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Inhibition: Mental Control Process or Mental Resource?

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The current study tested 2 models of inhibition in 45 children with language impairment and 45 children with normally developing language; children were aged 7 to 12 years. Of interest was whether a model of inhibition as a mental-control process (i.e., executive function) or as a mental resource would more accurately reflect the relations among mental-attentional (*M*) capacity, inhibition, updating, shifting, and language competence. Children completed measures of *M*-capacity (in the verbal and nonverbal domains), inhibition, updating, shifting, and language. Path analyses showed the data provided a poor fit to the model of inhibition as a mental-control process but a good fit to the model of inhibition as a mental resource. Results are consistent with the theory of constructive operators and suggest inhibition is a mental resource rather than a mental-control process.

Current conceptualizations of executive function (EF) include at least three distinct, but related processes—the ability to: a) deliberately inhibit prepotent or misleading responses (*inhibition*); b) hold, monitor, and update information in working memory (*updating*); and c) shift efficiently between mental sets (*shifting*). This three-factor model, originally found in adults (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000), has been replicated in studies with children (Lehto, Juujarvi, Kooistra, & Pulkkinen, 2003; Rose, Feldman, & Jankowski, 2011). However, in children there also is empirical support for EF as a unitary structure (Brydges, Reid, Fox, & Anderson, 2012; McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010; Wiebe et al., 2011) as well as for a two-factor model of EF that includes updating and shifting (Huizinga, Dolan, & van der Molen, 2006; Miyake & Friedman, 2012) or updating and inhibition (Miller, Giesbrecht, Muller, McInerney, & Kearns, 2012; St. Clair-Thompson & Gathercole, 2006).

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It has been suggested that the inconsistent findings with respect to the structure of EF in children may be due to methodological differences across studies (e.g., different statistical analyses or test batteries; Miller et al., 2012). For instance, the choice of statistical analysis (confirmatory factor analysis, Rose et al., 2011; or principal components analysis, St. Clair-Thompson & Gathercole, 2006) or performance indicators for a particular EF may influence obtained factor structures (Miller et al., 2012). We propose that another reason for contradictory findings in the EF literature is the descriptive nature of much of this research. Most of the literature is empirically driven, and the construct of EF is examined in a post-hoc fashion (e.g., Lehto et al., 2003; Willoughby, Wirth, & Blair, 2011; see Zelazo & Muller, 2002, for a review). Moreover, the relations among EF as they are implemented in a specific domain, such as language, are not well explained nor are they proposed a priori via a developmental theory. The current study uses the theory of constructive operators (TCO; Pascual-Leone, 1970, 1987; Pascual-Leone & Johnson, 2005, 2011) to examine relations among mental-attentional resources (e.g., processing capacity), EF, and language in a developmental sample with a wide range of language ability. In particular, we contrast effortful inhibition as a separate mental-control construct (which is part of EF) versus a mental resource that is part of mental attention and that EF processes help to control and coordinate.

Executive Function and Inhibition

Inhibition traditionally has been considered an important EF; however, its relation to other executive processes is not clear. Inhibition has been shown to be a distinct EF in some developmental studies (e.g., Lehto et al., 2003, Rose et al., 2011), but not in others (e.g., Wiebe et al., 2011). St. Clair-Thompson and Gathercole (2006) found that updating and inhibition were distinct factors that were not correlated with each other, which suggests inhibition may be dissociable from other EFs. These conflicting findings may reflect differing views regarding the relation between updating (an activation process) and inhibition (a deactivation process). Investigators have considered that the ability to activate a relevant response works in conjunction with the ability to effortfully inhibit an irrelevant response so that successful performance is determined by the coordination of activatory and inhibitory processes as dictated by the demands of a particular task (e.g., Bjorklund & Harnishfeger, 1990; Miller et al., 2012; Roberts & Pennington, 1996). Some propose that activatory/inhibitory processes are interactive and draw upon a common pool of resources (Roberts & Pennington, 1996), whereas others suggest these processes may be independent (Beveridge, Jarrold, & Pettit, 2002).

