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The contribution of inhibitory control to early literacy skills in 4- to 5-year-old children

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ABSTRACT

Inhibitory control is associated with the pre-academic skills, nevertheless it is unclear the role of the diverse inhibitory control dimensions especially in the development of early literacy skills. In the present longitudinal study, the multi-componential structure of inhibitory control was investigated, and the roles of two different inhibitory control abilities were examined with respect to early literacy skills, with other variables (vocabulary, working memory, and visual-motor integration skills) controlled. A sample of 147 typically developing children from 4 to 5 years of age was assessed in the winter (T1) and then in the spring (T2) at a preschool educational center. Confirmatory factor analysis yielded a response inhibition dimension and an interference suppression dimension. Path analysis was conducted to examine the contribution of these dimensions, considered formative indices, on phonological awareness and procedural writing knowledge, with the other variables controlled. The latent change score approach was used to investigate the variables associated with change in phonological awareness and procedural writing knowledge at T1 and T2. Our results demonstrated that interference suppression was concurrently associated with phonological awareness and procedural writing knowledge tasks together with the other measures at T1. Moreover, interference suppression is associated with changes in phonological awareness, whereas the other measures did not contribute significantly to literacy growth.

1. Introduction

During the preschool years, several pre-academic skills needed for later academic achievement are acquired (Duncan et al., 2007) and contribute to young children's school readiness (Willoughby, Magnus, Vernon-Feagans & Blair, 2017). Among these pre-academic skills, phonological awareness and early procedural knowledge related to the specific symbols and conventions involved in the production of writing (Puranik & Lonigan, 2014) are some of the most crucial precursors for literacy abilities (e.g. Caravolas, Hulme & Snowling, 2001) also in transparent orthographies (Torppa et al., 2016).

According to the 'not so simple view model' (Berninger & Winn, 2006), domain-general factors, such as self-regulation abilities, play a role in developing literacy skills (Gerde, Skibbe, Bowles & Martoccio, 2012 Puranik, Boss & Wanless, 2019). Self-regulation is a multidimensional construct (Baumeister & Vohs, 2004) encompassing different abilities such as working memory, attentional flexibility, and inhibitory control (Happaney, Zelazo & Stuss, 2004; McClelland & Cameron, 2012) that may be differently associated with early literacy skills.

Among self-regulation abilities, inhibitory control, which supports the voluntary control of behavior, emotions, and thoughts (Diamond, 2013), seems to play an important role when other associated variables are considered (Allan, Hume, Allan, Farrington & Lonigan, 2014). Inhibitory control itself is a multidimensional construct, with different abilities already differentiated in early childhood. Particularly, within the inhibitory control construct, a distinction exists between the ability to suppress impulses and behavioral responses that (although dominant or automatized) are not functional to the task's goal (response inhibition), and the ability to overcome interference due to external distracting information or different response options in performing a task (interference suppression). These two different inhibitory dimensions may account for early literacy skills in unique ways; nevertheless, previous research has not considered this distinction, and response inhibition tasks have primarily been used (Table 1). Given that insight into the role of different inhibitory components might deepen our understanding of the cognitive processes involved in early literacy skills, in the present study, we examined the contribution of these various inhibitory control dimensions to early literacy skills in children aged 4 to 5 years old while simultaneously considering

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Table 1
Review of studies on the association between inhibitory abilities and early literacy skills in preschool and kindergarten. Inhibitory abilities are labelled how originally reported by the authors.

Article	Age and sample size	Design	Predictors (excluding inhibitory control tasks)	Inhibitory control tasks	Early Literacy Outcomes considered	Latent / composite variable	Results (type of analysis)
Allan and Lonigan (2011)	36–71 months $n = 234$	Cross-sectional	Hot Effortful Control (Box search task; Delay of gratification shift task; Less is more; Gift delay task); Cool Effortful Control (next column tasks)	Grass–Snow task; Head to toes task; Kansas Reflection–Impulsivity Scale for Preschoolers; Walk a line slowly	Print Knowledge; Definitional Vocabulary; Phonological Awareness	Cool and hot effortful control in a one-factor	Effortful control significantly related to phonological awareness, print knowledge, and to less extent to definitional vocabulary (Structural equation model)
Becker et al. (2014)	53–80 months $n = 127$	Cross-sectional	Behavioral self-regulation (next column); Inhibitory control (next column); Working Memory (Woodcock–Johnson Auditory Working Memory subtest); Visuomotor skills (Beery Visual-Motor Integration 6th Edition)	Behavioral self-regulation (Head Toes Knees Shoulders task, HTKS); Inhibitory control (Day-Night Stroop Task)	Letter word identification; Picture vocabulary	–	Inhibitory control and behavioral self-regulation significantly related to Letter word identification and vocabulary (Structural equation model)
Blair and Razza (2007)	5 years 7 months - 6 years 11 months $n = 170$	Longitudinal (T1 preschool; T2 k)	Executive function (Inhibitory control task next column; Item selection measure of attention shifting); Effortful control (Children's Behavior Questionnaire); False belief understanding; Verbal (Peabody) and non-verbal (Raven) Intelligence	Peg-tapping	Phonemic awareness (Elision subtest) Letter knowledge	–	Inhibitory control assessed at T1 is associated with phonemic awareness and letter knowledge assessed at T2, but not concurrently (Multiple regression with Type III sums of squares controlling for verbal and fluid intelligence)
ten Braak et al. (2018) [a]	72 months $n = 90$	Longitudinal (T1 k; T2 grade 1)	Executive function (next column tasks) and sustained attention (Continuous performance test)	Head Toes Knees Shoulders task (HTKS); Hearts & Flowers task; Day/Night task; Flanker Fish task	Phonological awareness kindergarten (blending, segmentation, deletion and letter knowledge)	Two latent factors: Attentional (Flanker) and behavioral (HTKS; Hearts & Flowers task; Day/Night task) control	Attentional and behavioral control are uniquely associated with phonological awareness in kindergarten (Structural equation models)
Brock et al. (2009)	Missing $n = 173$	Longitudinal (T1 fall of k; T2 spring of k)	Cool (next column) and hot (Toy Sort task and Gift Wrap task) executive function (cool: next column; hot: Toy Sort and Gift Wrap tasks); Woodcock–Johnson III Test of Cognitive Abilities-Brief Intellectual Assessment; fall literacy scores; Family Demographic characteristics	Balance Beam task; Pencil Tap task.	Letter-word identification (Woodcock–Johnson III Tests of Achievement)	Hot and cool factors	Cool EF is not associated wtih literacy when all the variables are considered (Hierarchical Linear Models)
Cameron et al. (2012)	3–4 years $n = 213$	Longitudinal (T1 fall of k; T2 spring of k)	Fine and gross motor skills; executive function (next column); Woodcock– Johnson III (WJ III) Tests of Achievement (see outcomes)	Head Toes Knees Shoulders task (HTKS)	Letter–word identification; passage comprehension; expressive vocabulary; Phonological awareness (rhymes, syllabic and phonemic deletion, sound substitution, syllable and phonemes reversing)	–	Fall achievement: HTKS is associated with all the literacy tasks. Fall-Spring improvement: HTKS is associated with sound awareness (Multilevel models)

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Table 1 (*continued*)

Article	Age and sample size	Design	Predictors (excluding inhibitory control tasks)	Inhibitory control tasks	Early Literacy Outcomes considered	Latent / composite variable	Results (type of analysis)
Cameron et al. (2015)	2 years, 9 months - 5 years n = 467	Longitudinal (T1 fall of k; T2 spring of k)	Visuomotor integration (design copy); executive function (working memory, backward digit span; inhibitory control, next column); covariates (Age, gender, Maternal ed., Prim. lang. English	Pencil tap test	Receptive (PPVT) and expressive language (Picture vocabulary); Print knowledge (letter and word knowledge, letter-sound knowledge, and word–picture distinctions); expressive vocabulary; Phonological awareness (elision and blending); Approaches to learning (Preschool Learning Behaviors Scale)		Fall achievement: inhibitory control is associated with all the literacy tasks. Fall-Spring improvement: inhibitory control is associated with Print knowledge, Phonological awareness, and Approaches to learning (Multilevel models)
Chung et al. (2018)	57.99 months n = 369	Cross-sectional	Visual-motor integration; Executive function (next column); Rapid automatized Naming	Hearts & Flowers task	Word reading (Chinese pictograms) and single-character words dictation	–	VMI and executive function were unique correlates of Chinese word reading and writing (Hierarchical regression models)
Davidse et al. (2011)	51–57 months n = 228	Cross-sectional	Home literacy environment; Parent print exposure; Book-cover recognition; Nonverbal intelligence; Short-term verbal memory; Inhibition (next column); Sustained attention	Peg tapping	Receptive vocabulary (PPVT-III); Letter knowledge	–	Inhibition is not associated with either receptive vocabulary nor letter knowledge (Hierarchical multiple regression)
Georgiou et al. (2013)	64.29 months n = 80	Longitudinal (T1 beginning of k; T2 end of k; T3 end of grade 1)	Nonverbal IQ; Vocabulary; Speed of processing; Response inhibition (next column); Working memory (Word Series and Corsi Frog); Rapid naming speed; Phonological awareness (Initial Sound Identification and Syllable Segmentation); Letter–word identification; Early mathematics ability	Animal Stroop	Letter–word identification (T2)	–	Correlation between response inhibition and Letter-word identification not significant (Correlations)
Gerde et al. (2012)	37–61 months n = 103	Cross-sectional	Letter knowledge; decoding; fine motor skills; Problem behaviors (teacher report); home literacy environment;	Head Toes Knees Shoulders task (HTKS)	Name writing		The dominance analysis revealed that self-regulation explained only a small amount of unique variation (2,6%) in children's name writing when other variables were included in the model.
Kegel and Bus (2014)	55–71 months n = 312	Longitudinal (T1 k1; T2 k2)	Peabody Picture Vocabulary Test (PPVT); Parental education; Executive functions (digit span; next column)	Stroop-like task	Emergent spelling (words dictation); Letter knowledge; Word recognition; Phonemic analysis (segmentation)	–	Inhibitory control (Stroop-like task) was only significantly related to emergent spelling at T1 and to word recognition and phonemic analysis at T2. The fixed effects analyses (FEAs) to repeated measures of alphabetic skills and executive functions was significant for all four literacy variables. Changes in children's alphabetic skills concur with changes in executive functions (Fixed effects analyses)

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Table 1 (*continued*)

