling and keyboarding difficulties (MacArthur, 1999).

2.9 The Developing Text

Finally, ASR facilitates the creation of *the developing text*, which refers to the text displayed on the screen immediately after speech input. This feature fosters process-based writing by allowing the writer to continuously engage in reading, reviewing, planning (the remaining text), and revising the content throughout the composing process (Leijten & Van Waes, 2005). Research has underscored the importance of rereading, reviewing and revising the developing text in writing development (Flower & Hayes, 1980; Hayes, 1996).

3. The current study

Despite the multiple affordances that ASR offers to writers, its potential for L2 writing as well as its effects on the lexical diversity of texts have not been widely explored. Given that there is scant evidence available on what happens when L2 writers produce text using ASR (particularly regarding the behaviors employed), and how these behaviors affect the linguistic components of the text (e.g., lexical diversity), it is important to explore users' behaviors when producing text via ASR, and the association between lexical diversity and L2 writers' choice of behavior(s).

Cardoso (2022) proposed a four-stage chronological framework for computer-assisted language learning (CALL) research: (1) Development: creating a new technological tool (not applicable here because ASR is already developed); (2) Exploration: examining the pedagogical affordances and potential of the technology by assessing its practical and theoretical suitability; (3) Assessing suitability: researching learners' perceptions (level of acceptance) of using the technology; and (4) Assessing pedagogical effectiveness: evaluating the technology's ability to foster learning of a target skill. Since the present study is exploratory and causal in nature, the researcher will focus on stage 2 (exploration: research question #1) and stage 4 (assessing pedagogical effectiveness: research question #2).

Numerous studies have shown the pedagogical benefits of ASR in improving L2 pronunciation (Evers & Chen, 2021; Liakin et al., 2015; Mroz, 2018). However, only a small number of research has explored the impact of using ASR as a writing tool—as a tool for inputting text (exceptions include: Macarthur, 2000; Quinlan, 2004; Reece & Cummings, 1996). Following recommendations by Chapelle (2010), who call for studies exploring learners' behaviors when using technology with the aim of establishing a relationship between the strategy used and outcomes (in this study: the lexical diversity of ASR-written texts), two research questions are proposed:

RQ1: How do writers interact with ASR to produce text, in terms of behaviors employed?

RQ2: Is there an association between the ASR writers' choice of behaviors and lexical diversity of their final text?

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4. Method

4.2 Participants

This study recruited 30 adult participants (mean age: 28 years old) through random sampling. All participants were proficient English L2 speakers and were enrolled as undergraduate or graduate students in different academic domains (e.g., Computer Science, Education). The gender distribution was relatively balanced, with 46% male (n = 14) and 54% female (n = 16). Participants were proficient in speaking and writing in their first languages, which included Chinese, Farsi, French, German, Hindi, Portuguese, and Vietnamese. Approximately 95% of participants received their first writing instruction in their first language, and about 67% had lived in English-speaking countries for over four years.

Although the study did not explicitly control for participant-level variables such as language proficiency and native language, the relatively homogenous sample of university students helped mitigate variability in educational background and overall exposure to English. Prior experience with ASR tools was not a selection criterion; however, nine participants reported using tools such as Siri or Alexa for speaking practice and search queries, and only one had prior experience using ASR for writing tasks such as texting or emailing. To ensure confidentiality, a numerical coding system (e.g., P3) was employed to maintain participant anonymity.

4.3 Rationale for Selecting ASR and Study Design

ASR was chosen as the sole input modality for this study because of its growing importance in language learning contexts and its distinct features compared to traditional tools like keyboards or handwriting. ASR allows for process-based writing by providing immediate visual feedback on the developing text, enabling users to continuously revise and refine their text during the writing process. Unlike handwriting or keyboarding, ASR reduces the reliance on transcription skills, making it particularly accessible to writers with varied linguistic and motor abilities.

While the inclusion of control groups (e.g., handwriting or keyboard input) would provide comparative insights, practical constraints, such as participant availability and recruitment challenges, precluded the use of a multi-group design. Therefore, this study adopts an exploratory approach to investigate behaviors and preliminary associations with lexical diversity, laying the groundwork for future research with comparative designs.

