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Do Written Language Bursts Mediate the Relations of Language, Cognitive, and Transcription Skills to Writing Quality?

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Abstract

In this study, we examined burst length and its relation with working memory, attentional control, transcription skills, discourse oral language, and writing quality, using data from English-speaking children in Grade 2 ($N = 177$; $M_{age} = 7.19$). Results from structural equation modeling showed that burst length was related to writing quality after accounting for transcription skills, discourse oral language, working memory, and attentional control. Burst length completely mediated the relations of attentional control and handwriting fluency to writing quality, whereas it partially mediated the relations of working memory and spelling to writing quality. Discourse oral language had a suppression effect on burst length but was positively and independently related to writing quality. Working memory had an indirect relation to burst length via transcription skills, whereas attentional control had a direct and indirect relation. These results suggest roles of domain-general cognitions and transcription skills in burst length, and reveal the nature of their relations to writing quality.

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When an individual engages in writing activities, the production of texts does not occur at a constant rate. Instead, text production occurs as an uneven process, consisting of producing a chunk of text such as phrases and clauses, pausing, producing another chunk of text, and pausing (Hayes, 2012a; Kaufer et al., 1986). Periods of producing a chunk of text or "graphomotor activity in-between two consecutive pauses above 2 seconds" during the writing process is called bursts of written language (Limpo & Alves, 2017, p. 308). In other words, bursts of written language (bursts hereafter) refer to "a group of words produced by a writer for inclusion in a text that is bounded by breaks [that is more than 2 seconds] in the production process" (Chenoweth & Hayes, 2003, p. 103).

A growing body of studies indicates that bursts are related to writing proficiency and writing outcomes such as writing quality and writing fluency. Kaufer et al. (1986) found that expert adult writers had longer burst length and higher writing quality than novice adult writers. Studies with children also found a relation between bursts and written composition products/outcomes. In Alves and Limpo's (2015) study, burst length and pause duration predicted students' writing fluency and writing quality after accounting for grade level and composition time for Portuguese-speaking children in Grades 2 to 7. Limpo and Alves (2017) also found that burst length and pause duration predicted writing fluency while burst length predicted writing quality for Portuguese-speaking children in Grade 2. Connelly et al. (2012) reported a relation of burst length to writing quality, and children with developmental language disorder produced shorter burst length compared with an age-matched control group. In the present study, we build on and extend these previous studies by examining the direct and indirect relations of component skills of writing—transcription skills (spelling and handwriting fluency), discourse oral language skill, working memory, and attentional control—to burst length and writing quality.

Products of writing (e.g., writing quality of written composition) are outcomes of writing processes (Hayes & Flower, 1980), and therefore, to understand why writing bursts are related to a written product, we need to consider the writing processes that bursts tap into. Written composition involves recursive processes of planning, translation, transcription, and evaluation (Hayes, 2012a; Hayes & Chenoweth, 2006, 2007). The planning process includes setting goals and subgoals, and generating and organizing ideas. The translation process involves translating the generated ideas into language structure such as lexical items, phrases, and sentences. During the transcription process, the translated linguistic structures are produced in speech and/or written text. The evaluation process involves looking at meeting the writer's goals. According to Chenoweth and Hayes (2001) and Hayes (2012a), bursts primarily tap into the translation process. This was supported by studies with adults, which showed that bursts were present when idea generation was part of the given task while they were not present in a copying task which requires only transcription skills (Hayes & Chenoweth, 2006, 2007). If bursts capture the translation process, oral language skills should relate to writing bursts because the translation process involves access to and retrieval of linguistic knowledge to formulate ideas into linguistic form (vocabulary, phrases, clauses, and sentences). The role of oral language skills in bursts was supported in prior research. For example, Connelly et al. (2012) examined burst length, language skill (i.e., sentence formulation), spelling, and handwriting fluency and found that children's skills in formulating sentences and transcription were independently related to burst length after accounting for working memory, nonverbal ability, and developmental language disorder status.

Evidence also suggests that bursts tap into the transcription process—that is, one's transcription skill likely influences, to some extent, the number of words and letters that can be produced (i.e., bursts). Theoretical models such as the not-so-simple view of writing (Berninger & Winn, 2006), the writer(s)-within-community model (Graham, 2018), and the direct and indirect effects model of writing (Kim & Graham, 2022; Kim & Park, 2019) and a large body of evidence (e.g., Graham & Santangelo, 2014; Santangelo & Graham, 2016) clearly indicate the essential role of transcription skills in writing. Transcription skills are particularly relevant for beginning writers who are rapidly developing them. This hypothesis was supported as burst length was predicted by handwriting fluency and spelling for Portuguese-speaking children in Grade 2 (Limpo & Alves, 2017) and Grades 2 to 7 (Alves & Limpo, 2015). Furthermore, an intervention on handwriting fluency improved second-grade students' burst length as well as writing quality (Alves et al., 2016; Limpo & Alves, 2018). Taken together, these results suggest that bursts likely tap into or capture translation and transcription processes. Then, it is reasonable to hypothesize that bursts are influenced by the skills that are involved in the translation (oral language skills) and transcription processes (transcription skills—handwriting fluency and spelling), at least for developing writers.

If bursts tap into the translation and transcription processes, it is likely that bursts are influenced by domain-general cognitions or executive functions such as working memory and attentional control because domain-general cognitions are important to these processes. Working memory is important to supporting and coordinating writing processes (see Berninger & Winn, 2006; Graham, 2018; Hayes, 2012b; Kellogg, 2001) and skills that contribute to the writing processes (e.g., vocabulary, syntactic knowledge, transcription skills; Kim, 2020; Kim & Park, 2019). Writing text occurs within a limited working memory capacity, and therefore, working memory places constraints on writing processes, including translation and transcription processes, and influences writing outcomes such as writing quality and writing fluency (Berninger & Swanson, 1994; Hayes, 2012b; Kellogg, 2001). Working memory is necessary to maintain lexical and sentence representation for the translation process and phonological, orthographic, and morphological representation for the transcription process (Chenoweth & Hayes, 2001; Kellogg et al., 2007; Kim & Graham, 2022). If bursts capture the translation and transcription processes for which working memory is necessary, working memory would relate to bursts. Indeed, working memory was shown to be important to bursts for adults (Chenoweth & Hayes, 2003) and for developing writers (Connelly et al., 2012).