A problem with the empirical research investigating activatory/inhibitory processes is the lack of theoretical integration with the developmental literature on EF. In fact, investigators have highlighted that EF (Best & Miller, 2010)—and particularly inhibition (Harnishfeger, 1995)—lacks a defining developmental theory. Similar to EF, conceptualization of inhibition is debated and has been suggested to be multifaceted (e.g., Dempster, 1993) or to be composed of different processes (e.g., Harnishfeger, 1995). It is likely that inhibition, like EF, is affected by task demands, stimulus characteristics, and the developmental capacities of the individual (Johnson, Im-Bolter, & Pascual-Leone, 2003; Munakata et al., 2011). The TCO (Howard, Johnson, & Pascual-Leone, 2014; Pascual-Leone, 1970, 1984, 1987; Pascual-Leone & Johnson, 2005, 2011) proposes two forms of inhibition (automatic and effortful) and makes explicit the developmental relations among activatory, inhibitory, and executive processes, while relating them to task characteristics. This is important because it is well established that both the power and efficiency of attentional activation (working memory) and of attentional inhibition increase with chronological age up to later adolescence (Eigsti et al., 2006; Howard et al., 2014; Luna, Garver, Urban, Lazar, & Sweeney, 2004).

Theory of Constructive Operators

The TCO (Pascual-Leone, 1970, 1984, 1987; Pascual-Leone & Johnson, 2005, 2011) views cognitive growth in terms of the maturation of domain- general central processing resources—mental-attentional activation (*M*) capacity and attentional inhibition (interruption or *I*) capacity—and also includes mechanisms for logical-structural and content learning. In the TCO, mental attention is explained by activatory (*M*), inhibitory (*I*), and executive processes (*E*; as well as other constructs; see Pascual-Leone & Johnson, 2005, 2011, for a more detailed discussion). *M* functions to raise the activation level of task-relevant schemes (operative processes and mental representations) that are not sufficiently activated by the situation; *I* inhibits or effortfully lowers activation of task-irrelevant schemes; and *E* serves to control and monitor the allocation of *M* and *I* and has a general higher-order planning function. When assessed behaviorally, the capacity of *M* increases by one scheme unit every other year from 3 years to 15 years of age.

Utilization of mental-attentional resources depends on the characteristics of a particular task. In *misleading situations/tasks*, salient contextual or learning factors activate schemes that lead to incorrect or inadequate performance. As a result, the individual must *effortfully inhibit* (using *I*) the salient but misleading components of the task and must concurrently activate (using *M*) relevant schemes required for successful task completion. *Automatic inhibition* occurs when an act of mental attention (*M*-centration) takes place that boosts activation of centrated schemes, which concurrently causes suppression of schemes that were excluded from the *M*-centration (Howard et al., 2014; Pascual-Leone, 1984). This proposal is compatible with recent conceptualizations of inhibition that propose a similar distinction between targeted or effortful inhibition and indirect or automatic inhibition (e.g., Munakata et al., 2011). *Facilitating situations/tasks* are those in which contextual or learning factors activate only schemes that are *relevant* to the performance at hand; thus, automatic inhibition can be mobilized in them, but effortful inhibition is not required. The misleading/facilitating distinction (Pascual-Leone, 1984, 1987) is important when understanding the cognitive demand of a task; this is particularly important for developing more effective remediation of disorders such as language impairment.

It is possible to bypass irrelevant schemes via activation, instead of via effortful inhibition (Pascual-Leone, 1984, 1987). Indeed, when a strategy effectively excludes from *M*-centration the misleading schemes, the act of *M*-centration will suppress them via automatic inhibition. This, however, may require additional *M*-capacity, because often more schemes must be activated to apply this new detour/bypass strategy. Theoretically, this suggests that young children, who have less *M*-capacity, would have difficulty with misleading tasks because they may not mobilize *I* efficiently and may be unable to use detour/bypass strategies. Older children, who have more *M*, might bypass the irrelevant schemes or effortfully inhibit them. This dual option of a bypassing/detour strategy versus effortful inhibition of task-misleading schemes clarifies the sense in which inhibition is related to controlled attentional resources (Engle, Conway, Tuholski, & Shisler, 1995). Note that unlike some approaches (e.g., Baddeley, 1996; Miyake et al., 2000), the TCO considers effortful (or direct) inhibition to be a cognitive resource, not an EF—although executive processes are used to control it. *E* (executive processes) monitor allocation of *M* and *I* to serve the current goal. Thus, the efficiency with which an individual can mobilize and allocate *M* and *I* will depend on *E* as well as on characteristics of the problem-solving situation.