4.4 Measures

Google Voice Typing

The Google Voice Typing, an ASR system developed by Google, was employed in this study because it is cost-free and easily accessible. Additionally, Google Voice Typing is fairly accurate, even for non-native speakers (McCrocklin et al., 2019). Each participant was provided with a blank page on Google Docs, an online word processor, to create their texts. Participants were provided with instructions on how to use Google's ASR, e.g., how to activate the tool, dictate text, and format and make corrections via voice commands if needed.

Writing Tasks

Three narrative writing prompts, adapted from (Davis, 2019), were given to the participants; however, they were asked to select two of the prompts and utilize ASR to compose their narrative texts. Participants were given 20 minutes to complete each writing task which included time for planning, writing, and revising their text. There was no word count limit; participants were free to produce as much text as they could within the time limit to complete the tasks. While prompt selection varied among participants, all participants completed two prompts. For the analysis, written texts from the two prompts were merged into a single file to ensure consistency across participants. The study did not account for differences in prompt selection.

The motive for choosing narratives was determined by Weigle's (2010) view that this genre or "discourse mode" correlates highly with writing performance. According to Weigle (2010), "narrative … [is] often seen as cognitively easier and lend [itself] to less complex language than do exposition and argumentation" (p. 100). Likewise, Crowhurst (1980) indicates that narratives often evoke shorter T-units (text units that include one independent clause as well as any dependent clauses linked to it) than do argumentative texts. As a result, the present study opted for examining narratives due to its relative simplicity in terms of production. This choice allowed our participants to concentrate on utilizing ASR for text generation and on devising strategies to tackle challenges associated with ASR-assisted writing.

4.5 Procedure and Data Analysis

Data collection was conducted online using Zoom. Rigorous measures protected participants' rights, including a thorough consent process detailing the study's objectives, procedures, potential risks, and benefits. Participants provided informed consent before participation. All data were anonymized and securely stored, and participants were compensated $20 for their time.

An exploratory sequential design was adopted to answer the research questions. As such, following Geertz's (2008) method of thick description, this study examines participants' behaviors while using ASR to produce text. Thick description offers in-depth explanations of participants' perspectives underpinning their observable behaviors within a particular context (Geertz, 2008). Guided by a holistic approach for the analysis of users' behaviors and experience (Gil Urrutia et al., 2017), this study analyzed data gained through the video recordings and screen captures

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of participants' interactions with ASR, as well as the researcher's fieldnotes.

4.6 Video Recordings and Screen Captures

Participants' interactions with ASR were monitored using video recordings and screen captures to analyze their composing behaviors. Participants' faces and shared screens, including the text output files, were recorded to monitor the writing process. These behaviors were coded inductively. As Johnson and Christensen (2019) describe, "inductive codes … are generated by the researcher by directly examining the data during the coding process" (p. 548). The coding method allowed the researchers to discover how the participants interacted with ASR and to determine any association between their behaviors and the lexical diversity of ASR-written texts.

4.7 Indices of Lexical Diversity

In this study, the lexical diversity of the participants' texts (n = 30) was analyzed. The texts were imported to the Tool for the Automatic Analysis of Lexical Diversity (TAALED; Kyle et al., 2021), an analysis tool developed to compute a wide range of lexical diversity indices. TAALED, one of the most widely used software in the field of writing assessment (Zenker & Kyle, 2021), is open-source and free to use, featuring an intuitive interface that is compatible with both Mac and Windows operating systems. For this study, as mentioned earlier, four indices of lexical diversity that have been found to be relatively resistant to text length were selected, including Root type-token ratio (Root TTR; Guiraud, 1960), moving-average TTR (MATTR; Covington & McFall, 2010), the measure of textual lexical diversity (MTLD; McCarthy & Jarvis, 2010), and MTLD moving-average-wrap (MTLD-MA-W; McCarthy & Jarvis, 2010). The inclusion of four lexical diversity indices in this study was intended to provide a more comprehensive analysis, capturing a broader range of diversity dimensions rather than relying on a single metric, which might not fully reflect the multifaceted nature of lexical diversity in ASR-assisted writing. Each index is operationally described below.

Root TTR. This index is calculated by dividing the number of types (i.e., unique words in a text) by the square root of the number of tokens (i.e., total number of words in a text). For instance, if the verbs take, took, taken, and taking are present in a text, they would be considered as one type, but four different tokens. Texts with higher Root TTR scores are more lexically diverse (Guiraud, 1960).