Attentional control is also hypothesized to be important during writing processes such as translation and transcription according to the not-so-simple view of writing (Berninger & Winn, 2006), cognitive models of writing (Hayes, 2012b; Olive & Kellogg, 2002), the writer(s)-within-community model (Graham, 2018), and the direct and indirect effects model of writing (Kim, 2020; Kim & Park, 2019). For example, disruption of attention causes a reduction in sentence length in sentence generation (Ransdell et al., 2002) and a slowing in word production (Ferreira & Pashler, 2002). Attentional control is also important to the skills that contribute to the writing process, such as oral language and transcription skills. Attentional control is important to spelling and handwriting fluency (Kent et al., 2014; Kim, 2020), and language skills such as vocabulary (Kim, 2016; Stephenson et al., 2008), grammatical/syntactic knowledge (Kim, 2015, 2016), and discourse oral language (Kim, 2020; Strasser & del Rio, 2014).

Literature reviewed above indicates that bursts predict writing outcomes such as writing quality probably because they tap into translation and transcription processes. In line with this speculation, literature suggests that bursts are related to the skills that are involved in transcription and translation processes, including handwriting and spelling skills, oral language skills, and working memory. Despite our growing understanding, however, an important question remains: the direct and indirect nature of relations among domain-general cognitions, oral language, cognitive, and transcription skills; bursts; and writing quality. Evidence indicates that working memory, language, and transcription skills contribute to writing processes captured by bursts (see above) and to writing outcomes such as writing quality (e.g., Abbott & Berninger, 1993; Coker, 2006; Connelly et al., 2012; Graham et al., 1997; Kim et al., 2011, 2015; Kim & Schatschneider, 2017; Mayes & Calhoun, 2007; Perverly et al., 2014), and that bursts predict writing quality (see above). Then, it is reasonable to posit that bursts mediate, at least partially, the relations of domain-general cognitions, oral language, and transcription skills to writing quality (i.e., working memory and attentional control → oral language and transcription skills → bursts → writing quality). To our knowledge, only one previous study tested direct and indirect relations involving bursts. Limpo and Alves (2017) examined the relations of transcription skills (handwriting fluency and spelling) to bursts and writing outcomes (writing quality and writing fluency) with Portuguese-speaking second-grade students. They reported different patterns for spelling versus handwriting fluency: Burst length completely mediated the relation of spelling to writing quality while it partially mediated the relation of handwriting fluency to writing quality. That is, the effect of spelling on writing quality was completely mediated through bursts, whereas handwriting fluency made an independent contribution to writing quality over and above bursts. In the present study, we expand Limpo and Alves's (2017) work by including other important skills such as oral language, working memory, and attentional control. Specifically, we examined the mediating role of bursts with the following hypothesized paths: working memory and attentional control → oral language and transcription skills → bursts → writing quality.

Present Study

Our goal in the present study was to expand understanding of the direct and indirect nature of the relations among language, cognitive, and transcription skills (i.e., working memory, attentional control, spelling, handwriting fluency, and discourse oral language); bursts (burst length); and writing quality, using data from English-speaking students in Grade 2. Discourse oral language was included in the study because it captures ideation (Juel et al., 1986), text generation (Berninger & Winn, 2006), and oral composition (Bereiter & Scardamalia, 1987; Kim, 2020; Kim & Park, 2019), and therefore is a proximal predictor of writing quality in the simple view of writing (Juel et al., 1986) and the direct and indirect effects model of writing (Kim & Graham, 2022; Kim & Park, 2019). We worked with students in Grade 2 for two primary reasons. First, most of Grade 2 children are still in the beginning stage of writing development and rapidly developing skills that contribute to composition such as transcription, oral language, and cognitive skills. In addition, our pilot study indicated that Grade 2 children did not have difficulty writing with the Livescribe Pulse pen, which was used to capture bursts

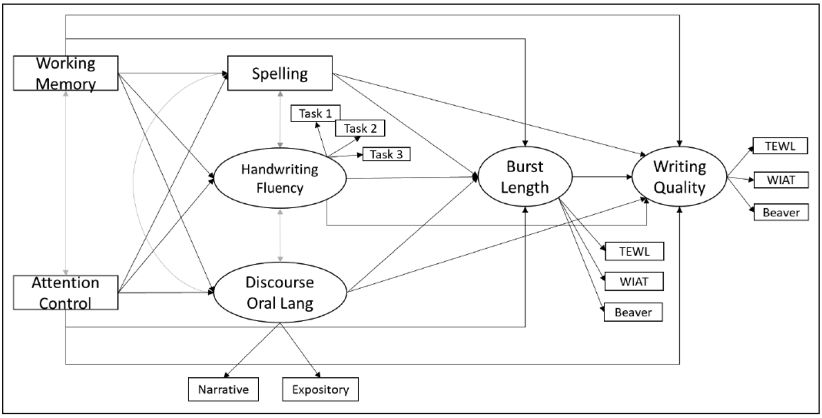

Figure 1. A structural equation model with hypothesized relations among working memory, attentional control, spelling, handwriting fluency, discourse oral language, burst length, and writing quality.
TEWL = Test of Early Written Language–Third edition; WIAT = Essay subtest of the Wechsler Individual Achievement Test-Third edition; Beaver = an experimental writing task, Beaver.

(see below for details), whereas many kindergartners and some first-grade children had a difficulty because the pen was slightly too thick for them (0.6 inch). Specific research questions were as follows.

> **Research Question 1:** Are working memory, attentional control, spelling, handwriting fluency, and discourse oral language related to burst length?
> **Research Question 2:** Does burst length mediate the relations of working memory, attentional control, spelling, handwriting fluency, and discourse oral language to writing quality?