Particularly relevant to the current study are the executive processes of recentration and decentration. *Recentration* can change the content of focal attention (i.e., *M*-centration) without shifting levels of analysis. An example is scanning a room or changing attention in the *n*-back task, or in language tasks, from schemes (visual patterns or words) already cognized to new schemes just activated by input. In contrast, *decentration* monitors or controls shifting focal attention to schemes that are constituted at a higher or lower level of analysis. For example, when one has to understand a complex and unfamiliar language utterance, the units already cognized and the new units being attended to must be synthesized into a hierarchically organized totality. This meaningful totality integrates parts into a composite, higher-order meaning structure. Recentration and decentration correspond respectively to updating and shifting, as formulated by Miyake et al. (2000) in their conceptualization of EF. Note that in the TCO, recentration provides executive control during the allocation of *M*, which is distinct from *M*-activation processes.

The Current Study

EF is associated with individual differences in children's language (Blair & Razza, 2007; Im-Bolter, Johnson, & Pascual-Leone, 2006), and deficits in EF have been proposed to underlie difficulties in this area (Henry, Messer, & Nash, 2012; Im-Bolter et al., 2006). An important next step in understanding EF (and its contribution to typical and atypical language development) is to model, theoretically, the specific relations between mental attention (activation or inhibition) and EF and how these relations might help to explain both language competence and disorders. Without theoretical guidance, findings are interpreted based exclusively on statistical considerations (e.g., Wiebe et al., 2011) or in a post-hoc manner that is likely to be sample-specific (Miller et al., 2012).

Theoretically, recentration is important for many aspects of everyday oral-language processing, because language usually involves changing the content of attention rather than shifting focal attention to a different level of analysis (Im-Bolter et al., 2006). This proposal has empirical support (Whitely & Colozzo, 2013). Thus, recentration (updating) should mediate the relations between *M* and language competence, but decentration (shifting) should not. According to the TCO, inhibition (*I*) would not have a direct effect on language competence. Im-Bolter et al. (2006) tested and confirmed this model but did not contrast it with an alternative model representing how inhibition is conceptualized in the EF literature.

Model 1 depicts the theoretical view of inhibition as an EF that can modulate the application of *M*-capacity (top panel of Figure 1). In this view, inhibition, along with updating and shifting, is seen as monitoring application of *M*-capacity on language processing and, therefore, mediating the *M*-capacity–language competence relation. Model 2 (bottom panel of Figure 1) depicts

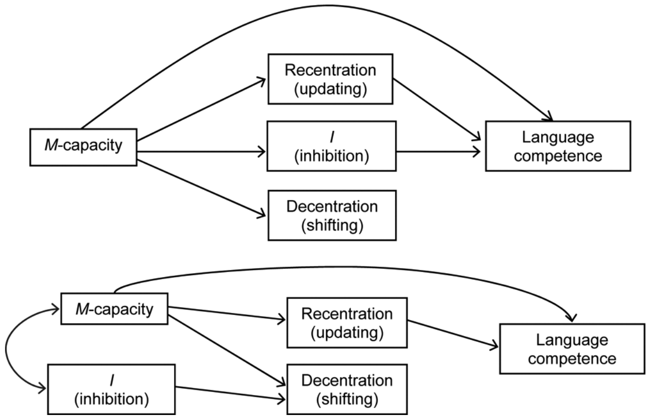

FIGURE 1 Top panel: Model 1. Inhibition as a mental-control process (i.e., executive function). Bottom panel: Model 2. Inhibition as a mental resource.

the theoretical view of inhibition as a mental-attentional resource that is distinct from but in a dialectical interrelation with *M*-capacity, as proposed by the TCO. As a result of this relation, inhibition is not associated with language directly. Theoretically, the application of *I* is associated with the controlled use of *M*. Hence, in the measurement model, *I* has an interactive relation with *M* only. There also is a path from *I* to shifting because the application of *I* assists in the shifting of focal attention to schemes that are constituted at a higher or lower level of analysis. Updating and shifting, which are *M*-control executives, mediate the *M*-capacity–language competence relation. We tested these two models in a sample of children with a wide range of language competence, including those with language impairment. We propose that children with language impairment differ from those with normally developing language in a quantitative manner. This is consistent with other views that suggest the developmental trajectories of children with learning disorders are not different in quality from those of children without learning disorders (e.g., Borella, Carretti, & Pelegrina, 2010).