MATTR. The moving average type-token ratio (MATTR) is obtained by averaging TTRs across overlapping, evenly sized chunks of text. For instance, for a 20-word chunk, TTR values are determined for tokens (words) 1–20, 2–21, 3–22, etc., until every token in the text appears in at least one chunk, and the final MATTR score is produced by averaging all the TTR values. Texts with higher MATTR scores are more lexically diverse (Kyle et al., 2021).

MTLD (Original). The measure of textual diversity (MTLD) calculates the average number of words required to achieve a TTR value of .720. MTLD evaluates each word's TTR sequentially, running both forwards and backwards through the text to ensure the default TTR value (.720) is achieved. It computes TTR on progressively longer word strings, known as 'factors.' As such, two MTLD scores are computed: One for the forward computation and one for the backward. The final MTLD score is calculated by averaging the two scores (McCarthy & Jarvis, 2010).

MTLD-MA-Wrap. This index is a revised version of MTLD that utilizes a moving average approach to calculate lexical diversity. MTLD-MA-Wrap prevents partial factors (i.e., the final words that do not reach the TTR value of .720) by moving back to the beginning of the text rather than proceeding through the text forwards and backwards (Zenker & Kyle, 2021).

5. Results

5.1 Behaviors Used by L2 Writers When Interacting with ASR

Adopting an exploratory approach, this study analyzed the collected video recordings and screen captures to examine participants' writing behaviors when interacting with ASR to produce text (RQ1). Each participant used a variety of behaviors, broadly categorized into four types: (1) ASR exclusively (ASR-∀, with the universal quantifier symbol "∀" to differentiate the strategy from the technology), (2) ASR in tandem with keyboarding (ASR=KB), (3) ASR followed by keyboarding (ASR>KB), and (4) ASR followed by both keyboarding and ASR (ASR>ASR=KB).

ASR Exclusively (ASR-∀)

Two participants (out of 30; /30 henceforth) produced text exclusively using ASR (ASR-∀ henceforth) for all stages of writing, including planning, drafting, revising, and editing. For example, regarding planning, the participants used several voice commands in place of graphic organizers (e.g., a hierarchical organizer, a bubble map) to show the connection between ideas. The commands given consisted of: "period" to separate ideas from one another; and "new line", "insert number", or "create bulleted list" to arrange and classify ideas throughout the planning phase. In terms of editing, the participants used the command "select [word or phrase]" to select the error word(s) then spoke the appropriate term to replace the selected one. For instance, during the intervention, P14 used ASR to produce the following sentence: "However I had the privilege to attend some French classes", which lacked a comma after the transition word 'however'. P14 asked ASR to "select [however]" then spoke to it, saying 'however,' in which she repeated the transition word followed by a comma to edit and fix the punctuation issue. These examples demonstrate how P14 carried out different stages of writing using only ASR.

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ASR in tandem with Keyboarding (ASR=KB)

Thirteen participants (/30) used ASR in tandem with the keyboard when producing text (ASR=KB). The simultaneous use of ASR and the keyboard was performed to revise and edit text at every level of writing (e.g., drafting, revising). Participants in this category preferred to edit their sentences (and paragraphs) before proceeding to the next one and completing their texts. For instance, using ASR, P3 wrote "he was 24 years old he was an accountant" and immediately turned to the keyboard to change it to "He was 24 years old when I met him. He was an accountant". In this example, P3 used ASR to create a sentence that missed the first-word capitalization, proper use of punctuation marks, and the conjunction "and". P3's output also lacked sentence complexity. She addressed these issues by immediately using the keyboard to complement the ASR output, for instance, by capitalizing the letter "h" in 'he', adding an adverbial clause 'when I met him' to increase the complexity of the sentence, and inserting a period to mark the end of the sentence.