These questions were addressed by a structural equation model where working memory and attentional control were hypothesized to predict spelling, handwriting fluency, and discourse oral language skills, which, in turn, predicted burst length and writing quality, and burst length predicted writing quality (see Figure 1). We hypothesized that language, cognitive, and transcription skills would all be related to burst length (e.g., Alves & Limpo, 2015; Chenoweth & Hayes, 2003; Connelly et al., 2012; Limpo & Alves, 2017). We also expected that burst length would mediate their relations to writing quality (Alves & Limpo, 2015; Connelly et al., 2012; Limpo & Alves, 2017). However, we did not have a clear hypothesis about whether burst length would completely or partially mediate their relations. Full mediation would mean that the effects of language (discourse oral language), cognitive (working memory, attentional control), and transcription skills (spelling and handwriting fluency) on writing quality are completely mediated or explained by burst length. Partial mediation would mean that although burst length captures the effect of language, cognitive, and transcription skills on writing, it does not fully capture their effects on writing quality, and therefore, language, cognitive, and transcription skills would be independently related to writing quality over and above burst length.

Method

Participants

Data were from children in Grade 2 (N = 177; 54% girls; M_{age} = 7.19, SD = 0.34) from 44 classrooms in 7 schools in the Southeastern region of the United States. These children participated in a longitudinal study of language and literacy development from kindergarten to Grade 2 (see Kim, 2017, which focuses on vocabulary in kindergarten). In the present study, the participating students' data in Grade 2 were used because their writing burst data were collected in Grade 2. The sample children were composed of 54% Whites, 35% African Americans, and 3% Hispanics. Two children received services for developmental language disorder, and one child was identified to have a developmental delay. The majority of children, 72%, were eligible for free and reduced lunch, and only one student was classified as an English learner according to the school district record. Participating teachers indicated that there was no official writing curriculum adopted at the district level, but they used the writer's workshop approaches in writing instruction.

Measures

Written composition. Written composition was measured by the following three writing tasks: The Test of Early Written Language–Third edition (TEWL-3; Hresko et al., 2012), the Essay subtest of the Wechsler Individual Achievement Test-Third edition (WIAT-III; Wechsler, 2009), and an experimental task called Beaver. In TEWL, the student was presented with an illustration and was told a story that goes with the illustration. Afterward, the student was shown another illustration and was asked to write a story that goes with that illustration. In the WIAT Essay task, the student was asked to write about his or her favorite game and three reasons for it. The Beaver task was a source-based writing task in which the student was provided with a passage about beavers (297 words; adapted from the Qualitative Reading Inventory [QRI]; Leslie & Caldwell, 2011). The original Beaver text did not include any illustrations, but three accompanying illustrations using publicly available images were added in the present study to aid comprehension of the text. The student was asked to write about what beavers do and how they do it. The student was given access to the beaver text while composing. Each of these three writing tasks was administered in different sessions. For each task, students were given 15 minutes to write in line with previous studies (Graham et al., 2002; Kim et al., 2015; Olinghouse, 2008).

Writing quality. Students' essays were typed up verbatim into a word file. Then, the typed-up versions of written compositions were used to code for writing quality—the extent to which ideas were developed and presented in an organized manner, on a rating scale of 1 to 10 (for a similar approach, see Graham et al., 2007; Hooper et al., 2002; Olinghouse, 2008). Compositions with clearer ideas, greater relevant rich details, and more logical arrangement of ideas (both globally and locally) received higher scores. Training of raters consisted of an initial meeting where the rubric and anchor essays were reviewed. Then raters independently practiced applying the rubric to written compositions, and met to discuss their scores, discuss and resolve any discrepancies, and update anchor essays as necessary. After several iterations, 40 written samples for each writing task (i.e., 120 written compositions) were used for reliability, and interrater agreement, Cohen's kappa, ranged from .81 to .96. After achieving reliability, the raters independently coded written compositions, but approximately 40% of them were cross-checked or double scored to ensure maintenance of reliability.

Burst length. To collect students' writing burst data, the student completed the above noted writing tasks using a digital pen, a Livescribe Pulse, and a paper sheet. The Livescribe Pulse looks like a regular pen, but has an infrared camera at its nib, which logs handwriting data. The paper had a microdotted pattern printed on it. The writing burst data were obtained by uploading students' handwritten composition to the HandSpy web application, which displays students' real-time writing process (see Limpo & Alves, 2017). Following previous studies, a burst was defined as graphomotor activity between two consecutive pauses longer than 2 seconds. Any time a word was split in two bursts (i.e., existence of a 2-second pause within a word), the full word was included in the burst where the greater part of the word was written. Training of scorers involved an initial meeting where the scoring manual was introduced, followed by a training on the HandSpy web application by Teresa Limpo who was also available for subsequent troubleshooting. Research assistants then had practice sessions until they reached a minimum of 95% exact agreement using 40 written samples.

Discourse oral language. Discourse oral language skill was measured by one narrative task, the Test of Narrative Language (TNL; Gillam & Pearson, 2004), and one experimental informational/expository task. There were three tasks in the TNL. In the first two tasks, the student heard a narrative story and was asked to retell the story; in the third task, the student was provided with an illustration and was asked to produce a story that goes with the illustration. In the experimental informational task, the student heard three informational texts from QRI (Leslie & Caldwell, 2011) and was asked to retell them after hearing each. Note that retell captures one's ability to recall and organize ideas based on the listener's mental model, and oral retell ability and oral production ability were found to be best described as a single construct (Gillam & Pearson, 2004).

Students' retell and production were digitally recorded and transcribed verbatim following the Systematic Analysis of Language Transcripts guidelines (Miller & Iglesias, 2006). The transcribed version was used for evaluation of quality. In the TNL tasks, quality was evaluated as the extent to which the student's retell included key narrative elements—the introduction, main characters, setting, mainline events, problem, resolution, and closing—and logical sequence of ideas (e.g., Barnes et al., 2014; Scott & Windsor, 2000).

For the informational texts, quality was evaluated as the extent to which main ideas and key details were included (see Kim & Schatschneider, 2017; Wagner et al., 2011). Exact agreement ranged from .90 to .99 using 50 retells.

Spelling. A researcher-developed experimental dictation task was used. The student heard a target word, a sentence with the target word, and then the target word again. The task included 22 items of developmentally appropriate words and spelling patterns that are relevant for students in second grade (e.g., *phone, shopping, marched*). Each item was scored dichotomously (correct = 1) for the total possible score of 22. Exact agreement in scoring was 98%, and any discrepancies were resolved through discussion. Cronbach's alpha was estimated to be .92.