METHOD

A detailed description of the study sample, measures, and procedure can be found in Im-Bolter et al. (2006). A brief account of the methodology described in that article is included here.

Participants

A total of 90 children aged 7 to 12 years old were included in the study. One group consisted of 45 children (M_{age} = 10;1, SD = 15.72 months) who were identified as having a language impairment (LI) and met research criteria for LI (see Im-Bolter et al., 2006, for details). This group included 26 boys and 19 girls. This group had a heterogeneous mix of impairments in receptive and expressive language, which ranged in severity from mild (54%) to severe (29%). A second group of 45 children (M_{age} = 10;2, SD = 15.96 months) had normally developing language (NL).

This group included 23 boys and 22 girls. Children in both groups had to meet certain criteria (e.g., estimated Performance IQ within the average range, English spoken in the home without significant dialectical differences, no hard signs of neurological damage) to be included in the study. Children in the NL group were chosen to match the LI children as closely as possible in age, gender, and Performance IQ.

Measures

Intelligence. The two-subtest (Vocabulary and Matrix Analogies) version of the *Wechsler Abbreviated Scale of Intelligence* (Wechsler, 1999) was used to estimate Verbal and Performance IQ and provide a Full-Scale IQ score.

Language. Each child received a short battery of standardized tests compiled to measure areas typically assessed by speech/language pathologists. These included receptive phonology (*Test of Auditory Analysis Skills*; Rosner, 1975), receptive and expressive vocabulary (*Peabody Picture Vocabulary Test*-Third Edition, Dunn & Dunn, 1997; and *Expressive Vocabulary Test*, Williams, 1997), and receptive and expressive syntax (*Test of Language Development*-Third Edition Grammatic Understanding/Comprehension subtest, Hammill & Newcomer, 1997a, 1997b; and *Clinical Evaluation Language Fundamentals*-Third Edition Formulated Sentences subtest, Semel, Wiig, & Secord, 1995).

M-capacity. *M*-capacity measures (*M*-measures) are designed to systematically vary in demand for *M*-capacity (*M* demand) rather than learning or previous experience, so that test items differ only in terms of the number of schemes that must be activated by *M* (Pascual-Leone & Johnson, 2011). As a result, *M*-measures yield the same metric across content domains, and performance on different *M*-measures can be compared directly, something that cannot be said for working-memory span tasks. Two individually administered *M*-measures were used. One was visuospatial (*Figural Intersections Test* [FIT] Version 8303; Pascual-Leone & Ijaz, 1989; Pascual-Leone & Johnson, 2001) and the other was language-based (*Direction-Following Task* [DFT]; Cunning, 2003; Pascual-Leone & Johnson, 2005, 2011). The FIT is a paper-and-pencil *M*-task that required the child to locate the one area of total intersection of two to eight overlapping, geometric shapes. The child first placed a dot in each discrete shape on the right side of the page and then placed a single dot in the total intersection area of the overlapping configuration on the left. There were 36 items, and all participants received the same random order of items. The DFT required children to follow oral directions of increasing complexity. The task used tokens of basic shapes, colors, and sizes as well as a simple repetitive command (''place X on Y'') to control for extraneous factors (e.g., preposition difficulty, degree of abstractness). Each *M*-measure provided an *M*-score, which represents the *M*-demand of the highest item class that is reliably passed. *M*-demand is the minimum number of schemes that must be kept simultaneously activated by *M*-capacity to solve the task.

Inhibition (I-capacity). The Antisaccade Task (Miyake et al., 2000) was used to measure *I*. Successful performance requires suppression of a reflexive saccade toward a visual cue. The Antisaccade Task has been found to be sensitive to prefrontal dysfunction and is widely viewed as a task of inhibitory control (see Best & Miller, 2010, for a short review). It has been used with a wide variety of populations, including children, because it is simple, nonverbal, and has minimal memory demands; at the same time, adults do not perform at ceiling levels (Roberts, Hager, & Heron, 1994). In this task, children were presented with a fixation point in the center of a computer screen and then a visual cue appeared on one side (e.g., left). Children were instructed not to look at this peripheral visual cue but in the opposite direction (e.g., right) to view a target stimulus (arrow pointing right, left, or up) that was presented for a brief time. Children indicated the direction of the arrow with a button-press response. The score was the proportion of correct responses.