Article	Age and sample size	Design	Predictors (excluding inhibitory control tasks)	Inhibitory control tasks	Early Literacy Outcomes considered	Latent / composite variable	Results (type of analysis)
Lan et al. (2011)	3–6 years N_{China}=119 $N_{U.S.}$=139	Cross sectional	Executive Function (next column); Working memory (Sentence Completion task); Attentional control (The Woodcock-Johnson Pair Cancellation)	Head Toes Knees Shoulders task (HTKS)	Letter-word identification (for US children) and Character recognition task (for Chinese children)	–	Inhibition was a nonsignificant predictor (Regression model with type III sums of Squares)
Lonigan et al., 2016	38–69 months n = 241	Cross-sectional	Executive function tasks: Inhibitory control (next column); Working memory (Size Ordering task, Word Span Reversed, Listening Span task, Animal Span task); Behavioral self-regulation (next column); Teacher-report measures of children's behavior (The Strengths and Weaknesses of ADHD Symptoms and Normal Behaviors Rating Scale; Conners' Teacher Ratings Scale; Social Competence and Behavior Evaluation)	Knock–Tap task; Picture Imitation task; Day–Night Stroop task; Head Toes Knees Shoulders task (HTKS)	Definitional Vocabulary; Phonological Awareness (elision and blending of sound units ranging from words to phonemes); Print Knowledge (print concepts, letter-name recognition, letter-sound recognition, and letter-name and letter-sound production)	Inhibitory control (Knock–Tap task; Picture Imitation task; Day–Night Stroop task) and working memory	Inhibitory control was significantly and positively correlated with Definitional Vocabulary, Phonological Awareness, Print Knowledge. Controlling for age, the association with Print Knowledge was no longer significant (Zero order and partial correlation)
Lonigan et al. (2017)	48–63 months n = 1082	Longitudinal (T1 fall; T2 winter; T3 spring of pre-k)	Block Design and Matrix Reasoning subtests of the Wechsler Preschool and Primary Scales of Intelligence	Head Toes Knees Shoulders task (HTKS)	Receptive and expressive language; Phonological awareness (blending and elision); Print knowledge (print concepts, letter-name recognition, letter-sound recognition, and letter-name and letter-sound production)	–	HTKS was significantly and uniquely associated with growth on Phonological awareness and Print knowledge (Latent Growth Models)
Matthews et al. (2009)	5.45 years n = 268	Longitudinal (T1 fall of k; T2 spring of k)	Child Behavior Rating Scale; Subtests of the Woodcock–Johnson III Tests of Cognitive Abilities (applied math skills, general academic knowledge, literacy, vocabulary, and sound awareness)	Head Toes Knees Shoulders task (HTKS)	Letter–word identification; Sound Awareness (rhyming of real words, deletion and substitution at the syllabic and subsyllabic levels, and reversal of syllables to form new words)	–	Fall-spring improvements in inhibition are significantly associate to fall-spring improvements in sound awareness (Hierarchical linear models)
McClelland et al. (2007)	4.43 years n = 310	Longitudinal (T1 fall of pre-k; T2 spring of pre-k)	Background questionnaire; Behavioral regulation (next column)	Head Toes Knees Shoulders task (HTKS)	Letter–word identification; Receptive and expressive vocabulary	–	Children with stronger growth in behavioral regulation, controlling for all other variables, demonstrated stronger early literacy score gains than did children with weaker growth in behavioral regulation (Hierarchical linear models).
Montoya et al. (2019)	3.4–5.5 years n = 419	Cross-sectional	Executive function (verbal and visual short-term memory; backward digit span)	Head Toes Knees Shoulders task (HTKS)	Receptive vocabulary (Spanish adaptation of the PPVT-R); Letter–Word Identification subtest	–	HTKS was associates with both Receptive vocabulary and early decoding (Seemingly Unrelated Regression Model)
Puranik et al. (2019)	Study 1: 48–81 months n = 200 Study2: 60–78 months n = 274	Cross-sectional	Age, gender.	Head Toes Knees Shoulders task (HTKS)	Study 1: Name writing; Letter writing; invented spelling; Letter-writing fluency (LWF); Composition Study 2: LWF; Sentence writing; text generation (essay)		Multilevel modeling: Self-regulation is related to emergent/early writing. Differences across the type and nature of the task used to examine the relation between self-regulation and emergent/early writing.

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Table 1 (*continued*)

Article	Age and sample size	Design	Predictors (excluding inhibitory control tasks)	Inhibitory control tasks	Early Literacy Outcomes considered	Latent / composite variable	Results (type of analysis)
Purpura et al. (2017)	3–5 years $n = 125$	Cross-sectional	Response inhibition (next column); Verbal working memory (computerized listening recall task); Cognitive flexibility (card sorting task based on the Three-Dimensional Change Card Sort); Demographic variables; General cognitive ability (Rapid automatized naming, RAN)	Stroop-like task	Print knowledge (print concepts, letter/word discrimination, letter name identification, and letter/sound identification); Definitional vocabulary; Phonological awareness. (blending and elision);	–	Response inhibition was associated with Print knowledge (Separate mixed-effects regression analyses)
Shaul and Schwartz (2014)	5–6 years $n = 54$	Cross-sectional	Vocabulary production; Naming speed; Short-term memory (Digit and word span); Executive function (next column);	Head Toes Knees Shoulders task (HTKS); Statue test	Phonological awareness skills (syllable and phoneme deletion; Identification of similar first phonemes); Orthographic knowledge skills (Letter naming; Letter, orthographic, and word recognition)	Executive function composite score	After controlling for naming speed and vocabulary, executive function did not contribute significantly to phonological awareness, but the contribution of executive function to orthographic knowledge, was still significant and relatively large (11%) (Multiple regression analysis)
Willoughby et al. (2011)	3–5 years $n = 759$	Cross-sectional	Cool (next column) and hot executive self-regulation tasks (Snack Delay and Tongue Tasks)	Balance Beam; Pencil Tapping	Letter-word identification and Sound awareness (Rhyming)	Two latent factors (cool and hot self-regulation)	The cool (but not hot) latent variable was uniquely and positively associated with Rhyming and Letter-Word scores. Cool and hot latent variables jointly explained R^2 from 0.25–.34 (Structural equation models).
Zhang et al. (2017)	4–5 years $n = 123$	Longitudinal (T1 pre-k fall; T2 pre-k spring)	Vocabulary (PPVT); Letter naming and letter sound knowledge; Phonological awareness (elision and blending); Executive function (next column); Name writing; Writing fluency (letters)	Head Toes Knees Shoulders task (HTKS)	Invented spelling; Letter naming and letter sound knowledge; Phonological awareness	–	No direct significant relation between executive function and children's invented spelling was detected after controlling children's early reading and writing skills in regression analyses. Executive function at the beginning of the school year significantly related to the amount of growth in letter naming and letter-sound skills across the year, but was not related to the growth of phonological awareness (Hierarchical regression analyses and Mediation analyses)

Note: pre-*k*=pre-kindergarten; *k*=kindergarten; T1, T2, and T3=waves of assessment.

[a] Concurrent associations at T1 are here only considered.

other associated variables (e.g. vocabulary, working memory, and visual-motor integration skills). Further, we investigated the role of inhibitory control dimensions in predicting short-term changes in early literacy skills. To our knowledge, our study is the first to take into account the concurrent contribution of separate inhibitory control dimensions, in addition to other domain-general and domain-specific factors in the transformation of early literacy skills. It is relevant to verify whether the acquisition of these early literacy skills is more related to response inhibition—which facilitates behavioral control (i.e. motor and verbal response control)—or to interference suppression, which is a more cognitive form of inhibition that allows us to focus on relevant information. Indeed, acquiring a more finely graded comprehension of the cognitive abilities that account for early literacy skills may enable the implementation of timely educational strategies in case of learning difficulties.

Inhibitory control in early childhood

In recent decades, inhibitory control has been considered one of the domain-general factors influencing early achievement (Allan et al., 2014). The literature suggests that inhibitory control may be a multidimensional process comprised of different dimensions (Dempster, 1993; Diamond, 2013; Nigg, 2000). In particular, the ability to manage conflict at the response level has been distinguished from the ability to manage conflict at the stimulus level; therefore, response inhibition has been differentiated from interference suppression, also called resistance to distractor interference or attentional inhibition (Bunge, Dudukovic, Thomason, Vaidya & Gabrieli, 2002; Cragg, 2016; Martin-Rhee & Bialystok, 2008; Rey-Mermet, Gade & Oberauer, 2018 Tiego, Testa, Bellgrove, Pantelis & Whittle, 2018; but Friedman & Miyake, 2004).

Different paradigms have been used to measure these two inhibitory control dimensions. Response inhibition is required in tasks in which one must control impulsive behavior and suppress prepotent (but inappropriate) motor or verbal responses and act according to the task's rule. A standard response inhibition task is the go no-go task. In this task, the experimenter asks the participant to respond (e.g. pressing a computer spacebar) to a certain stimulus called the 'go' stimulus, and to give no response to other 'no-go' stimuli. The task includes a large majority of go stimuli, which induces automatization of the response that the participant has to stop when a no-go stimulus appears.

Interference suppression is required when one has to detect and filter out information that is irrelevant to the task and must resolve a conflict due to interfering information. A traditional paradigm used to assess interference suppression is the flanker paradigm (Eriksen & Eriksen, 1974). In this task, the experimenter asks the participant to respond to a certain stimulus (the target) presented among other stimuli (distracters) that must not be considered. For example, participants are asked to detect the direction of an arrow that is flanked by other arrows that may point to the same direction as the target (the congruent condition) or in the opposite direction of the target (the incongruent condition). In the incongruent condition, participants' responses are slower and less accurate than in the congruent condition since they need to overcome the conflict arising from the opposite direction of the arrows. This cost is due to the necessity of inhibiting the interference due to the flankers.

Response inhibition and interference suppression become differentiated in early childhood (Gandolfi, Viterbori, Traverso & Usai, 2014). Beginning at 36 months of age, these two separate components better describe inhibitory control processes in young children (Gandolfi et al., 2014; Traverso, Fontana, Usai & Passolunghi, 2018), whereas before this age, a unitary dimension more appropriately represents the latent organization of inhibitory control (Gandolfi et al., 2014; Kochanska, Murray & Harlan, 2000).

In accordance with previous research (e.g. Senn, Espy & Kaufmann, 2004), a sequential development of these inhibitory processes has been proposed (Traverso et al., 2018), according to which response inhibition develops earlier and is involved in tasks requiring the ability to inhibit a dominant or impulsive response. During the preschool years, as suggested by Garon, Bryson and Smith (2008), the attentional system that allows for more voluntary shifts of attention may integrate with the anterior executive system, which is hypothesized to play a fundamental role in conflict resolution (Posner & Rothbart, 2000). Through the progressive integration of such systems, children develop a cognitive form of inhibition that may include the ability to suppress interfering information or overbearing mental representations, namely, the suppression of interference. This last dimension is strictly connected to attention: the management of interference in fact represents a particular mechanism of selective attention, and corresponds to a top-down control process that allows us to ignore distracting stimuli in situations with a high cognitive load and with a lower perceptual salience of the target stimuli (e.g. Lavie, 2005). We may posit that interference suppression development corresponds with the ability to exert progressively more flexible control, enabling us to shift the ability to resolve a conflict from the response level (response inhibition) to the level of representation and stimulus selection.

Notably, for our aim, previous research has shown that from early childhood, these two inhibitory control dimensions differently account for other cognitive abilities. For example, greater involvement of interference suppression in verbal and visual-spatial working memory tasks was found in a study investigating the relationship of the two inhibitory dimensions with working memory (Traverso, Viterbori, Malagoli & Usai, 2020). Therefore, compared to response inhibition, interference suppression may be a cognitive form of inhibitory control that permits us to focus on relevant information.

In sum, two separate inhibitory control components are described in early childhood: response inhibition and interference suppression. These diverse inhibition dimensions may support children differently in the learning process when dominant responses and interfering information need to be controlled. Nevertheless, a closer investigation of the specific associations between these two inhibitory control dimensions and early literacy abilities is lacking.

1.1. Inhibitory control and early literacy skills

Writing development may be considered the outcome of a multidimensional process (Berninger & Winn, 2006; Berninger et al., 2002; Puranik & Lonigan, 2014; for consistent orthographies, see Pinto, Bigozzi, Accorti Gamannossi & Vezzani, 2009) in which phonological awareness and procedural writing knowledge are important specific precursors (e.g. Caravolas et al., 2001), as well as in transparent orthographies (Torppa et al., 2016). Phonological awareness includes knowledge of the sound structure of words and the ability to manipulate these sounds (Wagner & Torgesen, 1987). Procedural writing knowledge comprises letter identification and letters, name, and word writing (Puranik & Lonigan, 2014). Phonological awareness and procedural writing knowledge are among the most significant predictors of conventional literacy outcomes in primary school (Lonigan, Schatschneider & Westberg, 2008).

As depicted in Table 1, which outlines the literature investigating the association between inhibitory control and early literacy skills development in preschool and kindergarten, several studies have analyzed the contribution of inhibitory control abilities to phonological awareness measured with rhyming, blending, segmentation, elision, or substitution tasks. All these studies, except for two (Shaul & Schwartz, 2014; Zhang, Bingham & Quinn, 2017), found that inhibitory control significantly contributes to phonological awareness. Interestingly, only these two studies considered vocabulary—either expressive (Shaul & Schwartz, 2014) or receptive (Zhang et al., 2017)—to be among the predictors, and not among the outcomes that others had examined (Allan & Lonigan, 2011; Cameron et al., 2012; Cameron et al., 2015; Lonigan, Allan & Phillips, 2017 Lonigan, Lerner, Goodrich, Farrington & Allan, 2016 Purpura, Schmitt & Ganley, 2017), thus indicating how vocabulary accounts for a large portion of the variability in phonological awareness.