ASR followed by keyboarding (ASR>KB)

Five participants (/30) utilized ASR only to complete the initial drafts of their texts; all further revisions and editing were done using the keyboard exclusively (ASR>KB). Following this behavior, the participants composed their first drafts relatively fast because they did not go back to fix problems. After completing their first drafts, these five participants exclusively used their keyboards (with ASR turned off) to correct errors and edit their texts. For example, using ASR to create the first draft, P8 wrote the following sentence "sometimes you are having like a good conversation sometimes we saw and it was on and off but suddenly I realize that's not a white relationship" (incorrect words are in italics to facilitate processing). Then, using his keyboard, P8 revised the sentence as "sometimes we had a good conversation and sometimes we found out that it was intermittent but suddenly, I realized that's not a right relationship". As the revised text shows, P8 minimized spoken colloquialism by removing the word 'like', increased the sentence formality by changing 'saw' to 'found out' and 'on and off' to 'intermittent', and corrected verb tenses by altering 'are having' to 'had' and adding the past marker -ed to 'realize'. P8 also added the missing punctuation and corrected the ASR recognition error by changing 'white' to 'right'.

ASR followed by both ASR and keyboarding (ASR>ASR=KB)

A final writing behavior identified among ten participants involved the exclusive use of ASR for generating the initial draft, followed by a combination of keyboarding and ASR for inputting and making corrections to the text (ASR>ASR=KB). For instance, with ASR, P30 wrote: "And the beginning of 2020, I started learning a very different language […] Interesting Lee, French was not my mother tongue". After finishing the initial draft, P30 asked the ASR to "select [And the beginning of]" and then said "backspace" to delete the selected words, thus substituting the deleted phrase with the preposition 'in'. P30 then used his keyboard to replace "Interesting Lee" with the intended "Interestingly".

Table 1 summarizes the behaviors adopted by the participants and their distribution in the data.

Table 1
ASR-based Strategies and Their Distribution

Strategies	n	%
ASR-∀	2	7
ASR=KB	13	40
ASR>KB	5	17
ASR>ASR=KB	10	33

5.2 Associations between Behaviors and Lexical Diversity

To answer the second research question regarding whether there is an association between the ASR writers' choice of behaviors and lexical diversity of their final written text, a three-step procedure was used. First, we ensured that text length did not confound our results. To address the potential confounding effect of text length on lexical diversity, we calculated the mean and standard deviation of text lengths for each group. As Table 2 shows, the means and standard deviations of text lengths across the groups indicate relatively consistent text lengths, with slight variations. ASR-∀ exhibited the smallest variability, as reflected by the lower standard deviation, likely due to the smaller sample size. ASR=KB displayed a wider range of text lengths, as expected for the largest group. ASR>KB and ASR>ASR=KB had means close to those of ASR=KB, with moderate variability. These results suggest that text lengths were reasonably similar across groups.

Table 2
Descriptive Statistics for Text Lengths across Groups

Groups	N	M	SD	σ
ASR-∀	2	378.00	4.25	3.00
ASR=KB	13	387.15	8.06	7.74
ASR>KB	5	386.00	6.32	5.65
ASR>ASR=KB	10	390.50	6.10	5.78

A one-way ANOVA was conducted to determine whether there were statistically significant differences in text length across groups. As shown in Table 3, the analysis revealed no significant differences, $F(3, 26) = 1.90$, $p > .05$. This indicates that variations in text length across the groups are unlikely to have introduced a confounding effect in the study.

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Table 3
ANOVA Summary for Text Lengths across Groups

Source	df	Sum of Squares	Mean Square	F	*p*
Between Groups	3	283.31	94.44	1.90	.15
Within Groups	26	1292.29	49.70		
Total	29	1575.59			

Next, the lexical diversity of participants' texts was calculated using TAALED, software developed by Kyle et al. (2021) to measure the level of lexical diversity in a text. TAALED provides measurements of the text's diversity in terms of its lexicon, capturing the range and variety of words used.

Table 4 shows the descriptive statistics for the four indices used to assess lexical diversity. Table 5 displays the t-scores and mean values for each index. A t-score, ranging from 20 to 80 with a mean of 50 and a standard deviation of 10, indicates how distant an observed value deviates from the mean. According to the mean t-scores obtained, a total of 21 narrative texts had lexical diversity equal to or greater than average. The n ≥ 50 for each index consists of: Root TTR (n=19); MATTR (n=16); MTLD Original (n=21); MTLD-MA-Wrap (n=20).