Handwriting fluency. Three sentence-copying tasks (e.g., Wagner et al., 2011) were used to measure handwriting fluency. The sentences included a pangram, *The quick brown fox jumps over the lazy dog*, as well as two experimental sentences, *My dog jumps and runs when I tell him to jump and run*, and *My mom put the lid on the pan to cook the food*. The student was presented with each sentence and was asked to copy it as many times as possible in 1 minute. The number of correctly copied letters was counted. Interrater agreement (the extent to which students' handwriting fluency scores were identical between scorers) was .90 based on 40 samples for each sentence-copying task.

Working memory. A listening span task (Daneman & Merikle, 1996; Kim, 2016, 2017) was used. In this task, the student was presented with a short sentence involving common knowledge familiar to children (e.g., Apples are blue) and was asked to identify whether the heard sentence was correct or not. The child heard multiple sentences (i.e., two to four) and was asked to identify the last word of each sentence. Children's yes/no responses regarding the veracity of the statements were not scored, but their responses on the last words in correct order were given a score of 0 to 2: correct last words in correct order were given 2 points, correct last words in incorrect order were given 1 point, and incorrect last words were given 0 point. There were four practice items and 13 experimental items with the total possible score of 26. Testing discontinued after three incorrect responses. Cronbach's alpha was estimated to be .77.

Attentional control. The Strengths and Weaknesses of ADHD Symptoms and Normal Behavior Scale (SWAN; Swanson et al., 2012; see also Arnett et al., 2013, for validity evidence) was used to measure children's behavioral attentiveness (e.g., "Engages in tasks that require sustained mental effort"). SWAN is a behavioral checklist that includes 30 items that are rated on a 7-point scale ranging from 1 (*far below average*) to 7 (*far above average*). Higher scores represent greater attentiveness. Participating children's teachers completed the SWAN checklist. Cronbach's alpha was estimated to be .98.

Procedures

Research assistants worked with students in a quiet space in the school. The measures were administered in three individual sessions and three group sessions, and the order of administration was as follows. Discourse oral language (TNL retell and expository retell) and working memory tasks were administered individually in three separate sessions. These were followed by the written composition, spelling, and handwriting fluency tasks, which were administered in groups (e.g., three to four children). Written composition and handwriting fluency each had three tasks, and these were assessed in three separate group sessions. Specifically, the Sentence Copying Task 1, spelling, and TEWL composition tasks were administered together in one group session. The Beaver task and the Sentence Copying Task 2 were administered in the second group session. This was followed by the Sentence Copying Task 3 and the WIAT composition task in the third group session. Across all the sessions, administration was allowed to discontinue if student fatigue was an issue although no students discontinued tasks in group sessions.

Data Analysis Strategy

Primary data analytic strategies were confirmatory factor analysis and structural equation modeling. M*plus* 8.1 software (Muthén & Muthén, 2017) with full information maximum likelihood estimation was used. Latent variables were created for constructs that were measured with multiple tasks: writing quality, writing burst length, discourse oral language, and handwriting fluency. Spelling, working memory, and attentional control were, respectively, measured by single measures and therefore observed variables were used for these constructs.

The two research questions were addressed by fitting the structural equation model shown in Figure 1. The prediction of spelling, handwriting fluency, and discourse oral language skills by working memory and attentional control was based on the direct and indirect effects model of writing as well as associated evidence (Kim, 2020; Kim & Graham, 2022; Kim & Park, 2019; Kim & Schatschneider, 2017). To test direct relations of domain-general cognitive skills to burst length and writing quality over and above transcription and discourse oral language skills, working memory and attentional control were allowed to directly predict burst length and writing quality. Similarly, spelling, handwriting fluency, and discourse oral language skills were allowed to have direct paths to writing quality over and above burst length. Note that when we included child age in the statistical model, it was not related to bursts or writing quality after accounting for the other variables in the model. Therefore, we report the results without including age for parsimony.

Model fit was evaluated by the chi-square statistic, comparative fit index (CFI; $>.90$ as acceptable), root mean square error of approximation (RMSEA; $<.10$ as acceptable), and standardized root mean square residual (SRMR; $<.08$ as acceptable).

Results

Descriptive Statistics and Preliminary Analyses

Missingness ranged from 2% in spelling and handwriting fluency to 15% in burst length in the WIAT writing task. The vast majority of missing data in writing bursts were due to malfunction of the Livescribe pen (22 cases in the WIAT task, four cases in the TEWL task, and three cases in the Beaver task). An

Table 1. Descriptive Statistics.

Variable	*N*	*M*	*SD*	Min	Max	Skewness	Kurtosis
Working memory	175	6.86	4.17	0	18	0.22	−0.27
SWAN (attentional control)	177	121.04	30.86	40	210	0.41	0.44
TNL retell	177	31.36	11.77	0.00	52.00	−0.44	−0.29
Expository retell	177	10.92	7.65	0.00	42.00	0.78	0.93
Spelling	173	10.31	6.03	0.00	22.00	−0.06	−1.03
Handwriting1 LCPM	173	39.80	17.45	3.00	91.00	0.26	−0.31
Handwriting2 LCPM	172	40.41	17.01	0.00	94.00	0.14	−0.17
Handwriting3 LCPM	172	48.22	18.17	0.00	99.00	0.05	−0.03
TEWL quality	173	3.25	1.50	0.00	9.00	0.12	1.26
TEWL burst length	168	1.77	1.07	0.29	5.97	1.23	1.63
WIAT quality	172	2.44	1.26	0.00	6.00	0.15	−0.06
WIAT burst length	150	2.02	1.48	0.14	9.78	2.34	7.20
Beaver quality	173	2.12	1.23	0.00	5.00	−0.57	−0.74
Beaver burst length	169	1.13	0.71	0.00	4.17	1.59	3.17

Note. SWAN = Strengths and Weaknesses of ADHD Symptoms and Normal Behavior Scale; TNL = Test of Narrative Language; LCPM = letter correctly spelled per minute; TEWL = Test of Early Written Language; WIAT = Wechsler Individual Achievement Test; Beaver = Beaver writing prompt; ADHD = attention deficit hyperactivity disorder.

exception was one Livescribe file for the Beaver task could not be located for analysis, despite our record showing that it was uploaded to the HandSpy software. According to the Little's test, the hypothesis that data are missing completely at random could not be rejected: $\chi^2 = 56.273$, $df = 54$, $p = .39$.