Updating of working-memory contents (recentration). The visual *n-Back Task* (Cohen et al., 1997; Nystrom et al., 2000) was used to measure updating of working memory in the visual content domain. The child indicated whether or not each stimulus (one of nine three-dot patterns) matched the stimulus shown *n* items earlier in the sequence (from zero to two). The zero-back condition is the least complex condition and requires the child to hold in mind the target pattern to compare it with each incoming stimulus. In the one-back condition, children compare each incoming stimulus with the previously viewed stimulus. The two-back condition is the most complex and requires children to monitor and hold in mind three ordered stimulus configurations to compare the incoming stimulus with the one that was presented prior to the previous stimulus (i.e., two back). The score was the proportion of correct responses to the target stimulus in each condition.

Shifting of mental sets (decentration). Latency to complete Part B of the *Children's Trail-Making Test* (Reitan, 1992) was used to measure shifting. The Children's Trail-Making Test has been used as a measure of set shifting and EF (see Morris, 1996, for brief review) and is part of a battery of neuropsychological tests often administered to children (Rourke, Bakker, Fisk, & Strang, 1983). In addition, Lehto et al. (2003) found latency to complete Trails B to be the best indicator of a shifting factor.

RESULTS

A detailed description of the participant sample and results for group differences can be found in Im-Bolter et al. (2006). Briefly, the two groups did not differ with respect to gender, age, or Performance IQ (see Im-Bolter et al., 2006, Table 1), but as expected, the LI group had significantly lower language skills, Verbal IQ, and Full-Scale IQ. The LI group also had lower scores on both *M*-capacity measures, which suggests that children with LI have reduced domain-general attentional capacity or reduced efficiency in applying this capacity. As predicted, the LI group performed more poorly than the NL group on measures of inhibition and updating, but the two groups did not differ on the measure of shifting. Of note is that the average age of the NL group was 10 years, which corresponds to a theoretically expected *M*-capacity of about 4, and their scores on both measures of *M*-capacity were as expected for their age.

Data Screening

For path analyses, we examined bivariate, residual, and influence plots. Multivariate outliers did not appear to have an undue influence on the variables (with the exception of three participants,

TABLE 1
Means, Standard Deviations, and Intercorrelations for Measures of Language Competence, *M*-Capacity, Shifting, Updating, and Inhibition for the Entire Sample ($N = 87$)

Measure	*M*	*SD*	*1*	*2*	*3*	*4*
1. Language competence	–0.45	0.79	—			
2. *M*-capacity	3.45	0.93	.62***	—		
3. Shifting	41.24	19.55	–.40***	–.47***	—	
4. Updating	0.80	0.13	.42***	.34***	–.21*	—
5. Inhibition	0.66	0.18	.45***	.48***	–.53***	.25*

Note. Language competence = composite language score (mean language *z* score based on standard scores); *M*-capacity = mean of the Figural Intersection Test and Direction-Following Task *M* scores; shifting (of mental sets) = latency on Part B of the Trail-Making Test; updating (of working memory) = proportion of correct target identifications in the one-back condition of the *n*-back task; inhibition (of prepotent responses) = accuracy on the Antisaccade Task.

*$p < .05$. **$p < .01$. ***$p < .001$ or $p < .0001$.

who are described more fully in the appropriate section). All variables appeared to have linear relationships.

Model Comparison

Path analysis was conducted to compare the two models. We used the following variables: a) Language competence was indexed by a standardized composite language score (mean language *z* score based on the normative mean) Correlations between language measures ranged from $r(88) = .45$ to $r(88) = .75$ (all $p < .0001$). b) *M*-capacity was indexed by the mean of *M*-scores in the visual and language *M*-measures (i.e., FIT and DFT), $r(88) = .44$, $p < .0001$). c) Inhibition (*I*) was indexed by accuracy on the Antisaccade Task. d) Updating of working memory (recentration) was indexed by the proportion of correct target identifications in the one-back condition of the *n*-back task. Note that the zero-back task was too simple and seemed to reflect the ability to discriminate between patterns rather than updating, and the two-back condition was too difficult for all children. e) The cost of shifting mental sets (decentration) was reflected by latency on Part B of the Trail-Making Test.