Most studies that have assessed writing via tasks such as letter-word identification have extensively investigated the contribution of inhibitory control abilities to procedural writing knowledge. Six of these studies revealed inhibitory control measures to not be related to procedural knowledge tasks (Brock, Rimm-Kaufman, Nathanson & Grimm, 2009 Davidse, de Jong, Bus, Huijbregts & Swaab, 2011 Georgiou, Tziraki, Manolitsis & Fella, 2013 Lan, Legare, Ponitz, Li & Morrison, 2011; Lonigan et al., 2016). Importantly, in one of these studies, previous early literacy scores were entered as predictors (Brock et al., 2009), and in three cases, short-term memory (Davidse et al., 2011) or working memory (Lan et al., 2011; Lonigan et al., 2016) was also included as a predictor. In these cases, the results imply that when other variables are considered, inhibitory control is not associated with early literacy skills. However, in the other four studies, inhibitory control was also found to be related to procedural writing knowledge in the presence of short-term or working memory as predictors (Becker, Miao, Duncan & McClelland, 2014; Cameron et al., 2015; Kegel & Bus, 2014; Montoya et al., 2019; Purpura et al., 2017).

A few studies have explored the contribution of inhibitory control to procedural knowledge through writing tasks such as name writing (Gerde et al., 2012), word writing (Kegel & Bus, 2014), and invented spelling (Puranik et al., 2019; Zhang et al., 2017). For these abilities, the results do not converge either. Kegel and Bus (2014) demonstrated that inhibitory control was related to invented spelling concurrently but not longitudinally. In addition, changes in children's alphabetic skills co-occurred with shifts in inhibitory control after age, sex, receptive vocabulary, and parental education were controlled for. On the other hand, Zhang et al. (2017) did not detect a direct significant relationship between inhibitory control and invented spelling. However, they found an indirect relationship between children's inhibitory control and invented spelling mediated by growth in letter-sound knowledge.

In most studies outlined in Table 1, response inhibition tasks have been included, whereas the interference suppression component is marginally considered. For example, a widely used task is the Head-Toes-Knees-Shoulders task (HTKS, McClelland et al., 2007), which requires different abilities, including that the child refrain from touching the part of the body named by the adult (the prepotent response) and to perform a non-dominant response. Other examples of tasks that require refraining from giving a response that are used in the studies presented in Table 1 are the grass-snow task, in which the child is required to point to a green or white block when the experimenter says 'snow' or 'grass' (Allan & Lonigan, 2011); the Stroop-like task, in which, for instance, the child has to say 'day' for a picture representing the moon or 'night' in the presence of a picture representing the sun (e.g. Lonigan et al., 2016; Purpura et al., 2017); the peg tapping task, in which the child has to tap once when the experimenter taps twice and vice versa (e.g. Blair & Razza, 2007); and the knock-tap task in which, after an imitation phase, the child is required to knock on the table with his/her knuckles or to tap with an open palm when the experimenter taps (Lonigan et al., 2016). Interestingly, only a few studies have evaluated the interference suppression component with paradigms such as the flanker task or the hearts and flowers task (also called the dots task, Diamond, Barnett, Thomas & Munro, 2007). In these tasks, the child is required to focus on task-relevant features and to ignore interfering ones presented within the task (Chung, Lam & Cheung, 2018; ten Braak, Kleemans, Størksen, Verhoeven & Segers, 2018).

Although the literature is still lacking in this regard, response inhibition and interference suppression may play different roles in early literacy task processing. Response inhibition may support the child in blocking a dominant (but not required) response or in controlling an impulse during a task. For example, in the blending task, the child is required to wait until the examiner finishes to pronounce the syllables, and to stop the tendency to simply repeat the sequence of the split syllables without blending them. Thus, children who have better behavioral control may perform better in a variety of situations that require them to refrain from impulsive or dominant off-task behavior. This may explain why the significant associations between inhibitory control and literacy tasks are not significant when a covariate that may share the same source of variance is introduced (Shaul & Schwartz, 2014; Zhang et al., 2017). Interference suppression, as a cognitive form of inhibition, may support the child throughout the entire cognitive process necessary to perform meta-phonological and procedural knowledge tasks by allowing him/her to select the relevant information among confounding stimuli or representations, and to overcome conflict due to such interfering stimuli or representations. Moreover, interference suppression may be important in inhibiting low-level perceptual processes that may interfere with analytical and metalinguistic processes. For instance, interference suppression may be crucial in tasks in which the child is required to focus on an aspect of the stimulus, such as the smallest part of speech, the phoneme. Indeed, in a minimal pairs task, the child has to distinguish between similar or different phonemes without being distracted by the entire word. Additionally, interference suppression supports the identification of the correct response across a set of alternatives when an association between a stimulus and a response is not automatized. For example, when the child is asked to write a word, he/she has to distinguish among the representations of different phonemes and to identify the corresponding grapheme.

In this vein, a meta-analysis considering the contribution of inhibitory control to the early academic skills of children in preschool and kindergarten (Allan et al., 2014) pointed out that the association between inhibitory control and early literacy may vary according to which inhibitory measure is considered, suggesting that different inhibitory control dimensions may be differently related to early literacy skills. Tasks tapping more cognitive components of inhibitory control were more related to academic skills than other self-regulation tasks. Interference suppression may be particularly relevant when both meta-phonological and procedural knowledge are not yet consolidated and automatized (Puranik et al., 2019). Therefore, interference suppression, rather than response inhibition, may uniquely influence early literacy tasks.

Finally, in many cases, a single measure (Cameron et al., 2012; Lan et al., 2011; Lonigan et al., 2017; Matthews, Ponitz & Morrison, 2009; McClelland et al., 2007; Montoya et al., 2019; Zhang et al., 2017) or separate indicators (Becker et al., 2014) have been used to assess inhibitory control abilities, whereas six of the articles presented in Table 1 report latent or composite scores for self-regulation abilities (Allan & Lonigan, 2011; Brock et al., 2009; Shaul & Schwartz, 2014; ten Braak et al., 2018; Willoughby, Kupersmidt, Voegler-Lee & Bryant, 2011) or inhibitory control (Lonigan et al., 2016). The use of a single indicator to assess inhibitory control raises the impurity task problem, which refers to the concurrent involvement of several different cognitive processes in the performance of an inhibitory task, in addition to inhibitory processes (Miyake et al., 2000). Consequently, the association between inhibitory control and another task, such as a literacy measure, may reflect the association between the non-inhibitory demands common to the two measures. The use of factorial or composite scores may limit task impurity, especially if a latent factor approach is used to obtain more accurate measures of inhibitory control that better reflect the true organization of the inhibitory abilities of preschool children (Miller, Giesbrecht, Müller, McInerney & Kerns, 2012).

In sum, inconsistent results have been found when the association between inhibitory control and early literacy skills has been investigated. As suggested by Puranik et al. (2019), some factors may explain the inconsistent results. These factors include the level of acquisition of a certain ability (cognitive control is required mostly when a given ability has not been fully acquired) and the complexity of the literacy task involved. Another possible source of variation that is largely unexplored entails the specific role of different inhibitory control dimensions. Response inhibition is related to diverse early literacy skills, whereas a closer investigation of the specific association between interference suppression and early literacy abilities is lacking. Interestingly, no previous studies have examined the relationship between inhibitory control and early literacy while considering the numerous inhibitory dimensions identified in early childhood, since single measures of inhibitory control have primarily been employed as predictors.

1.2. Other predictors of early literacy skills

It is generally recognized that multiple interrelated variables, such as oral language skills (Whitehurst & Lonigan, 1998), working memory (Berninger & Winn, 2006), and visual-motor integration skills (Weil & Amundson, 1994), are related to early literacy (for a review see Berninger, 2009). The studies in Table 1 examined the concurrent role of inhibitory control together with other variables such as vocabulary, working memory, and visual-motor integration skills (Becker et al., 2014; Cameron et al., 2012; Cameron et al., 2015; Chung et al., 2018). Vocabulary was found to be significant in predicting phonological awareness (Kegel & Bus, 2014) and procedural writing knowledge (Blair & Razza, 2007; Georgiou et al., 2013; Kegel & Bus, 2014) when the influence of inhibitory control was examined, thus confirming the role of language knowledge in early literacy skills (Whitehurst & Lonigan, 1998).

Working memory concurrently scrutinized with inhibitory control significantly predicts phonological awareness (Cameron et al., 2015; Lonigan et al., 2016; Purpura et al., 2017). The findings regarding procedural knowledge have been more inconsistent, as some studies have demonstrated a significant contribution of working memory (Becker et al., 2014; Lan et al., 2011; Lonigan et al., 2016) while others have not (Cameron et al., 2015; Montoya et al., 2019; Purpura et al., 2017). A possible explanation for this inconsistency may lie in the level of cognitive requests due to working memory tasks that, if low (Cameron et al., 2015; Montoya et al., 2019), or when considered with other complex measures that capture the same shared variance (Purpura et al., 2017), are not associated with procedural knowledge.

One line of research suggests that the relationship between inhibitory control and early literacy skills may be influenced by other components, such as visual-motor integration skills, both in logographic (Chung et al., 2018) and alphabetic orthographic systems (Becker et al., 2014; Cameron et al., 2012; Cameron et al., 2015). Visual-motor integration skills predict letter and/or print knowledge concurrently with inhibitory control (Becker et al., 2014). In particular, the ability to copy designs is associated with fall–spring gains shown by preschoolers in early decoding abilities and phonological awareness (Cameron et al., 2012). Children for whom it is difficult and effortful to hold a pencil and to execute the movements needed to write letters may find it harder to exert the effort required for early literacy skills processes, given that motor and cognitive demands are in competition in a given task. In conclusion, Cameron et al. (2015) signaled that visual-motor integration skills and inhibitory control may work in a compensatory way; therefore, either strong visual-motor integration skills or inhibitory control allows children to improve their early literacy skills, which is what happens when both skills are strong.

To summarize, the contribution of diverse abilities has been taken into account along with inhibitory control in predicting early literacy skills. Vocabulary, verbal working memory, and visual-motor integration skills may separately play a role in the execution of literacy tasks; however, none of the abovementioned studies simultaneously considered these abilities. To investigate the unique contribution of diverse inhibitory control dimensions, a comprehensive model of early literacy skills should consider these abilities together.

1.3. The present study

For the present study, we analyzed the unique contribution of different inhibitory control dimensions (i.e. response inhibition and interference suppression) to phonological awareness and procedural writing knowledge in a transparent orthography system in light of their importance as predictors of subsequent achievements in writing (Berninger & Winn, 2006). Response inhibition and interference suppression dimensions have been previously tested through a confirmative approach.

To establish the unique contribution of different inhibitory abilities, we simultaneously examined vocabulary, working memory, and visual-motor integration skills. These variables may account directly for literacy tasks; moreover, including these variables facilitates controlling for the already mentioned impurity problem that affects inhibitory tasks. Based on previous literature, in which hierarchical regression models have mostly been employed, we expected inhibitory control to be related to both phonological awareness and procedural writing knowledge skills. We also expected to find a stronger contribution of interference suppression (versus response inhibition) to early literacy. Indeed, although response inhibition may support children in halting dominant or impulsive behaviors, interference suppression may be deeply involved throughout early literacy task processing by acting in stimuli or representation selection when the child is requested to overcome a conflict due to multiple interfering items.

Exploring concurrent associations may be important in understanding which processes are crucial for (resulting in being uniquely associated with) early literacy skills. However, this does not automatically imply that such abilities are directly involved in the development of early literacy skills. In fact, Lonigan et al. (2017) found that inhibitory control measured with the HTKS was significantly and distinctively associated with phonological awareness and procedural knowledge, but growth in these abilities was particularly predicted by teacher-rated inattention. In other words, the finding that inhibitory control is associated with early literacy tasks might be the outcome of different paths, including the existence of a common third (and unexplored ability) that influences both inhibitory control and early literacy skills. To understand the dynamics of the relationships between constructs as they evolve over time, we investigated the role of inhibitory abilities in predicting changes in early literacy skills, and we also considered whether the initial levels of the variables might predict later changes. In particular, we examined the role of response inhibition and interference suppression in uniquely predicting short-term changes in phonological awareness and procedural writing knowledge skills.