Table 1 displays descriptive statistics. Mean writing quality ranged from 2.12 in the Beaver task to 3.25 in the TEWL writing task, with sufficient variation around the means. Mean burst length ranged from 1.13 in the Beaver task to 2.02 in the WIAT task. Distributional properties as indicated by skewness (≤ 3) and kurtosis (< 7) were in the acceptable ranges (West et al., 1995).

Bivariate correlations are displayed in Table 2. Burst length was moderately related to writing quality ($.31 \leq r\text{s} \leq .48$), and discourse oral language and transcription skills were weakly to moderately related to writing quality ($.25 \leq r\text{s} \leq .59$). Discourse oral language skills measured by the TNL and QRI tasks were weakly related to burst length ($.14 \leq r\text{s} \leq .28$), whereas spelling and handwriting tasks were moderately to strongly related to burst length ($.43 \leq r\text{s} \leq .63$). Working memory and attentional control were weakly to moderately related to burst length ($.22 \leq r\text{s} \leq .33$), discourse oral

Table 2. Correlations Between Variables.

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Working memory	—												
2. Attentional control	.25	—											
3. TNL retell	.18	.24	—										
4. Expository retell	.32	.25	.54	—									
5. Spelling	.42	.37	.26	.41	—								
6. Handwriting1 LCPM	.29	.21	.29	.32	.52	—							
7. Handwriting2 LCPM	.44	.21	.24	.26	.49	.77	—						
8. Handwriting3 LCPM	.34	.23	.26	.26	.49	.65	.70	—					
9. TEWL burst length	.25	.25	.14+	.19	.48	.61	.63	.46	—				
10. WIAT burst length	.22	.27	.28	.15+	.43	.57	.51	.48	.55	—			
11. Beaver burst length	.26	.33	.17	.16	.53	.60	.55	.51	.68	.60	—		
12. TEWL quality	.34	.18	.25	.37	.55	.52	.46	.42	.43	.34	.46	—	
13. WIAT quality	.39	.40	.30	.33	.59	.48	.49	.44	.35	.31	.40	.44	—
14. Beaver quality	.38	.31	.31	.32	.43	.40	.43	.33	.37	.27	.48	.49	.48

Note. All coefficients are statistically significant at .05 except for those marked with +; Attentional control measured by SWAN = Strengths and Weaknesses of ADHD Symptoms and Normal Behavior Scale; TNL = Test of Narrative Language; LCPM = letter correctly spelled per minute; TEWL = Test of Early Written Language; WIAT = Wechsler Individual Achievement Test; Beaver = Beaver writing prompt; ADHD = attention deficit hyperactivity disorder.

language ($.18 \leq r$s $\leq .32$), transcription skills ($.21 \leq r$s $\leq .44$), and writing quality ($.18 \leq r$s $\leq .40$).

The observed variables for each latent variable—writing quality, burst length, discourse oral language, and handwriting fluency—were moderately to strongly related to each other (Table 2). For example, the three handwriting fluency tasks were strongly related ($.65 \leq r$s $\leq .77$), and burst lengths from the three writing tasks were moderately to strongly related ($.55 \leq r$s $\leq .68$). Confirmatory factor analysis was conducted for the latent variables of writing quality, writing burst length, discourse oral language, and handwriting

Table 3. Correlations Between Latent Variables (Writing Quality, Writing Burst Length, Handwriting Fluency, and Discourse Oral Language) and Observed Variables (Spelling, Working Memory, and Attentional Control).

Variables	1	2	3	4	5
1. Writing quality	—				
2. Writing burst length	.72	—			
3. Spelling	.77	.61	—		
4. Handwriting fluency	.77	.82	.59	—	
5. Discourse oral language	.60	.27	.46	.40	—
6. Working memory	.53	.33	.41	.43	.36
7. Attentional control	.44	.37	.37	.25	.31

Note. All coefficients are statistically significant at .01 level.

fluency, and loadings ranged from strong to very strong ($.63 \leq \lambda s \leq .89$, $ps < .001$; see Figure 1).

Correlations between the latent variables (i.e., writing quality, writing burst length, discourse oral language, and handwriting fluency) and with the observed variables (i.e., spelling, working memory, and attentional control) are shown in Table 3. Burst length was strongly related to writing quality ($r = .72$). Spelling ($r = .61$) and handwriting fluency ($r = .82$) were strongly related to burst length, whereas discourse oral language was positively but weakly related to burst length ($r = .27$). Working memory was moderately related to writing quality ($r = .53$) and burst length ($r = .33$). Similarly, attentional control was also moderately related to writing quality ($r = .44$) and burst length ($r = .37$).

The Relations Among Working Memory, Attentional Control, Spelling, Handwriting Fluency, Discourse Oral Language, Burst Length, and Writing Quality

The structural equation model in Figure 1 was fitted to the data, and the model fit was excellent: $\chi^2(59) = 89.81$, $p = .006$, CFI = .97, RMSEA = .05 [.03-.08], SRMR = .04. However, there was a multicollinearity problem—because of the strong relation between handwriting fluency and burst length ($r = .82$), both were not statistically significantly related to writing quality (see the appendix). Therefore, the direct path of handwriting fluency to writing quality was removed. The model fit of the revised model (Figure 2) was excellent: $\chi^2(60) = 92.57$, $p = .04$, CFI = .97, RMSEA = .06 [.03-.08],