Three multivariate outliers—two older children from the LI group and a younger child from the NL group—were excluded from the path analysis because we felt they were not representative of the LI and NL samples being drawn from the population. The younger child performed extremely well on the semantic language tasks (greater than the 90th percentile) but at age appropriate levels (i.e., ‘‘average’’) on other measures. The two older children performed extremely poorly on the language tasks (performance ranging from 1st percentile to the 2nd percentile) but were less impaired on other measures. Examination of notes indicated that although both children did all their schooling in Canada (6 years) and indicated they spoke English in the home, they were born elsewhere, suggesting possible unresolved issues with English as a second language or dialect.

Means, standard deviations, and intercorrelations of the relevant variables are shown in Table 1.

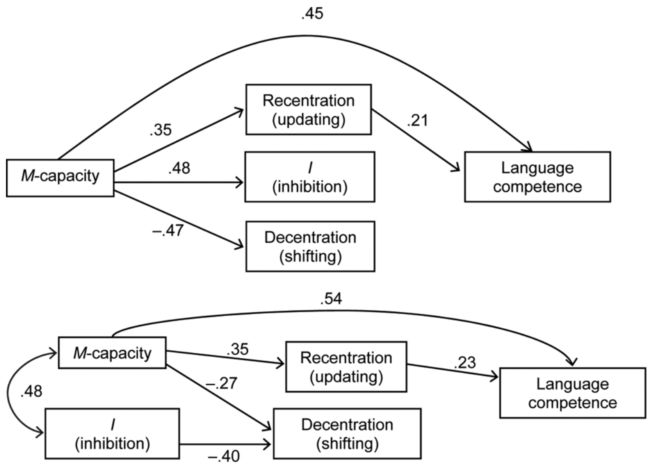

FIGURE 2 Top panel: Model 1. Inhibition as a mental-control process (i.e., executive function) with standardized path coefficients; all paths were significant. Bottom panel: Model 2. Inhibition as a mental resource model with standardized path coefficients; all paths were significant.

We used the SAS CALIS procedure to conduct a comparison of the two models. Analysis of Model 1 indicated a poor fit to the data as shown by a large and significant $\chi^2(3, N = 87) = 16.10$, $p < .001$; large residuals (root mean square error of approximation [RMSEA] = .23 and average absolute standardized residual [AASR] = .88); and fit indices less than .95 (comparative fit index [CFI] = .89, goodness-of-fit index [GFI] = .93, normed fit index [NFI] = .87, non-normed fit index [NNFI] = 0.62; see Figure 2). Analysis of Model 2 indicated a good fit to the data as indicated by a small and nonsignificant $\chi^2(3, N = 87) = 0.07$, $p > .79$; small residuals (RMSEA =.00 and AASR =.07); and fit indices greater than .95 (CFI = 1.00, GFI = 1.00, NFI = 1.00, NNFI = 1.08). The indirect effect of *M*-capacity on language (i.e., with updating as a mediator) was assessed through bootstrap standard errors. A significant indirect effect was found for *M*-capacity on language ($\beta = .08$, $p < .01$). The R^2 value (percent of variance accounted for by direct paths) for updating, shifting, and language were .12, .34, and .44, respectively, indicating medium, large, and large effect sizes, respectively (Cohen, 1992).

In summary, the path analyses are consistent with the TCO and suggest that inhibition (*I*) is a mental resource, rather than a mental-control process (i.e., EF); and inhibition is indirectly related to language performance via its dialectical relationship with *M*-capacity.

DISCUSSION

In the current study, we tested two models of inhibition in a developmental sample within the language domain. One model depicted inhibition as an EF. The second model positioned inhibition as a mental resource that operates interactively with *M*-capacity and is directed by EF for efficient allocation. Our results support a model of inhibition as a mental resource as construed by Pascual-Leone's TCO (Pascual-Leone, 1984). This is congruent with the idea that inhibition is a component of controlled attentional resources (Engle et al., 1995).