Investigating which mechanisms are involved in the rapid changes observable in a short period of time (five months) permitted us to gain insight into the improvement of early literacy skills development as it happens, which further allowed us to accumulate fine-grained knowledge on the acquisition process, and not only on acquired competence. To the best of our knowledge, few studies have examined change dynamics in a short period of time. Given that interference suppression supports children in focusing on relevant information, we hypothesized that this inhibitory dimension, more than response inhibition, would play a role in the growth of literacy skills. Indeed, as reported above, Lonigan et al. (2017) did not find response inhibition—measured with the HTKS—to predict the growth of phonological awareness and procedural knowledge.

We considered a wide age range (4 to 5 years of age) to ensure enough variability in performance. Indeed, in a transparent orthography system such as that of the Italian language, children generally learn to spell through grapheme-phoneme mapping, and mastery of this procedure is achieved early, in general at the end of first grade (Notarnicola, Angelelli, Judica & Zoccolotti, 2012). Therefore, it is very common for children, especially 5-year-olds who are about to move on to primary school, to spontaneously attempt to write simple words.

In sum, we investigated three research questions: (1) Are response inhibition and interference suppression separate inhibitory control dimensions between 4 and 5 years of age?, (2) Are response inhibition and interference suppression uniquely and differently associated with phonological awareness and procedural writing knowledge assessed at time 1 when vocabulary, working memory, and visual-motor integration skills are concurrently considered? and, (3) Are response inhibition and interference suppression uniquely associated with changes in phonological awareness and procedural writing knowledge, simultaneously taking into account the initial levels and contribution of these same early literacy skills?

2. Method

2.1. Participants

We recruited a convenience sample of 161 Italian children by presenting the research project at four public preschool educational centers located in the northwest of the country. These educational centers offer children aged 3 to 5 a pre-primary curriculum that promotes social skills, autonomy, and learning before beginning primary school at age six. We carried out the study in accordance with the recommendations of the National Psychology Association for Research (for further details, see http://www.aipass.org/node/26), and all experimental procedures were approved by the Ethics Committee of the Department of Education Sciences at the University of Genoa (16/2017). In accordance with the principles expressed in the Declaration of Helsinki, all parents agreed to participate in the study and provided informed consent. We excluded 14 children from the initial sample for the following reasons: having an ascertained developmental disorder (n = 4), undergoing an in-year transfer to another school (n = 5), or having a score below the 10th percentile in the Colored Progressive Matrices Test (n = 5). The final sample included 147 typically developing children (50% female) from 49 to 72 months of age ($M_{age\text{-}in\text{-}months}$=59.28; S.D.=6.26). All children were born in Italy and were Italian. All children spoke Italian as their mother tongue at home, even though 20% of the parents spoke languages other than Italian. As shown in the annual reports provided by the educational centers, the preschools show socioeconomic diversity; that is, a mix of students from different income levels and social backgrounds. We categorized one preschool as having a low- to mid-socioeconomic status (with 36% of families receiving subsides for meal payments at school); another preschool was reported to serve families from a diverse range of socioeconomic statuses. Mothers' education level (years of education), provided by a subsample of 48 families, ranged from 5 to 18 years (M = 15.77, SD = 3.63); specifically, 2% of the mothers had completed primary school education (5 years), 2% had completed middle school education (8 years), 44% had also completed high school (13 years), and 52% had a university degree. The Colored Progressive Matrices (Raven, 1947) ranged from 6 to 28 (M = 15.71; S.D.=3.59) in the final sample.

2.2. Procedure

We conducted testing at time 1 (winter, the middle of the preschool year) and five months later at time 2 (spring, the end of the preschool year). At time 1, the experimenters assessed children for fluid intelligence, inhibitory skills, working memory, vocabulary, visual-motor integration, and early literacy skills. At time 2, they assessed children for early literacy skills only, using the same tasks as those employed at time 1. At both time points, a trained experimenter assessed children individually in a quiet room of each respective preschool center during the school day. The experimenters were two postdoctoral researchers responsible for supervising the data collection, and were assisted by psychology graduate students who were specifically trained in executive functioning and emergent literacy assessment. The assessment was carried out in the Italian language during three sessions, each lasting approximately 20 to 30 min, on different days to avoid testing fatigue. The order of the tasks was fixed as follows: the Colored Progressive Matrices, the backward word span, the blending task, the HTKS task, the letter writing task (the first session); the Peabody Picture Vocabulary Test (PPVT), the NEPSY-II copying subtest, the NEPSY-II Stroop task, the rhyme detection task (the second session); the fish flanker task; a minimal pairs task; a word writing task; and the dots task (the third session). The Colored Progressive Matrices task was administered with the aim of screening children's non-verbal reasoning skills. Children were given a sticker for their effort after each assessment session.

2.3. Measures

2.3.1. Fluid intelligence

The Colored Progressive Matrices (Raven, 1947). This is a non-verbal measure of general intellectual functioning that consists of 36 items. Each item contains a figure with a missing piece. Below the figure, there are six alternative pieces to complete it, only one of which is correct. Children are presented with a demonstration trial and are then instructed on successive trials to point to the piece that best completes the pattern. The score is the total number of correct responses (range: 0–36). The test was standardized on an Italian sample of 3390 children from 3;0 to 11;6, and its validity and reliability properties have been established (Belacchi, Scalisi, Cannoni & Cornoldi, 2008; Giofrè & Belacchi, 2015). The Cronbach's alpha for the present study was 0.577.

2.3.2. Inhibitory control

Response inhibition. The following tasks were administered to assess response inhibition; both tasks require the ability to suppress a prepotent (but inappropriate) response to a stimulus.

HTKS (McClelland et al., 2007). The HTKS task requires the child to pay attention, to remember the instructions while responding, and to use inhibition mostly by controlling the motor response elicited by the examiner's verbal instructions; the child is in fact asked to do the opposite of what the examiner states. Validity properties for the HTKS have been established by comparing HTKS scores to teacher ratings and parent reports of attention and inhibitory control (Cameron, Connor, Morrison & Jewkes, 2008; McClelland et al., 2007). Moreover, some previous research has defined the task as predominantly tapping inhibitory control or response inhibition (Fuhs & Day, 2011; Lan et al., 2011). For our study, we slightly modified the verbal instructions, and the child, seated at a table, was asked to touch hisor her head, the desk, hisor her shoulder, or hisor her nose. First, children were asked to touch their head or to touch the desk, and they had to do the opposite of the request (touch the desk or touch their head, respectively). After two training items, 10 items were proposed. Subsequently, the experimenter introduced two new rules, namely, 'touch your nose' and 'touch your shoulders', and the child was still asked to inhibit the request and do the opposite. After two training items, 10 assessment items were proposed. Overall, the test included 20 items, and each item could result in a score of 0 (an incorrect response), 1 (self-correction), or 2 (a correct response). The score was the sum of the score assigned to each of the 20 items (range: 0–40). The Cronbach's alpha for the present study was 0.99, and the test-retest, calculated with the traditional version of the task one month later on a subsample of 94 children, was $r = 0.461$, $P < 0.001$.

The Stroop NEPSY–II task (Korkman, Kirk & Kemp, 2011). This is a subtest included in the NEPSY–II Attention and Executive Functioning domain, whose validity has been extensively established (Davis & Matthews, 2010; Urgesi, Campanella & Fabbro, 2011). The task is designed to assess the ability to inhibit automatic responses in favor of novel ones. The child looks at a series of black-and-white shapes, and is required to label the black shape 'white' and the white shape 'black'. After demonstration trials, 40 items are proposed. The score is the total of the correct responses (range: 0–40). The Cronbach's alpha for the present study was 0.94.

Interference suppression. The following tasks were administered to assess interference suppression; they both require the ability to address the interference of potentially conflicting characteristics of a stimulus or a set of stimuli.

The fish flanker task (adapted from Ridderinkhof & van der Molen, 1995; Gandolfi et al., 2014; Traverso, Viterbori & Usai, 2015). The flanker task is a well-known task used to evaluate the ability to inhibit irrelevant interfering stimuli (Eriksen & Eriksen, 1974). In the flanker task used in this study, the children were required to respond to a left or right fish presented at the center of the computer screen by pressing a left or right response button. The fish were flanked by two other fish pointing in the same direction (the congruent condition, 16 items) or in the opposite direction (the incongruent condition, 16 items). After a brief training session consisting of four items (two of each condition), 32 items were randomly presented (16 items per condition, half left and half right). A warning cross (500 ms in duration) preceded the stimulus. After the response, the screen turned blank for 500 ms. Accuracy on incongruent items was recorded (range: 0–16). The flanker paradigm has been widely used to assess interference suppression both in adults (Friedman & Miyake, 2004) and in children (Bossert, Kaurin, Preckel, & Frings, 2014; Gandolfi et al., 2014). The validity of the task has been confirmed in previous studies that revealed the fish flanker task to be a significant predictor of the interference suppression dimension in early childhood (Gandolfi et al., 2014; Traverso, et al., 2018; Traverso et al., 2020). The Cronbach's alpha for the present study for incongruent items was 0.78, and 0.88 when both congruent and incongruent items were considered.

The dots task (also called the hearts and flowers task, adapted by Diamond et al., 2007; Traverso et al., 2015). This task is a high cognitive conflict task (Diamond et al., 2007; Diamond & Lee, 2011). In the dots task used in this study, a flower or a star appeared on the right or left of a computer screen. The child was told to press on the same side of the flower but on the opposite side of the star, which required the child to inhibit the tendency to respond on the side where the stimulus appeared and to control the response, based on which the stimulus appeared. After a brief training session with flower and star items, the test began, and 10 flowers and 10 stars were intermixed in the test. The sum of correct responses was recorded (range: 0–20). Regarding validity, previous studies have revealed the dots task to be a significant predictor of the interference suppression dimension (Traverso et al., 2020) and significantly correlated with other interference suppression tasks, such as the fish flanker task (Traverso et al., 2020). The Cronbach's alpha for the present study was 0.83.

2.3.3. Working memory

The backward word span (Ciccarelli, 1998) was used. This task is a standard working memory task (Alloway, Gathercole & Pickering, 2006), in which the child is required to recall a sequence of spoken words in reverse order. Words are presented at a rate of approximately one per second. After an illustration trial, the test begins with three trials of two words. The number of words increases by one every three trials until three lists are recalled incorrectly. The sum of correct items is recorded (range: 0–21). Validity and reliability for this task are well established (e.g. Alloway et al., 2006). The Cronbach's alpha for the present study was 0.63.

2.3.4. Vocabulary

The PPVT, specifically the Italian version (Stella, Pizzoli & Tressoldi, 2000), was administered. This is a widely used task for assessing vocabulary knowledge in children and adults (Hoffman, Templin & Rice, 2012), and its validity has been previously established (Rice, Redmond & Hoffman, 2006). For this test, the experimenter reads a word aloud, and the child is asked to select the corresponding picture among a set of four. According to the guidelines, the first item, or starting point, is determined based on the child's PPVT age. Then, if the child gives 8 correct responses before the first error, a 'basal' is established (if the child gives an incorrect response before 8 consecutive correct answers, testing proceeds backwards, beginning at the item just before the starting point, until the child gives 8 consecutive correct responses). Subsequently, the task continues until the child reaches an error rate of 6 on the last 8 items. The score is the sum of correct responses; the items before the basal are considered correct (range: 0–175). The Cronbach's alpha for the present study was 0.96.

2.3.5. Visual-motor integration

The copying subtest from the NEPSY–II battery (Korkman et al., 2011) was used. This is a subtest that assesses visual-spatial processing, and its validity has been previously demonstrated (Kemp & Korkman, 2010; Pila-Nemutandani, Pillay & Meyer, 2018 ; Urgesi et al., 2011). This test is designed to assess fine motor skills and visual-perceptual skills associated with the ability to copy geometric figures. The child is required to copy up to eight figures with increasing complexity using a paper and pencil. A score of 0 indicates an absence of correspondence between the target figure and the child's drawing, a score of 1 reflects partial success in copying the figure, and a score of 2 shows complete success. The score is the sum of the scores assigned to each drawing (range: 0–16). The Cronbach's alpha for the present study was 0.87.