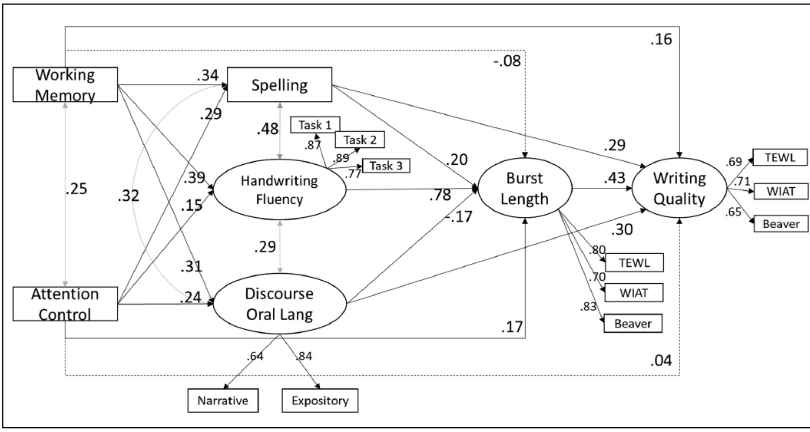

Figure 2. Standardized coefficients and loadings for the final structural equation model.
Note. Solid lines represent statistically significant relations, whereas dashed lines represent nonsignificant relations at .05 level. Gray lines with double headed arrows represent covariances (correlations).

SRMR = .04. Because the model fit of the revised model did not significantly differ from the original model, $\Delta\chi^2 = 2.76$, Δdegrees of freedom = 1, $p = .10$, the revised model shown in Figure 2 was chosen as the final model for parsimony.

Standardized coefficients are presented in Figure 2. The first research question was about the relations of working memory, attentional control, transcription, and discourse oral language skills to burst length. Working memory and attentional control were both independently related to spelling, handwriting fluency, and discourse oral language (.15 to .39, *p*s $< .05$). Attentional control was weakly but directly related to burst length (.17, $p = .005$), whereas working memory was not directly related to burst length (−.08, $p = .22$). Spelling was weakly related to burst length (.20, $p = .008$), whereas handwriting fluency was strongly related to writing burst length (.78, $p < .001$). Discourse oral language had a weak, but statistically significant suppression effect on writing burst length (−.17, $p = .03$).

The second research question was whether burst length mediates the relations of working memory, attentional control, transcription, and discourse oral language skills to writing quality. Results in Figure 2 show that working memory (.16, $p = .02$), spelling (.29, $p < .001$), discourse oral language (.30, $p < .001$), and burst length (.43, $p < .001$) were all positively and independently related to

Table 4. Indirect and Total Effects for Burst Length and Writing Quality, Using Standardized Estimates, Based on the Results in Figure 2.

	Burst length		Writing quality	
Skills	Indirect effect (*SE, p*)	Total effect (*SE, p*)	Indirect effect (*SE, p*)	Total effect (*SE, p*)
Working memory	.32 (.07, <.001)	.24 (.08, .002)	.29 (.06, <.001)	.45 (.07, <.001)
Attentional control	.13 (.07, .04)	.31 (.08, <.001)	.29 (.06, <.001)	.32 (.08, <.001)
Spelling	—	.20 (.08, .008)	.09 (.04, .02)	.37 (.08, <.001)
Handwriting fluency	—	.78 (.07, <.001)	.33 (.07, <.001)	.33 (.07, <.001)
Discourse oral language	—	−.17 (.08, .03)	−.07 (.04, .052)	.22 (.09, .01)

writing quality, whereas attentional control (.04, $p = .59$) was not independently related to writing quality. In other words, burst length partially mediated the relations of working memory, spelling, and discourse oral language to writing quality, whereas it completely mediated the relations of attentional control and handwriting fluency.

Indirect effects and total effects (direct and indirect effects) of the included skills on burst length and writing quality are reported in Table 4. Working memory (.32) and attentional control (.13) had statistically significant indirect effects on burst length via discourse oral language, spelling, and handwriting fluency. Indirect effects of working memory, attentional control, and handwriting fluency on writing quality were also substantial, ranging from .29 to .33. The indirect effects of working memory and attentional control on writing quality were via spelling, handwriting fluency, discourse oral language, and burst length. The indirect effect of handwriting fluency on writing quality was completely via burst length. The included variables explained 77% of total variance in burst length and 83% of variance in writing quality.

Discussion

Prior evidence suggests that bursts likely tap into translation and transcription processes and relate to writing outcomes such as writing quality. In the present study, our goal was to elucidate the nature of relations of burst length, working memory, attentional control, discourse oral language, spelling, and handwriting fluency to writing quality, using data from English-speaking students in

Grade 2. Overall, we found that language, cognitive, and transcription skills were related to burst length and writing quality; burst length was related to writing quality; and burst length differentially mediated the relations of cognitive and transcription skills to writing quality. The relation of burst length to writing quality is convergent with prior evidence (Alves & Limpo, 2015; Connelly et al., 2012; Limpo & Alves, 2017), and the present study extends previous work by showing its relation over and above well-established key skills, such as spelling, handwriting fluency, discourse oral language, working memory, and attentional control. In other words, children who wrote more words and letters per burst episode had higher quality of written composition, even after controlling for the included language, transcription, and domain-general cognitive skills. The included variables explained the vast majority of total variance in writing quality (83%).

Our hypothesis that bursts are predicted by transcription and language skills was partially supported. We found that burst length was strongly predicted by handwriting fluency and was weakly but independently predicted by spelling, suggesting that students with advanced handwriting fluency and spelling skills had longer burst length. These findings are in line with previous studies (Alves & Limpo, 2015; Connelly et al., 2012; Limpo & Alves, 2017), and suggest that transcription skills influence the writing process captured by burst length. In other words, burst length taps into the transcription process. By contrast, discourse oral language was weakly but positively related to burst length in bivariate correlations (.27; see Table 3), but when it was included in a model simultaneously with the other variables, it had a weak suppression effect. The suppression effect appears to be due to the relations of discourse oral language with spelling and handwriting fluency, which were strongly related to *both* burst length and writing quality (Table 3). The current finding is divergent with that of Connelly et al. (2012), who reported a unique relation of an oral language skill, sentence construction, to burst length. There might be several potential explanations for the divergent finding. The first one is a difference in study sample. Connelly et al.'s study was composed of children with developmental language disorder and their typically developing peers. As such, the study included a greater representation of children with developmental language disorder than the present study, and for such a sample, the role of oral language skills during the translation process (captured by bursts) may be particularly evident compared with a sample mostly composed of typically developing children as in the present study. The translation process involves accessing and retrieving linguistic knowledge to produce words and sentences, and children with developmental language disorder have difficulties and problems with these processes, which would affect the translation process during writing.