Table 4
Descriptive Statistics for the Indices Calculated

Index	N	Min	Max	M	SD
Root TTR	30	35.73	67.25	51.26	9.65
MATTR	30	34.01	67.09	50.87	9.40
MTLD	30	27.58	70.25	53.19	11.59
MTLD-MA-Wrap	30	31.29	70.79	52.69	11.14

Finally, eta (η) and eta-squared (η2) tests were conducted to quantify the strength of associations between the writing behaviors used and the lexical diversity of the written narratives. Eta is a measure indicating the strength of the association between the independent and dependent variables, whereas Eta-squared is an effect size measure indicating how much of the variance in the dependent variable can be explained by the independent variable.

As Table 6 shows, five levels of lexical diversity were identified in the collected narratives, ranging from 'below average' (<50) to 'above average' (>50). Our analysis reveals that while the two narrative texts produced using ASR-∀ obtained below-average lexical diversity, texts written using ASR=KB showed slightly above (n=7) and above-average (n=4) lexical diversity. Texts utilizing ASR>KB were rated as having below-average (n=3), slightly below-average (n=1), and slightly above-average (n=1) lexical diversity. Lastly, most texts using ASR>ASR=KB displayed slightly above average (n=4) to above average (n=4) levels of lexical diversity.

Table 5
T-scores of Indices Measured

Participants	Root TTR	MATTR	MTLD	MTLD-MA-W	M
P1	58.37	55.28	62.52	60.24	**59.10**
P2	36.22	38.74	40.23	39.58	38.69
P3	58.95	57.91	63.89	64.54	**61.32**
P4	36.15	34.01	27.58	34.02	32.94
P5	65.28	63.59	68.87	66.47	**66.05**
P6	51.89	52.91	57.65	58.33	**55.20**
P7	53.56	50.55	51.98	54.85	**52.74**
P8	55.48	59.73	51.95	50.67	**54.46**
P9	37.22	42.46	39.97	39.81	39.87
P10	46.20	60.00	51.68	50.40	**52.07**
P11	48.69	46.83	54.21	55.88	**51.40**
P12	54.91	48.19	56.82	52.84	**53.19**
P13	54.91	58.56	63.74	61.06	**59.57**
P14	50.83	47.83	60.01	57.40	**54.02**
P15	50.08	47.63	52.84	49.82	**50.09**
P16	49.84	50.19	55.91	57.18	**53.28**
P17	38.45	39.74	41.86	42.65	40.68
P18	53.99	52.91	54.89	54.32	**54.03**
P19	58.45	59.55	66.75	63.38	**62.03**
P20	67.25	64.91	70.25	69.23	**67.91**
P21	35.73	36.37	33.23	31.34	34.17
P22	44.29	41.1	48.02	46.40	44.95
P23	62.34	62.37	63.60	60.92	**62.31**
P24	36.72	41.1	33.89	31.29	35.75
P25	59.37	52.91	51.55	52.58	**54.10**
P26	37.07	38.74	36.68	34.31	36.70
P27	57.10	48.19	61.20	62.57	**57.27**
P28	53.85	43.46	44.38	47.99	47.42
P29	61.42	63.19	69.65	70.79	**66.26**
P30	63.33	67.09	59.93	59.91	**62.57**

Bolded numbers indicate mean values equal to or above average.

Table 6
Writing Strategies and Associations with Lexical Diversity

		Levels of Lexical Diversity					
		Below	Slightly below	Average	Slightly above	Above	Total
WS	ASR-∀	2	0	0	0	0	2
	ASR=KB	1	1	0	7	4	13
	ASR>KB	3	1	0	1	0	5
	ASR>ASR=KB	0	1	1	4	4	10
Total		6	3	1	12	8	30

As displayed in Table 7, the results show a moderate association between ASR-∀ and the lexical diversity (ASR-∀; η = .4). The eta-squared value indicates a significant and meaningful association between ASR-∀ and lexical diversity of the texts, $F(29) = 6.80$, $p < .05$, $\eta 2 = .19$, with 95% CI [373.84, 382.16] (for further details on effect sizes, see Cohen, 1992). In addition, the findings suggest a weak association between ASR=KB and the lexical diversity (η = .2). Although the p-value did not reach statistical significance, $F(29) = 1.77$, $p > .05$, the eta-squared indicates a medium effect size (η2 = .05) with 95% CI [382.94,

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391.35], which suggests that a meaningful association may require a larger sample size.