2.3.6. The emergent literacy skills battery

Tasks measuring phonological awareness and procedural writing knowledge abilities were used to assess early literacy skills. *Phonological awareness tasks*. We administered three phonological awareness subtests of an Italian metalinguistic standardized battery (the CMF, Marotta, Trasciani & Vicari, 2004. This battery was standardized on an Italian monolingual sample of 1336 children from 4;11 to 11;10 and shows adequate psychometric properties. The test-retest reliability, specifically Spearman's coefficient, calculated on a randomized sample of 15 six-year-olds, ranged from 0.90 to 0.97 for the three subtests included in the current study.

For the rhyme detection task, the child is required to identify the word with the same last syllable as the word produced by the examiner. The child is presented with a cardboard table with four pictures: one picture corresponds to the target word, another corresponds to the word that ends with the same syllable as the target, and two pictures are the distractors. Starting with the target, the examiner points and names all the pictures, and then asks the child to point to the picture corresponding to the word that ends with the same sound as the target word previously named. The task includes a training item and then 15 word items. The score is the number of words correctly identified by the child (range: 0–15). The Cronbach's alpha for the present study was 0.87

The blending task, also called syllable fusion, gauges children's ability to combine sounds to make a spoken word. The child is required to blend two, three, or four orally presented syllables into a complete word. There is one practice word item (a 2-syllable word) and a total of 15 test trials including four 2-syllable words, six 3-syllable words, and four 4-syllable words. The items are presented in order of increasing difficulty, with 2-syllable items being administered before the 3- and 4-syllable words. The score is the number of words correctly combined by the child (range: 0– 14). The Cronbach's alpha calculated for the present study was 0.91.

The minimal pairs task assesses the ability to detect the phonological features of words. The child is orally presented with pairs of words, and is required to determine whether they are composed of the same or different phonemes. The instruction is as follows: 'Now will I tell you a pair of words, and you tell me if they are exactly the same word or if they are different words; for example, if I say, 'POLLO-BOLLO', did I say the same word or two different words'? There were two training trials and a total of 30 test trials, including 15 words and 15 non-words. The score is the total number of correct responses (range: 0–30). The Cronbach's alpha for the present study was 0.89.

Procedural writing knowledge tasks. We administered the letter and word writing tasks to assess the children's knowledge of the specific symbols and conventions involved in the production of writing. They are both experimental tasks; however, their concurrent validity was displayed in the present study by their significant correlations both in the winter (r = 0.693, P < 0.01) and spring (r = 0.417417 P < 0.01) assessments after controlling for age. In the letter writing task (adapted by Molfese et al., 2011), children were asked to write 12 dictated letters (A, C, E, F, I, L, N, O, S, T, U, V) that were selected because they represent sounds acquired early in the Italian language (Zanobini, Viterbori & Saraceno, 2012; Zmarich & Bonifacio, 2005). Each child's performance was scored as follows: 0 for drawing or scrabbling; 1 for writing random letters (i.e. the letters were properly graphically reproduced, but with no sound-letter correspondence rule); and 2 for reproducing the letters following sound-letter correspondence rules. Scores for the 12 letters were added (range: 0–24). The Cronbach's alpha for the present study was 0.91.

The word writing task (Traverso, Viterbori & Usai, 2019) requires the child to write the names of four different pictures (dog 'cane', sun 'sole', table 'tavolo', and elephant 'elefante') represented on a cardboard table. These words were selected based on their number and types of syllables; there were two 2-syllable words ('ca-ne', 'so-le'), one 3-syllable word ('ta-vo-lo'), and one 4-syllable word ('e-le-fan-te'). All words except 'elefante' are simple and include the C-V-C-V sequence. The examiner asked the child to name the figures and then to write them down. Following Ferreiro and Teberosky's (1982) approach, we assigned a score ranging from 0 to 5 to each of the four figures. Specifically, a score of 0 indicated writing by the use of drawing or scribbling (the scribble stage). A score of 1 denoted writing by the use of random letters, with no correspondence between the grapheme and the sound it represented (i.e. the child wrote the letters E-F-A-C-R when the examiner asked him or her to write 'TAVOLO', signifying the pre-conventional or pre-syllabic stage). A score of 2 signaled writing by reproducing the letters that stand for the syllables; in this stage, one letter stood for one syllable with no conventional association between the letter and the phoneme (i.e. the letter). The letters X-Y-Z represented the 3-syllable word TA-VO-LO, signifying the pre-conventional syllabic stage. A score of 3 indicated writing by reproducing the letters that stand for entire syllables, following the conventional grapheme-phoneme association rule; the child spells one—and only one—letter for each syllable in the word following the conventional rule (i.e. the letters T-V-L represented the three syllables of the word TA-VO-LO). A score of 4 represented writing by reproducing more than one letter to reproduce one whole syllable; for example, TA-V-L stood for the 3-syllable word TA-VO-LO (signifying the syllabic-alphabetic stage), and a score of 5 denoted writing by reproducing each letter according to the sound it represents, following the grapheme–phoneme association rule (signifying the alphabetic stage). The final score was given by the mean of the scores obtained in each of the four pictures (range: 0–5). The Cronbach's alpha for the present study was 0.97. Two judges (the authors L.T. L and E.G.) coded each child's performance independently after having shared all coding rules. The correlations between the two judges indicated adequate coding reliability (r = 0.99 P < 0.001). Additionally, we verified that the final score, calculated according to Ferreiro and Teberosky's (1982) approach, was highly related to the score obtained by focusing mostly on the letter-sound relationship (r = 0.97).

2.4. Statistical analyses

We calculated descriptive analyses for each variable. Additionally, we used a repeated measures analysis of variance (ANOVA) to investigate the effect of time on literacy performance. We calculated zero-order correlations (Pearson) and partial correlations to control for age among the measures. We then performed confirmatory factor analysis (CFA) using the inhibitory task scores to verify the characteristics of the inhibition construct in early childhood. Based on the CFA results, as suggested by Willoughby and Blair (2016), we computed composite scores as formative indices of inhibitory components, which we entered into the structural equation model (SEM). Subsequently, we performed path analysis using the SEM based on raw data to examine the role of the two inhibitory dimensions in literacy performance at time 1, together with working memory, vocabulary, and visual-motor abilities as predictors (we used the fluid intelligence score as a screening measure to determine the eligible sample; we did not include it in the model to reduce model complexity). We entered age as a predictor of all variables. Finally, to establish the contribution of all predictors to literacy achievement between winter and spring, we tested a latent change score (LCS) model by taking into account the improvements in phonological awareness and procedural writing knowledge skills between the two waves of observation. The LCS model (McArdle & Hamagami, 2001) is a specific class of SEM that is useful for model changes at the construct level. In contrast to other techniques, such as hierarchical regression, this approach allows one the capture of dynamic features of growth and interrelations between processes (Ferrer & McArdle, 2010). Therefore, LCS modeling permitted us to combine the evaluation of change in phonological awareness and in procedural writing knowledge skills, and to gage their reciprocal influences.

We conducted all these analyses using MPlus 7.4 software (Muthen & Muthen, 2007). We used the optimal full information maximum likelihood approach to estimate missing data (Collins, Schafer & Kam, 2001). We evaluated the fit of each model to the data by examining multiple fit indices (Schermelleh-Engel, Moosbrugger & Müller, 2003). Specifically, we employed the χ^2 test to determine the appropriateness of the SEM model; non-significant values indicated a minor difference between the co-

Table 2
Descriptive statistics of the inhibitory control, the working memory (backward word span), the vocabulary (Peabody picture vocabulary test), and the visual-motor integration task (copying subtest from the NEPSY–II battery) performance.

	n	Min	Max	Mean	S.D.	Skewness	Kurtosis
HTSK	146	0	40	23.88	11.97	−0.565	−0.931
Stroop	146	0	40	33.10	8.22	−1.815	3.286
Flanker	144	2.08	16	12.61	3.77	−1.015	−0.058
Dots	146	7	20	15.07	4.19	−0.217	−1.587
Working memory	147	0	6	2.32	1.49	−0.263	−0.776
Vocabulary	147	11	112	61.06	21.20	−0.082	−0.259
Visual-motor	147	0	16	10.31	3.93	−0.592	−0.460

Table 3
Descriptive statistics of the early literacy task performance and results of the repeated measures analysis of variance (Anova).

	Time 1					Time 2							
	n	min	max	Mean	S.D.	*n*	min	max	Mean	S.D.	F	*P*	ηp^2
Ryme detection	147	1	15	8.00	4.61	144	1	15	10.09	4.70	41.859	<0.001	.23
Syllable fusion	147	0	14	10.66	3.85	143	0	24	12.80	2.42	49.569	<0.001	.26
Minimal pairs	146	6	30	21.65	6.39	144	5	30	22.95	6.53	7.079	.009	.05
Letter writing	146	0	24	14.89	5.64	144	0	24	16.34	5.67	1237.16	<0.001	.17
Word writing	141	0	5	1.40	1.30	142	0	5	1.67	1.42	13.352	<0.001	.09

variance matrix generated by the model and the observed matrix, thus indicating an acceptable fit. We used the CFI to compare the covariance matrix predicted by the model with the observed covariance matrix, and to compare the null model with the observed covariance matrix. A CFI value greater than 0.97 suggested a good fit, whereas a value greater than 0.95 reflected an acceptable fit (Schermelleh-Engel et al., 2003). SRMR stands for the 'square root of averaged squared residuals' (i.e. the differences between observed and predicted covariances). SRMR values less than 0.05 were considered to denote a good fit, but values <0.10 were also considered acceptable (Schermelleh-Engel et al., 2003). The RMSEA measured how closely the covariances predicted by the model matched the actual covariances (the approximate fit in the population). RMSEA values ≤ 0.05 represented a good fit, values between 0.05 and 0.08 indicated an adequate fit, values between 0.08 and 0.10 signaled a mediocre fit, and values greater than 0.10 were unacceptable (Browne & Cudeck, 1993).

3. Results

Table 2 portrays descriptive statistics for inhibition, working memory, vocabulary, and visual-motor integration skills. Table 3 depicts descriptive statistics and repeated measures for the early literacy skill tasks. The data points of the four predictors were more than three standard deviations from the mean; thus, we regarded them as outliers and considered them to be missing values. The percentage of total missing values ranged from 0%-4%; we observed the highest percentage of missing values in the word writing task, with 3% and 4% in the first and second assessments, respectively (some children refused to perform the task). The children significantly increased their performance on both the phonological tasks and the writing procedural knowledge task in five months. We performed zero-order (Pearson) and partial correlations to control for age (lower triangle, Table 4) among the measures.

Subsequently, we addressed the first research question: 'Are response inhibition and interference suppression separate inhibitory control dimensions between 4 and 5 years of age'? Specifically, we performed a series of CFAs based on raw data to verify whether a two-factor model, in which we distinguished between response inhibition and interference suppression, fit the observed data better than a one-factor model. The one-factor model fit indices were X^2 = 18.593, df=5, *P* = 0.002, CFI = 0.869, SRMR =0.061, RMSEA = 0.136, and 90% CI = [.074, 0.205]. The two-factor model fit indices were X^2 = 5.200; df= 2; *P* = 0.074, CFI = 0.969, SRMR = 0.035, RMSEA = 0.10 and 90% CI = [.000, 0.219]. The one-factor model had a significant X^2 value and poorer fit indices than the two-factor model.

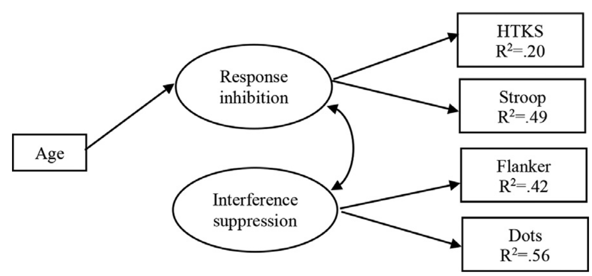

Fig. 1. Two-factor model with response inhibition and interference suppression factors. In order to increase the figure's clarity only main information are shown. The detailed parameters information is reported in Table 5.

Fig. 1 depicts the two-factor model standardized solution, and Table 5 displays the parameter information for the CFA models. The two factors were highly correlated; nevertheless, the two-factor model showed the best fit for the data observed. We calculated two composite scores representing response inhibition and interference suppression as the mean of the z-scores, as follows: the z-score average of the HTKS and of the Stroop task for response inhibition, and the z-score average of the fish flanker and dots tasks for interference suppression, respectively. These composite measures can be considered formative indicators of the two inhibitory dimensions (Willoughby & Blair, 2016).