The second potential explanation is that sentence construction skill, compared with discourse oral language skill, may be particularly important to the translation process (Hayes & Flower, 1986). In other words, the translation process may be more heavily dependent on lower level language skills such as vocabulary or sentence construction than on discourse oral language. Discourse oral language is a high-order language skill that captures ideation/oral composition (i.e., mental representation of text; Juel et al., 1986; Kim, 2020; Kim & Park, 2019). As such, discourse oral language is a complex skill that draws on and captures a multitude of language skills (e.g., vocabulary, syntactic knowledge), cognitions (e.g., working memory, inference, perspective taking), and knowledge (topic, world, and discourse knowledge; Kim, 2016). Although discourse oral language is important to writing processes and writing products (Berninger & Abbott, 2010; Juel et al., 1986; Kim & Schatschneider, 2017), sentence construction may have immediate relevance to the translation process (e.g., Saddler & Graham, 2005) captured by bursts, particularly for children who are still developing sentence-level skills.

A third explanation for the divergent finding between the present study and Connelly et al.'s (2012) work is a difference in data analysis. In the present study, burst length was included as a mediator in a structural equation model so that the relation of discourse oral language to burst length was examined in the context of writing quality and other predictors. Connelly et al.'s study did not address the question of mediation, employing a multiple regression model where burst length was the outcome and oral language was one of the predictors.

It should be noted that although discourse oral language did not have a positive independent relation to burst length, it had an independent and positive relation to writing quality after accounting for burst length, spelling, handwriting fluency, working memory, and attentional control. As noted above, discourse oral language captures oral composition or ideation and is posited to be important to writing performance. The role of discourse oral language found in this study is convergent with previous studies (Berninger & Abbott, 2010; Juel et al., 1986; Kim & Schatschneider, 2017) and indicates that children's ability to produce oral texts is important to writing quality.

The unique and independent role of attentional control in burst length is novel in the present study. The role of attentional control in writing is recognized in theoretical models (Berninger & Winn, 2006; Graham, 2018; Hayes, 2012b; Kim, 2020; Kim & Park, 2019), and previous studies showed its role in writing quality (Kent et al., 2014; Kim, 2020), word and sentence production processes (Ferreira & Pashler, 2002; Ransdell et al., 2002), and transcription and language skills (Kim, 2020; Kim & Graham, 2022; Stephenson et al., 2008). The present study showed that attentional control makes a contribution to burst length both directly and indirectly. The indirect contribution was via transcription skills, indicating students who were better at attentional control had more advanced transcription skills, which contributed to producing more words and letters per burst period (see Table 4 and Figure 2). The direct contribution indicates that students with better attentional control also produced more words and letters per burst period even after accounting for transcription skills. These results underscore the role of attentional control in writing processes and writing products. In fact, the contribution of attentional control to writing quality was completely mediated by burst length and language and transcription skills (i.e., spelling, handwriting fluency, and discourse oral language; see Figure 2).

In contrast to attentional control, working memory was not directly related to burst length over and above transcription skills, discourse oral language, and attentional control. The lack of a direct relation does not indicate absence of its contribution to burst length. Instead, what the present results indicate is that the relation of working memory to burst length was mediated by transcription skills. In fact, the indirect effect of working memory on burst length was substantial (see Table 4). Although the absence of a direct relation to burst length is divergent with Connelly et al.'s (2012) work, as noted above, the results cannot be directly compared due to the difference in what was accounted for in the statistical models.

The results also revealed differential mediating roles of burst length in the relations of the domain-general cognitive and transcription skills to writing quality: Burst length completely mediated the relations of attentional control and handwriting fluency to writing quality, whereas it partially mediated the relations of working memory and spelling to writing quality. The roles of attentional control and handwriting fluency in written composition are well-recognized in theoretical models (Berninger & Winn, 2006; Kim, 2020; Kim & Park, 2019) and are backed by evidence (e.g., Abbott & Berninger, 1993; Kim, 2020; Santangelo & Graham, 2016). The present findings indicate that their roles in writing quality are largely tapped or captured by burst length and that their indirect effects on writing quality are substantial, at least for English-speaking children in Grade 2. In contrast, burst length partially mediated the relations of working memory and spelling to writing quality, suggesting that for English-speaking second graders, burst length does not fully capture the roles of working memory and spelling in writing quality.

Interestingly, the current pattern of mediation results for handwriting fluency and spelling is opposite of what was reported in a previous study with Portuguese-speaking children in Grade 2. Limpo and Alves (2017) reported a complete mediation by burst length for the relation between spelling and writing quality, and a partial mediation for the relation between handwriting fluency and writing quality. Reasons for these discrepancies are not clear. One potential explanation is a difference in what was accounted for in the statistical model. Limpo and Alves' study included handwriting fluency, spelling, burst length, and pause duration, whereas the present study additionally included discourse oral language, working memory, and attentional control. The studies also differ in terms of measurement—in the present study, bursts, writing quality, handwriting fluency, and discourse oral language were measured with multiple tasks and therefore latent variables were used for these constructs, which reduces measurement error, whereas all the skills in Limpo and Alves' study were measured by single tasks. Finally, the spelling task in Limpo and Alves' study was taken from written composition, whereas ours was a separate measure. Future replications are needed to clarify the nature of the mediating role of burst length in the relations between transcription skills and writing quality.

The present findings overall add to our theoretical understanding about the relations between writing processes and the skills that contribute to them. As noted above, writing involves iterative processes of planning, translation, transcription, and evaluation. Bursts are hypothesized to capture two of these processes, translation and transcription (see evidence in the literature review section above), and thus, to relate to writing quality, an outcome or product of writing processes. Our results, along with previous studies, support this hypothesis. Furthermore, as writing processes draw on a number of skills and knowledge such as language, cognition, content and discourse knowledge, and transcription skills (Berninger & Winn, 2006; Graham, 2018; Hayes, 2012b; Kim, 2020; Kim & Graham, 2022), these skills should relate to bursts, an indicator that captures translation and transcription processes. If these skills contribute to writing processes, and writing processes contribute to written outcomes, a corollary is the nature of direct and indirect relations (partial or complete mediation) among them. This was shown in the present study and adds to our understanding of the nature of relations (e.g., see the direct and indirect effects model of writing; Kim & Graham, 2022; Kim & Park, 2019).