Our results also show a moderate association between ASR>KB and lexical diversity (η = .4). The large effect size and statistical significance obtained suggest that the observed effect of ASR>KB on lexical diversity is meaningful, $F(29) = 8.99$, $p < .05$, $\eta 2 = .24$, 95% CI [381.04, 390.95]. Lastly, the results show a weak association between ASR>ASR=KB and lexical diversity (η = .3). However, the eta-squared result shows that this behavior is not significant, despite a large effect size, $F(29) = 3.68$, $p > .05$, $\eta 2 = .11$, 95% CI [386.91, 394.08].

Some observed behaviors gained statistical significance (e.g., ASR>KB; p = .006), while some approached (e.g., ASR>ASR=KB; p = .065). However, these findings should be interpreted with caution due to the limited sample size. This study adopts an exploratory approach, and the observed usage behaviors provide valuable preliminary insights despite potential limitations in statistical power. Notably, the effect size reported indicates no meaningful relationship between the behavior used and the texts' lexical diversity. Although our findings, particularly those pertaining to ASR=KB and ASR>ASR=KB, failed to attain statistical significance, the large effect sizes suggest the potential for meaningful significance with a larger sample size. The findings of the Eta and Eta-squared tests are summarized in Table 7.

Table 7
Summary of the Measures of Associations and their Effect Sizes

WS	F	p	η	η2
ASR-∀	6.80	.014	.44	.19
ASR=KB	1.77	.194	.24	.05
ASR>KB	8.99	.006	.49	.24
ASR>ASR=KB	3.68	.065	.34	.11

In summary, our findings reveal that ASR-∀ corresponds to a moderate relationship with lexical diversity with a significant effect, while ASR=KB has a weak relationship without statistical significance. ASR>KB points to a moderate relationship with lexical diversity and a significant effect, while ASR>ASR=KB exhibits a weak relationship with lexical diversity but no significant impact.

6 Discussion

This study investigated how participants interact with ASR to produce narrative texts (RQ1) and whether the behaviors employed affect the lexical diversity of their narratives (RQ2). Thirty English NNSs participated in an intervention in which they were asked to create texts utilizing ASR and other writing tools at their disposal (e.g., keyboards, pen and paper). Our findings demonstrate that (1) participants employed four writing behaviors to produce text utilizing ASR, and (2) certain behaviors (i.e., ASR=KB, ASR>ASR=KB) are more likely to be associated with the production of higher quality texts, as they yielded greater lexical diversity.

While this study offers valuable insights into L2 writers' behaviors when using ASR and their impact on lexical diversity, it is important to note the absence of control groups as a methodological limitation. Without comparative data from other input modalities, such as handwriting or keyboarding, the independent effect of ASR on lexical diversity cannot be conclusively isolated. This limitation reflects the exploratory nature of this study, which aims to identify trends and associations rather than establish causality.

Despite these constraints, the findings underscore the unique affordances of ASR for L2 writing, such as its capacity to support process-based composition and provide real-time visual feedback. These features differentiate ASR from other input methods and justify its selection as the focal input modality for this exploratory investigation.

6.1 Behaviors Used in ASR-based Writing

An exploratory analysis was carried out concerning the first research question, which asked what behaviors L2 writers use when interacting with ASR to produce texts. Using video capture recordings and field notes, four distinct behaviors were observed: (1) ASR exclusively (ASR-∀); (2) ASR in tandem with keyboarding (ASR=KB); (3) ASR followed by keyboarding (ASR>KB); and (4) ASR followed by both keyboarding and ASR (ASR>ASR=KB). *The imbalance in group sizes (e.g.,* ASR-∀: n = 2; ASR=KB: n = 13) *reflects authentic usage behaviors observed during the experiment, which aligns with the study's goal of capturing real-world ASR writing behaviors. Although this imbalance may limit direct comparability across groups, it provides an ecologically valid foundation for interpreting the results.*

The diverse range of behaviors suggests that writers have preferences shaped by individual differences (IDs) in cognitive abilities and learning styles (e.g., visual, auditory). Dörnyei (2005) defines IDs as attributes that distinguish individuals. As such, the two participants who exclusively employed ASR-∀ for composing and editing might have stronger auditory and oral abilities, leading them to rely on ASR throughout all writing phases—planning, drafting, revising, and editing (for a discussion of these types of learners in SLA, see Pawlak & Kruk, 2022).