Next, using path analysis, we addressed the second research question: 'Are response inhibition and interference suppression uniquely and differently associated with phonological awareness and procedural writing knowledge assessed at time 1 when vocabulary, working memory, and visual-motor integration skills are concurrently considered?' The model had the following adequate fit indices: χ^2 = 1.122, df= 2, *P* = 0.57, CFI = 1.000, SRMR = 0.008, RMSEA = 0.000, and 90% CI = [.000, 0.138]. Fig. 2 shows the standardized solution, and Table 6 portrays the parameter information of the path analysis model. The model revealed that interference suppression—but not response inhibition—was significantly associated with three outcome measures: minimal pairs, letters, and

Table 4
Zero-order (Pearson) and partial correlations controlled for age (lower triangle) among all the measures considering both winter and spring assessments.

				Winter assessment (T1)												Spring assessment (T2)				
			1	2	3	4	5	6												
Winter assessment	1	HTKS	-	.298*	.314*	.187	.423*	.427*	.397*	.385*	.267*	.267*	.207	.353*	.314*	.356*	.176	.261*	.343*	.293*
	2	Stroop	.250*	-	.357*	.439*	.354*	.236*	.363*	.299*	.307*	.258*	.239*	.281*	.188	.394*	.294*	.394*	.313*	.216
	3	Flanker	.275*	.301*	-	.478*	.388*	.252*	.358*	.383*	.214*	.349*	.423*	.370*	.332*	.314*	.308*	.425*	.332*	.280*
	4	Dots	.132	.382*	.440*	-	.402*	.143	.350*	.406*	.334*	.275*	.363*	.419*	.375*	.360*	.240*	.412*	.439*	.354*
	5	Working m.	.340*	.353*	.399*	.399*	-	.413	.523*	.445*	.493*	.479*	.474*	.466*	.394*	.534*	.358*	.498*	.468*	.385*
	6	Fluid intell.	.345*	.300*	.246*	.147	.363*	-	.432*	.443*	.273*	.282*	.264*	.336*	.196	.336*	.205	.346*	.175	.197
	7	Vocabulary	.251*	.333*	.320*	.300*	.454*	.361*	-	.486*	.451*	.444*	.488*	.562*	.515*	.532*	.313*	.515*	.467*	.521*
	8	Visual-motor	.237*	.155	.321*	.401*	.398*	.382*	.339*	-	.484*	.303*	.371*	.570*	.412*	.504*	.184	.417*	.485*	.449*
	9	Rhyme 1	.173	.244*	.178	.306*	.442*	.212	.392*	.426*	-	.317*	.350*	.526*	.559*	.677*	.217*	.386*	.430*	.545*
	10	Blending 1	.133	.274*	.330*	.254*	.408*	.261*	.398*	.316*	.275*	-	.482*	.379*	.324*	.403*	.439*	.591*	.304*	.305*
	11	Minimal p. 1	.164	.235*	.415*	.366*	.467*	.224	.450*	.350*	.341*	.501*	-	.401*	.440*	.387*	.376*	.612*	.334*	.326*
	12	Letter writ. 1	.229*	.203	.351*	.430*	.420*	.252*	.492*	.460*	.492*	.369*	.418*	-	.723*	.478*	.253*	.449*	.807*	.702*
	13	Word writ. 1	.246*	.112	.313*	.355*	.337*	.128	.436*	.312*	.530*	.320*	.409*	.693*	-	.446*	.199	.373*	.640*	.851*
Spring	14	Rhyme 2	.222	.334*	.266*	.329*	.482*	.222	.423*	.390*	.641*	.385*	.359*	.409*	.387*	-	.190	.442*	.459*	.460*
	15	Blending 2	.103	.380*	.322*	.295*	.306*	.133	.279*	.172	.214	.332*	.293*	.286*	.183	.156	-	.374*	.218*	.115
	16	Minimal p. 2	.148	.361*	.410*	.393*	.439*	.307*	.454*	.394*	.342*	.538*	.587*	.435*	.338*	.391*	.278*	-	.356*	.352*
	17	Letter writ. 2	.221	.164	.311*	.416*	.434*	.132	.329*	.363*	.398*	.271*	.314*	.767*	.586*	.407*	.224	.293*	-	
	18	Word writ. 2	.179	.088	.234*	.322*	.349*	.120	.440*	.308*	.513*	.316*	.327*	.638*	.838*	.398*	.118	.322*	.417*	-

Underlined coefficients are significant at p <.05.
* p < .01.

Table 5
Parameters of the models identified with the CFA.

		Factor model parameters	Standardized estimates	S.E.	Unstandardized estimates	S.E.	Est./S.E.	*P*
CFA One-factor model	Inhibition BY	HTSK	0.429	0.089	1.000	0.000	999	999
		Stroop	0.649	0.078	1.043	0.264	3.949	<0.001
		Flanker	0.635	0.077	0.466	0.122	3.812	<0.001
		Dots	0.667	0.074	0.544	0.151	3.615	<0.001
	Inhibition ON	Age	0.235	0.098	0.193	0.097	1.987	0.047
CFA Two-factor model	Response inhibition BY	HTSK	0.442	0.089	1.000	0.000	999	999
		Stroop	0.699	0.105	1.090	0.307	3.544	<0.001
	Interf. suppression BY	Flanker	0.646	0.082	1.000	0.000	999	999
		Dots	0.750	0.088	1.285	0.289	4.442	<0.001
	HTSK WITH	Flanker	0.182	0.106	5.607	3.579	1.566	0.117
	Response inhibition WITH	Interf. suppression	0.815	0.135	9.561	3.308	2.890	0.004
	Response inhibition ON	Age	0.401	0.117	0.339	0.132	2.564	0.010
	Interf. suppression ON	Age	0.094	0.101	0.037	0.040	0.924	0.356

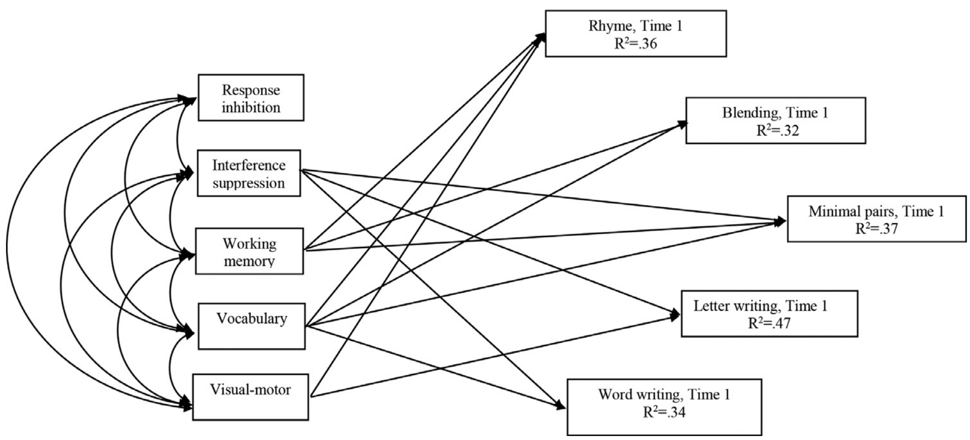

Fig. 2. Path analysis model specifying the relationships among the two inhibition dimensions (composite scores), the working memory (backward word span), the vocabulary (Peabody picture vocabulary task), the visual-motor integration (copying subtest from the NEPSY–II battery), and the phonological awareness abilities and the procedural writing knowledge abilities. In order to increase the figure's clarity only main information are shown. The detailed parameters information are reported in Table 6.
Note: To increase readability age is not included in the figure, but it was included in the model, as reported in Table 6.

word writing. Vocabulary was associated with all outcomes except for letter writing, verbal working memory was associated with all phonological awareness outcomes, and visual-motor integration skills were found to contribute to rhyme and letter writing tasks. The model predicted 36% of the variance in the rhyme detection score, 32% of the variance in the blending task, 37% of the variance in the minimal pairs score, 47% of the variance in the letter writing score, and 34% of the variance in the word writing task score.

Finally, we investigated the third research question: 'Are response inhibition and interference suppression uniquely associated with changes in phonological awareness and procedural knowledge, simultaneously taking into account the initial levels and contribution of these same early literacy skills'? We computed two composite scores as the mean of the z-scores in the phonological awareness tasks and in the procedural writing knowledge tasks. Subsequently, we executed an LCS model to establish the role of response inhibition and interference suppression in the latent change scores of phonological awareness and procedural writing knowledge. The model had the following adequate fit indices: χ^2 = 0.553, df= 1, P = 0.457, CFI = 1.000, SRMR = 0.003, RMSEA = 0.000, and 90% CI = [.000, 0.196]. Fig. 3 depicts the standardized solution, and Table 7 shows the parameter information of the path analysis model. The main finding was that the model indicated interference suppression to be significantly associated with the change in phonological awareness. Moreover, interference suppression contributed significantly to the procedural writing knowledge score at time 1. All other predictors (i.e. vocabulary, verbal working memory, and visual-motor integration skills) were significantly associated with phonological awareness abilities at time 1; in addition, vocabulary and visual-motor integration were associated with procedural writing knowledge skills at time 1. Phonological awareness and procedural writing knowledge skills at time 1 greatly contributed to the same abilities at time 2. The model predicted 38% of the variance in the composite latent change score of phonological awareness, and 19% of the variance in the latent change score of procedural writing knowledge.

4. Discussion

In the present longitudinal study, we investigated the roles of different inhibitory control components (i.e. response inhibition and interference suppression) in uniquely contributing to early literacy skills, as measured by phonological awareness and emergent writing assessments in 147 children aged between 4 and 5 years. Moreover, we examined the association between these inhibitory control abilities and changes in early literacy skills, also consid-

Table 6
Parameters of the model identified with the Path analyses.

	Factor model parameters	Standardized estimates	S.E.	Unstandardized estimates	S.E.	Est./S.E.	*P*
Rhyme task ON	Response inhibition	0.059	0.084	0.335	0.48	0.697	0.486
	Interf. suppression	−0.052	0.085	−0.279	0.456	−0.612	0.54
	Working memory	0.269	0.084	0.831	0.264	3.15	0.002
	Vocabulary	0.191	0.087	0.042	0.019	2.168	0.03
	Visual-motor integ.	0.308	0.085	0.362	0.103	3.534	<0.001
	Age	−0.09	0.079	−0.066	0.058	−1.138	0.255
Blending ON	Response inhibition	0.063	0.088	0.299	0.417	0.716	0.474
	Interf. suppression	0.067	0.09	0.3	0.402	0.747	0.455
	Working memory	0.274	0.086	0.705	0.227	3.112	0.002
	Vocabulary	0.294	0.089	0.053	0.016	3.24	0.001
	Visual-motor integ.	0.062	0.09	0.061	0.088	0.692	0.489
	Age	−0.198	0.081	−0.122	0.05	−2.435	0.015
Similar pairs ON	Response inhibition	−0.102	0.083	−0.808	0.659	−1.227	0.22
	Interf. suppression	0.265	0.084	1.955	0.628	3.114	0.002
	Working memory	0.22	0.084	0.938	0.36	2.604	0.009
	Vocabulary	0.307	0.085	0.092	0.026	3.519	<0.001
	Visual-motor integ.	0.073	0.087	0.119	0.141	0.841	0.4
	Age	−0.077	0.079	−0.078	0.081	−0.97	0.332
Letter writing ON	Response inhibition	−0.013	0.076	−0.093	0.531	−0.176	0.86
	Interf. suppression	0.171	0.078	1.111	0.509	2.182	0.029
	Working memory	0.115	0.078	0.431	0.292	1.475	0.14
	Vocabulary	0.262	0.079	0.07	0.021	3.272	0.001
	Visual-motor integ.	0.271	0.079	0.389	0.115	3.392	0.001
	Age	0.107	0.073	0.096	0.065	1.467	0.142
Word writing ON	Response inhibition	−0.017	0.086	−0.028	0.145	−0.197	0.844
	Interf. suppression	0.198	0.088	0.31	0.139	2.233	0.026
	Working memory	0.083	0.089	0.076	0.08	0.94	0.347
	Vocabulary	0.303	0.088	0.019	0.006	3.356	0.001
	Visual-motor integ.	0.146	0.089	0.05	0.031	1.628	0.104
	Age	0.046	0.083	0.01	0.018	0.555	0.579
Response inhibition ON	Age	0.323	0.074	0.042	0.01	4.117	<0.001
Interference suppression ON	Age	0.066	0.083	0.009	0.011	0.798	0.425
Working memory ON	Age	0.187	0.08	0.045	0.019	2.313	0.021
Vocabulary ON	Age	0.406	0.069	1.376	0.255	5.389	<0.001
Visual-motor integ. ON	Age	0.415	0.068	0.26	0.047	5.523	<0.001
Response inhibition WITH	Interf. suppression	0.464	0.066	0.304	0.06	5.035	<0.001
	Working memory	0.452	0.066	0.504	0.101	4.969	<0.001
	Vocabulary	0.395	0.07	5.814	1.317	4.415	<0.001
	Visual-motor integ.	0.34	0.073	0.922	0.238	3.867	<0.001
Interf. suppression WITH	Working memory	0.468	0.065	0.588	0.115	5.095	<0.001
	Vocabulary	0.428	0.068	7.106	1.508	4.712	<0.001
	Visual-motor integ.	0.497	0.063	1.523	0.286	5.33	<0.001
Working memory WITH	Vocabulary	0.498	0.062	14.062	2.602	5.403	<0.001
	Visual-motor integ.	0.411	0.069	2.141	0.464	4.611	<0.001
Vocabulary WITH	Visual-motor integ.	0.381	0.07	26.219	6.608	4.321	<0.001
Word writing WITH	Rhyme	0.409	0.069	1.649	0.362	4.556	<0.001
	Blending	0	0	0	0	999	999
	Similar words	0.098	0.071	0.54	0.396	1.366	0.172
	Letter writing	0.542	0.06	2.424	0.425	5.699	<0.001
Letter writing WITH	Rhyme	0.254	0.077	3.836	1.284	2.988	0.003
	Blending	0.057	0.07	0.734	0.903	0.813	0.416
	Similar words	0	0	0	0	999	999
Rhyme WITH	Blending	−0.015	0.076	−0.169	0.886	−0.191	0.848
	Similar words	0.035	0.08	0.644	1.481	0.435	0.664
Blending WITH	Similar words	0.227	0.079	3.622	1.36	2.663	0.008