The correlational nature of the present study precludes any causal inferences. Nonetheless, taken together with prior work, the present study highlights the importance of developing transcription skills as well as domain-general cognitions for writing processes, as captured by burst length, and for written products (writing quality; Graham et al., 2012; Graham & Santangelo, 2014; Santangelo & Graham, 2016). Obviously, achieving longer bursts per se is not the goal of writing; instead, the goal is to achieve quality writing. However, burst length is important because it is an indicator of underlying writing processes, which contribute to writing products such as writing quality. The results in this study indicate that children who have more advanced working memory, attentional control, spelling, and handwriting fluency have longer bursts, which, in turn, result in higher quality written composition. These results, in conjunction with existing evidence (e.g., Alves & Limpo, 2015; Coker, 2006; Connelly et al., 2012; Kim & Graham, 2022; Kim & Schatschneider, 2017; Limpo & Alves, 2017, 2018; Santangelo & Graham, 2016), further support the importance of developing language, transcription, and cognitive skills for writing development. A large body of previous studies has shown that attentional control, spelling, and handwriting fluency are malleable with quality instruction (see Graham & Santangelo, 2014; Peng & Miller, 2016; Santangelo & Graham, 2016, for meta-analyses). Although discourse oral language was not independently positively related to burst length after controlling for transcription skills, working memory, and attentional control, it made a unique contribution to writing quality in the present study. Thus, instruction to improve discourse oral language skill is expected to have a positive effect on students' writing skills.

Limitations and Future Directions

As with any study, the generalizability of the findings should be limited to the population from which the sample was drawn—that is, English-speaking second graders many of whom were from low socioeconomic families. Thus, the present study needs to be replicated and extended in future studies with individuals in different developmental phases and those learning in languages other than English. Furthermore, in the present study we did not distinguish between bursts for text production and bursts for revision because of the absence of revision bursts. Previous work with adults included bursts for text production (P-bursts) and for revision (R-bursts; Chenoweth & Hayes, 2001). However, R-bursts did not occur in our sample of second-grade children, which is in line both with the finding that beginning writers rarely engage in revision (Graham et al., 1995) and with previous work that examined bursts with developing writers (e.g., Alves & Limpo, 2015; Alves et al., 2016; Connelly et al., 2012; Limpo & Alves, 2017, 2018).

Another important direction in future studies is inclusion of a sentence construction skill. In the present study, we used discourse oral language as a proximal predictor of written composition in line with the simple view of writing (Berninger et al., 2002; Juel et al., 1986) and the direct and indirect effects model of writing (Kim & Park, 2019; Kim & Schatschneider, 2017). Discourse skill, of course, is built on smaller grain sizes such as sentences and phrases. Therefore, sentence generation is a key part of text generation, and was recognized as a critical skill for the writing process (Hayes & Flower, 1986). Poor sentence construction impacts the quality of written composition (Saddler & Graham, 2005), and inefficient sentence construction can interfere with other composition processes by demanding cognitive resources (e.g., Bereiter & Scardamalia, 1987; Saddler & Graham, 2005). Furthermore, fourth graders who received sentence construction instruction improved their story writing and employed sentence construction skills in revising their drafts (Saddler & Graham, 2005).

Future replications are also needed with a larger sample size with all the constructs measured with greater precision. There is no simple answer about a sufficient sample size for structural equation models as it depends on the complexity of the model, quality of the measures, and distributional properties of the variables. Because sample size has important implications for statistical power, standard error, and associated p-values, in studies with insufficient sample sizes coefficients with small or even moderate magnitudes may not reach conventional statistical significance ($p < .05$). In the present study, all the paths were statistically significant except for those with very weak or little relations (standardized coefficients of .04 and −.08). Furthermore, it would have been ideal to measure all of the included constructs with multiple tasks and use latent variables, which reduces measurement error. This was not allowed in this study due to the constraints of working in schools where researchers are given limited time to work with students.

Overall, our results suggest that burst length is influenced by transcription skills and domain-general cognitions, and partially or completely mediates the relations of language, cognitive, and transcription skills to writing quality. Future studies are needed to investigate whether instruction on these skills improves writing processes captured by bursts and writing quality (e.g., Alves et al., 2016).

Appendix

Results of the Original Model (Figure 1)

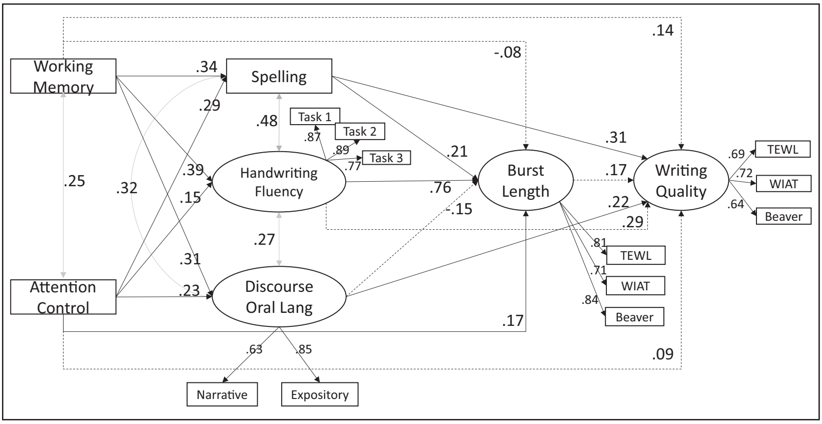

Figure A1. Standardized coefficients and loadings for the original structural equation model where handwriting fluency was allowed to have a direct path to writing quality.
Note. Solid lines represent statistically significant relations, whereas dashed lines represent nonsignificant relations at .05 level. Gray lines with double headed arrows represent covariances (correlations).

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