The prevalence use of ASR=KB among the thirteen participants may indicate cognitive flexibility (Spiro et al., 1991), allowing them to adapt to the task by using ASR for efficient verbal expression and keyboarding for precision (e.g., during editing). The five participants who utilized ASR>KB can be classified as "linear" writers. Following Papert's (1996) concept of linearity, these participants initially used ASR for its compatibility with their communication style and overcoming the challenge of generating text (Weigle, 2010). As their writing needs became more complex, they switched to keyboarding for greater precision in revising and editing.

Lastly, the second most used behavior, ASR>ASR=KB, was adopted by ten participants, possibly relying on their

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working memory (i.e., the capacity to retain and manipulate information), an ID attribute that affects how writers manage cognitive load. According to Sweller's (1988) Cognitive Load Theory, working memory has finite capacity, and when it is overloaded, learning can be hindered. In L2 drafting, switching between ASR and keyboard may cause cognitive overload, disrupting the writing process. Thus, we hypothesize that the participants' use of this strategy reflects their relatively low working memory capacity, which was alleviated by using ASR-∀ in the initial writing stages.

6.2 ASR-associated Behaviors and Lexical Diversity

Regarding the second research question, eta (η) and eta-squared (η2) tests were conducted to investigate the connection between the writing behaviors employed and the lexical diversity of the written narratives. Our findings show a weak association between ASR combined with keyboarding as in ASR=KB and ASR>ASR=KB, and possibly higher lexical diversity, supporting Leahy and Sweller's (2011) modality effect theory, which postulates that using multiple input modalities (visual and auditory) helps evenly disperse cognitive load, leading to more effective writing outcomes. These behaviors allowed participants to develop and refine ideas while avoiding constant text monitoring and corrections using ASR-∀, thereby resulting in more lexically diverse texts. Likewise, it can be claimed that certain writers may adopt this behavior because they are given more flexibility to use different input modalities to create text.

Another theory that could explain the abovementioned results is the Cognitive Theory of Multimedia Learning proposed by Mayer (2005). According to this theory, learners can process information in two separate channels: a visual/pictorial channel and an auditory/verbal channel. The concurrent use of both methods, as observed in ASR=KB and ASR>ASR=KB, could potentially activate both channels simultaneously, resulting in an increased level of lexical diversity. For ASR-∀ and ASR>KB, on the other hand, writers may have engaged only one channels at a time, possibly explaining the low lexical diversity in texts produced utilizing these behaviors.

Overall, the results demonstrate that integrating ASR and keyboarding in tandem (ASR=KB) can enhance lexical diversity, underscoring ASR's potential as a valuable tool for fostering vocabulary range in writing.

6.3 Limitations and Future Directions

Given the exploratory nature of this research, it is important to acknowledge the limitations inherent in studying uncharted territory. A key limitation is the small sample size, which may restrict the generalizability of our findings. Future research could use a larger sample size to enhance the external validity of the findings. Another limitation is the short duration of the study. Longitudinal designs could provide deeper insights into how the observed behaviors influence lexical diversity over time. Additionally, since there was no control group in the study, it is difficult to attribute the observed effects solely to the use of behaviors used by the participants. Future research should address this gap by incorporating control groups employing alternative input modalities, such as handwriting or keyboarding, to provide a more robust comparison and isolate the specific contributions of ASR. This study did not explicitly control for participant-level variables such as prior ASR experience and native language. However, future studies should consider these factors and explore socio-cultural influences. Finally, future research could examine the relationship between the writing behaviors and other text measures (e.g., sentence complexity) written by ASR.

7 Conclusion

The findings of this study suggest that L2 writers adopt a variety of behaviors for inputting text when interacting with ASR, highlighting the presence of individual differences in their approach. Moreover, the employment of various input modalities (e.g., ASR, keyboarding) can impact the lexical diversity of narrative texts. According to our findings, combining ASR with keyboarding (ASR=KB or ASR>ASR=KB) strongly associated with lexical diversity, while the exclusive use of ASR (ASR-∀) or ASR followed by keyboarding (ASR>KB) did not.

Overall, learning behaviors that can potentially increase lexical diversity (e.g., combining ASR and keyboarding) can improve the development and instruction of ASR-assisted L2 writing. Teachers can leverage ASR as a powerful tool to motivate L2 learners in writing. Combining ASR with keyboarding provides a more efficient way to draft texts, which fosters active engagement and enhances productivity throughout the writing process.

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