Note: BY indicates that a latent variable is predicted by one or more others observed variables; ON means that a variable is predicted from one or more others observed variables; WITH indicates a correlation between variables.

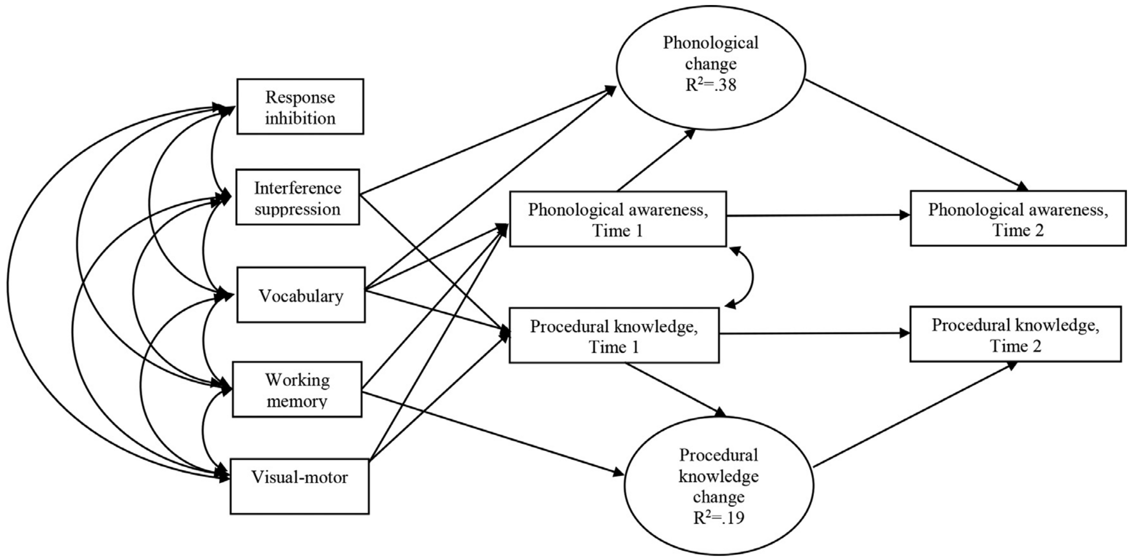

Fig. 3. Latent Change Score (LCS) model specifying the relationships among the two inhibition dimensions (composite scores), the working memory (backward word span), the vocabulary (Peabody picture vocabulary task), the visual–motor integration (copying subtest from the NEPSY–II battery), and the growth in the phonological awareness abilities and in the procedural writing knowledge task performance composite scores occurred between T1 and T2. In order to increase the figure's clarity only main information are shown. The detailed parameter information are reported in Table 7.
Note: To increase readability age is not included in the figure, but it was included in the model, as reported in Table 7.

ering the dynamic interrelations between phonological awareness and early writing skills.

The preliminary analyses showed that performance in early literacy tasks improved significantly from winter to spring. Moreover, the cognitive and literacy tasks were all (with a few exceptions) significantly intercorrelated, with coefficients denoting low to moderate associations.

4.1. Inhibitory control dimensions

The first research question pertains to whether response inhibition and interference suppression are separate inhibitory control dimensions between 4 and 5 years of age. In accordance with previous literature, we identified two separate inhibitory dimensions (Gandolfi et al., 2014; Traverso et al., 2020; 2018). The response inhibition component accounted for the HTKS task and the Stroop task, whereas the interference suppression component was represented by the fish flanker task and the dots task. In both the HTKS and the Stroop tasks, the child was required to focus on one attribute of the stimulus, to suppress prepotent (but inappropriate) motor or verbal responses, and to act according to the task's rule. In the HTKS task, the child had to listen to the command dictated by the adult and to control his and/or her response by touching the body part not named by the adult. Similarly, in the Stroop task, the child had to be able to focus on the stimulus, to halt the dominant response (i.e. the correct color of the shape), and to give the correct response (i.e. to label another color). In contrast, in interference suppression tasks, complex stimuli are presented, and the child is required to filter out irrelevant information, detect the relevant stimuli, and choose between two possible response sets. Specifically, in the fish flanker task, the child was required to focus on the direction of the central fish filtering out the flankers; in the dots task, the child had to consider both the type and position of the stimulus in choosing between two possible responses. In both of these interference suppression tasks, the child had to overcome interference arising from the diverse features of the stimulus and from competing responses.

The identification of two separate inhibitory dimensions accounting for different tasks confirmed that inhibitory control is a multidimensional construct from 4 to 6 years of age (Bunge et al., 2002; Cragg, 2016; Martin-Rhee & Bialystok, 2008; Rey-Mermet et al. 2018; but Friedman & Miyake, 2004). Therefore, given the contribution of inhibitory control to the development of other domains, the ability to manage conflict at the response level (i.e. response inhibition) should be considered distinct from the ability to manage conflict at the level of the stimulus (i.e. interference suppression).

4.2. The role of inhibitory abilities in early literacy skills

The second research question investigates whether response inhibition and interference suppression are uniquely and differently associated with phonological awareness and procedural writing knowledge tasks when concurrently considering the relationships with vocabulary, working memory, and visual-motor integration skills. As reviewed in the introduction, writing development is depicted as a multidimensional process in which domain-general abilities may also play a role (Berninger & Winn, 2006). Studies analyzing the relationships between inhibitory control and early literacy skills (Table 1) have mostly employed response inhibition tasks, and have not considered the differential role of diverse types of inhibitory processes. Considering the separate and concurrent contribution of different inhibitory dimensions to early literacy skills allowed us to focus on key abilities that may facilitate writing development.

As hypothesized, we found that interference suppression—but not response inhibition—is singularly related to phonological awareness and procedural writing knowledge at time 1; in particular, it is related to minimal pairs and both writing tasks (Fig. 2). Interference suppression is more involved in performing tasks that require selecting the right piece of information among confounding stimuli, such as in the minimal pairs task (which assesses the ability to detect the phonological features of words differing in a single phoneme). At the same time, interference suppression may be involved in overcoming conflict due to multiple interfering phonological inputs and detecting the phonological features of words (ten Braak et al., 2018). The same process may support children in selecting the right letter from among different competing sym-

Table 7
Parameters identified with the Latent Change Score (LCS) model.

		Factor model parameters Standardized estimates	S.E.	Unstandardized estimates	S.E.	Est./S.E.	*P*
Phonological awar. change BY	Phonological T2	0.678	0.056	1.000	0.000	999	999
Writing procedural k. change BY	Writing T2	0.505	0.041	1.000	0.000	999	999
Phonological change ON	Writing change	0.115	0.263	0.110	0.252	0.435	0.664
Writing procedural k. change ON	Phonological change	0.078	0.145	0.081	0.152	0.536	0.592
Phonological awar. change ON	Phonological T1	−0.831	0.099	−0.498	0.065	−7.602	<0.001
	Response inhibition	0.169	0.087	0.096	0.050	1.921	0.055
	Interf. suppression	0.209	.086	0.111	0.046	2.442	0.015
	Working memory	0.111	0.110	0.034	0.034	1.008	0.313
	Vocabulary	0.205	0.101	0.004	0.002	2.018	0.789
	Age	−0.030	0.111	−0.002	0.008	−0.268	0.789
Writing procedural k. change ON	Writing T1	−0.351	0.106	−0.180	0.056	−3.243	0.001
	Response inhibition	−0.082	0.102	−0.049	0.061	−0.799	0.424
	Interf. suppression	0.004	0.105	0.002	0.058	0.040	0.968
	Working memory	0.213	0.101	0.069	0.033	2.088	0.037
	Vocabulary	−0.073	0.108	−0.002	0.002	−0.677	0.498
	Visual-motor integr.	−0.022	0.106	−0.003	0.013	−0.211	0.833
	Age	0.382	0.094	0.029	0.008	3.847	<0.001
Phonological T2 ON	Phonological T1	1.132	0.056	1.000	0.000	999	999
Writing T2 ON	Writing T1	0.985	0.041	1.000	0.000	999	999
Phonological T1 ON	Response inhibition	0.008	0.069	0.008	0.066	0.121	0.904
	Interf. suppression	0.123	0.071	0.110	0.063	1.739	0.082
	Working memory	0.330	0.069	0.169	0.036	4.657	<0.001
	Vocabulary	0.343	0.072	0.012	0.003	4.692	<0.001
	Visual-motor integr.	0.196	0.072	0.038	0.014	2.699	0.007
	Age	−0.163	0.066	−0.020	0.008	−2.460	0.014
Writing T1 ON	Response inhibition	−0.018	0.078	−0.021	0.090	−0.238	0.812
	Interf. suppression	0.223	0.080	0.242	0.088	2.760	0.006
	Working memory	0.079	0.080	0.050	0.050	0.992	0.321
	Vocabulary	0.308	0.080	0.014	0.004	3.767	<0.001
	Visual-motor integ.	0.199	0.080	0.048	0.019	2.462	0.014
	Age	0.109	0.074	0.016	0.011	1.462	0.144
Response inhibition ON	Age	0.324	0.074	0.042	0.010	4.137	<0.001
Interf. suppression ON	Age	0.071	0.083	0.010	0.011	0.862	0.388
Working memory ON	Age	0.187	0.080	0.045	0.019	2.313	0.021
Vocabulary ON	Age	0.406	0.069	1.376	0.255	5.389	<0.001
Visual-motor integ. ON	Age	0.415	0.068	0.260	0.047	5.523	<0.001
Writing change WITH	Phonological change.	−0.163	0.344	−0.025	0.054	−0.466	0.641
Writing T1 WITH	Phonological a. T1	0.302	0.076	0.106	0.031	3.488	0.001
Response inhibition WITH	Interf. suppression	0.460	0.066	0.301	0.060	5.003	<0.001
	Working memory	0.450	0.066	0.500	0.101	4.951	<0.001
	Vocabulary	0.393	0.070	5.776	1.312	4.401	<0.001
	Visual-motor integ.	0.338	0.074	0.914	0.238	3.848	<0.001
Interf. suppression WITH	Working memory	0.470	0.065	0.561	0.116	5.116	<0.001
	Vocabulary	0.431	0.068	7.159	1.510	4.742	<0.001
	Visual-motor integ.	0.494	0.063	1.511	0.285	5.299	<0.001
Working memory WITH	Vocabulary	0.498	0.062	14.062	2.602	5.403	<0.001
	Visual-motor integ.	0.411	0.070	2.141	0.464	4.611	<0.001
Vocabulary WITH	Visual-motor integ.	0.381	0.076	26.219	6.068	4.321	<0.001

Note: BY indicates that a latent variable is predicted by one or more others observed variables; ON means that a variable is predicted from one or more others observed variables; WITH indicates a correlation between variables.

bols while writing. This may be the case, for instance, when they are retrieving a letter between letters with similar shapes, or with confounding sounds such as /p/ and /b/, especially when skills are emerging. Hence, interference suppression may be especially relevant when metaphonological and procedural knowledge are not yet consolidated and automatized (Puranik et al., 2019). This does not mean that the response inhibition component does not contribute to early literacy skills. The models show an overall excellent fit; in addition, response inhibition is significantly associated with the other predictors. However, the unique contribution of this ability to early literacy skills is comparatively lower and not statistically significant.

Interference suppression is associated with the outcomes above and beyond the other variables considered. This suggests that the relationship between interference suppression and phonological awareness or procedural writing knowledge is not influenced by underlying and common components such as language abilities, working memory, and visual-motor integration skills. Nevertheless, interference suppression was not associated with the rhyme detection task or blending task performance. Regarding rhyme detection, in the task we used, the alternative words proposed were largely different from one another at the global phonological level. For example, in one item, the target word was 'riso' (rice); the alternatives were 'pasta' (pasta), 'pecora' (sheep), and 'viso' (face). Therefore, it is possible that interference suppression—which allows one to manage multiple interfering phonological inputs—was not highly required, and that it could have been required if the alternative items in the rhyme were very similar (i.e. 'riso', 'vivo', and 'viso', which are alternatives comprising voiced fricatives where only the articulation point changes). Similarly, in the blending task, in which the child has to blend different syllables, other abilities may support the child's performance more than interference suppression or response inhibition, such as the ability to maintain and elaborate information in one's mind, as we will discuss later. In this regard, diverse phonological awareness tasks may require manipulating sounds at different levels. Interference suppression (and not response inhibition) may account for tasks in which one has to focus on specific parts of words without becoming confused by the word's global sound; this ability enhances phonological awareness.

As for the other abilities, as expected, vocabulary was concurrently related to both early literacy abilities (see, e.g. McDowell, Lonigan & Goldstein, 2007; Whitehurst & Lonigan, 2001). Language ability is associated with literacy, and has been linked to phonological awareness and inhibitory control by some studies (Kegel & Bus, 2014; Shaul & Schwartz, 2014), but not others (Blair & Razza, 2007; Zhang et al., 2017).

According to previous research, other abilities are significantly associated with early literacy skills at time 1 when inhibitory abilities are also considered. Specifically, as expected, working memory was concurrently associated with phonological awareness, also taking inhibitory control abilities into account (Cameron et al., 2015; Lonigan et al., 2016), indicating that these competencies may play a different role in contributing to early literacy skills. Phonological awareness tasks are known to be cognitively demanding (Cassano & Steiner, 2016). Nevertheless, rhyme and blending tasks rely less on inhibitory control than on working memory, suggesting that the cognitive load due to the amount of information to retrieve is more relevant for these tasks than inhibitory requests. Working memory may affect children's ability to store and consequently manipulate phonological input (Torrington, Eaton & Ratner, 2016); storing is involved in the process of forming stable phonological representations, whereas manipulation is used to update or overwrite phonological rules (Munson, Johnson & Edwards, 2012).

We found visual-motor integration skills to contribute to both phonological awareness and procedural writing skills when measured concurrently. Previous studies have shown that visual-motor integration skills, together with inhibitory control, are related to early literacy (Becker et al., 2014; Cameron et al., 2012; 2015; Chung et al., 2018). As suggested by Cameron et al. (2015), visual-motor integration skills and inhibitory control may interact through a compensatory association in which 'strengths in visual-motor integration may compensate for low inhibitory control' and 'strong inhibitory control may compensate for weak visuomotor skills' (p. 1537). In particular, Cameron et al. (2012) suggested considering the relationship between visual-motor integration skills and early literacy skills in light of the competing motor and cognitive demands of the specific task.

4.3. The role of response inhibition and interference suppression in changes in early literacy skills

The third research question explores whether response inhibition and interference suppression are uniquely associated with changes in early literacy skills, controlling the initial levels of phonological awareness and procedural knowledge in predicting later changes. In contrast to most prior studies, which have used a regression approach to identify the predictors of early literacy (except for Kegel & Buss, 2014), in our study, we employed an LCS approach. LCS models, as well as cross-lagged regression models or hierarchical linear models, help to evaluate hypotheses that involve interrelations among variables, together with changes in those variables over time. Additionally, unlike the techniques cited above, the LCS approach allowed us to capture dynamic features and to estimate how current levels in the variables are related to later changes (Ferrer & McArdle, 2010).

Overall, the model explained 38% and 19% of the changes in phonological awareness and procedural writing knowledge, respectively. These results indicate that the main predictors of changes in phonological awareness and procedural writing knowledge are previous levels of performance in the same abilities. Children starting with lower phonological ability tend to fill in the gap and to grow more than the higher performing children at time 1, independent of their age. On the other hand, changes in writing production are explained only by prior performance on the same task and by age. Children showing lower performance on the writing tasks during the winter assessment were more prone to change, especially if they were younger. Interestingly, there were no reciprocal influences between changes in phonological awareness and changes in writing skills. Most likely, the dynamics of reciprocal influences between an increase in phonological awareness and procedural knowledge, largely documented in the literature, would take more than five months; that is, the time between the two waves of assessment in this study.

Interference suppression, together with vocabulary, is uniquely associated with an increase in phonological awareness skills. In other words, children who are more able to manage interfering stimuli or conflictual responses, as well as show a richer receptive vocabulary, are more prone to exhibit changes in phonological awareness. On the other hand, children who struggle with interfering stimuli or conflictual responses and have a poor vocabulary tend to display a smaller increase in phonological awareness.

The interaction between interference suppression and language may account for phonological awareness growth. In fact, language could be related to interference suppression in many ways. On the one hand, language plays a role in the development of the self-regulation of behavior through inner speech (e.g. Winsler, Fernyhough, & Montero, 2009); on the other hand, inhibitory control is particularly relevant in supporting language acquisition in young children, especially vocabulary and early grammar (Gandolfi & Viterbori, 2020).

Moreover, vocabulary resulted in a significant increase in phonological awareness skills (e.g. Lonigan, 2007). The presence of different paths of influence may also explain the reason for the absence of a significant contribution from inhibitory control to phonological awareness when vocabulary is considered (Shaul & Schwartz, 2014; Zhang et al., 2017). These linkages may support the hypothesis that vocabulary and interference suppression set the stage for phonological awareness. Importantly, our findings concern a sample of children who were tested in their native tongue. This partially ensured that—even though most executive tasks are non-verbal in nature—the cognitive load due to verbal task instruction had no significant effect on the final results.

Interference suppression may influence early literacy skills through different paths; for example, it may intervene during the execution of a task, as the abilities required in literacy tasks have not yet been automatized. As suggested above, for instance, interference suppression may help the child while performing a phonological awareness task or writing, or while selecting the right piece of information in the presence of interfering stimuli. Moreover, interference suppression might be important in inhibiting low-level perceptual processes that could potentially interfere with an analytical and metalinguistic comparison between stimuli (e.g. a minimal pairs task).

Another path of influence concerns the role of interference suppression in supporting the child during exposure to educational activities. Children with higher interference suppression abilities may have an advantage since they are better able to filter useless or distracting stimuli, and to be more focused on the relevant pieces of information, thus allowing them to benefit more from educational activities. Traverso et al. (2019) posited a similar claim to explain the outcomes of a study aimed at verifying the effectiveness of an intervention to foster executive functioning in 5-year-old children. They found training to be effective in improving interference suppression, which in turn fully mediates the enhancement in emergent writing skills (Traverso et al., 2019). As suggested by Bryce, Whitebread and Szűcs (2015), interference suppression may contribute to metacognitive monitoring by preventing children from becoming distracted by environmental factors while they update their representations.

Among the other abilities considered, only working memory appears to be significantly associated with growth in procedural writing knowledge. Writing tasks are more challenging for children aged 4 to 5 years old (Puranik et al., 2019); hence, a greater working memory capacity allows them to retrieve letter representations and keeps them active during the motor plan execution necessary for writing.

Response inhibition is not associated with changes in phonological awareness, procedural writing knowledge, or visual-motor integration. These results imply that the improvements in early literacy skills are less influenced by the level of motor responses and response control than by cognitive control processes, such as interference suppression, working memory, and language abilities.

4.4. Strengths and limitations

To the best of our knowledge, our study is the first to consider different inhibitory dimensions represented by composite scores of multiple measures in order to investigate the contribution of inhibitory control to early literacy skills. The results suggest that interference suppression, more than response inhibition, significantly contributes to early literacy skills over and above other variables. Indeed, other important related factors make a significant contribution, but interference suppression is uniquely associated with the outcomes. The investigation of change with respect to the LCS is another strength of this study because it shows that inhibitory abilities, more than other skills, may support short-term changes.

Nevertheless, this study has some limitations. First, we addressed changes in a narrow interval of time without considering long-term relationships among early observed variables and outcomes. Further, we did not consider a possible reciprocal association between inhibitory abilities and early literacy skills, which may support the development of interference suppression and response inhibition. Another critical issue is that the processes by which inhibitory control influences early literacy skills are inferred and not directly measured. Future studies should examine other early literacy skills and take other variables into account—such as the home literacy environment (Davidse et al., 2011) or other sociocultural information that is important for early literacy skills—that are not included in the model.

5. Conclusion

We confirmed that two different inhibitory abilities (i.e. response inhibition and interference suppression) may be found in children between 4 and 5 years of age. Given the concurrent contribution to early literacy skills, interference suppression—but not response inhibition—is related to phonological awareness and writing tasks when the influence of language, verbal working memory, and visual-motor abilities are also contemplated. In addition, interference suppression and vocabulary are uniquely associated with a growth in phonological awareness, whereas working memory is associated with a growth in procedural writing knowledge.

Overall, our findings signal that children between 4 and 5 years of age show the greatest progress in early literacy skills, such as phonological awareness and procedural writing knowledge, when these same skills are still immature. However, at the same time, they should exhibit adequate vocabulary, together with strong interference suppression and working memory abilities.

These results have important implications for education by suggesting that these control processes may play a crucial role, particularly in children with low early literacy skills. As previously shown, children who display impaired or delayed control processes may have pronounced academic problems in kindergarten (Willoughby et al., 2017); therefore, including direct assessments of inhibitory control and, in particular, interference suppression during early childhood may be useful to identify children who could benefit from early intervention to enhance their self-regulation abilities, which in turn are effective in promoting academic skills (Pandey et al., 2018). Educational activities supporting the development of cognitive control processes, as well as early literacy and language skills, could be considered supplementary strategies to promote the acquisition of written language.

Author statement

Laura Traverso: Conceptualization, Methodology, Investigation, Formal Analysis, Data Curation, Writing - Original Draft. Paola Viterbori: Conceptualization, Methodology, Writing - Review & Editing. Elena Gandolfi: Investigation, Data Curation, Writing - Review & Editing. Mirella Zanobini: Methodology, Writing - Review & Editing. Maria Carmen Usai: Conceptualization, Methodology, Formal Analysis, Writing - Original Draft.

Compliance with ethical standards

Ethical approval: All procedures performed in this study involving human participants were approved by the local Research Ethical Committee, and were in accordance with the Ethical Standards of the Institutional and National Research Committee (Ethical Code of the Italian National Council of Psychologists and the Ethical Guidelines of the Italian Association of Psychology), as well as with the 2013 Helsinki declaration. Informed consent: We obtained informed consent from the parents of all child participants included in the study.

Conflict of Interest

We declare that we have no conflicts of interest.

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