Activation and Inhibition

Our findings, which support inhibition as a mental resource as proposed by the TCO, are also congruent with Miyake and Friedman's (2012) unity/diversity framework of EF. The results of their factor analysis suggest a common EF factor (unity) that reflects the ability to actively maintain schemes, which subsumes inhibition (i.e., inhibition is not a separate factor) as well as two distinct factors (diversity) of updating and shifting. Our findings, consistent with the TCO, help to give a more refined theoretical explanation to Miyake and Friedman's model. The two distinct factors (updating and shifting) are consistent with recentration and decentration as proposed by the TCO; these EFs monitor efficiency or success of the goal-directed activity. We suggest that Miyake and Friedman's common EF factor reflects *M* and *I*, which are required to maintain relevant goals and inhibit irrelevant information. According to the TCO, *I* never works in isolation during a problem-solving situation (Pascual-Leone, 1984, 1987; Pascual-Leone & Johnson, 1999, 2011). Although *I* is required to actively inhibit prepotent misleading schemes, it is never enough to guide correct action; *M* is necessary to help synthesize the correct response (i.e., *M* must activate the relevant nonsalient schemes).

This idea is further supported by findings from a longitudinal study that indicate that self-restraint in infancy predicts individual differences in the common EF factor 15 years later (Friedman, Miyake, Robinson, & Hewitt, 2011). Self-restraint (''Do not touch'') may appear to be a task that primarily requires inhibition; however, continued activation of the goal scheme *do not touch* is necessary for successful task performance. According to the TCO, self-restraint tasks represent a misleading situation in which the attractive toy placed in front of the child is an environmental cue that activates the irrelevant scheme *touch*. This scheme interferes with successful performance (i.e., not touching the toy as requested by the adult). To show successful self-restraint, the child must not only inhibit this irrelevant scheme, but also keep active the relevant scheme *do not touch*. Therefore, we propose that difficulty in this task is caused not just by the strength of the prepotent response (e.g., Roberts & Pennington, 1996), but by difficulty in coordinating the inhibition of the irrelevant response with the maintained *M*-activation of the relevant response.

Prior findings (Im-Bolter et al., 2006) indicate that children with language impairment have less efficient inhibitory control, which could result in activation of unrelated but similar language cues (e.g., separating sounds like /ba/ and /pa/). This may lead to the formation of linguistic schemes that are not well elaborated or not well connected in a meaningful network (i.e., encoding stage). Poorly elaborated or connected linguistic schemes would particularly affect acquisition and use of morphology and syntax, which are structurally complex compared with semantic knowledge. For example, use of the English regular past tense incorporates semantic, morphological (suffixation), and phonological knowledge. Errors in language use or understanding could take place because of failure to activate a correct scheme or the activation of poorly elaborated schemes (Im-Bolter et al., 2006). The end result would be a reduced ability to deal with more structurally complex language forms.

Our model, which outlines the roles and functions of *M, I*, and EF, also has implications for how other impairments might be viewed. Deficits in EF have been associated with a variety of developmental disorders (e.g., attention-deficit hyperactivity disorder, autism, reading disability, math disability), but it seems unlikely that pure quantitative differences in EF could result in such a wide range of disorders. Although not included in the current study, the TCO also incorporates automatic perceptual attention and automatic inhibition, which typically are used in facilitating situations (Howard et al., 2014; Johnson et al., 2003; Pascual-Leone, 1984). It would be helpful to examine the involvement and interaction of both effortful and automatic cognitive processes to determine whether a profile of risk and of protective factors could be delineated for language impairment as well as other developmental disorders.

Working Memory and Updating

In the TCO, executive processes (such as recentration or updating) assist in the control and coordination of *M*-capacity and inhibition or *I*. Application of *M*-capacity and *I* depends on the nature of the situation (misleading or facilitating) in which they must operate. The idea of processing capacity as a limited cognitive resource is often discussed in the literature, and processing capacity has been found to be deficient in children with learning disabilities (Kibby & Cohen, 2008; Malstädt, Hasselhorn, & Lehmann, 2012), including those with language impairment (Hanson & Montgomery, 2002; Montgomery, 2002a; Windsor & Hwang, 1999). These researchers use the term processing capacity interchangeably with working memory, which is itself often referred to as updating. However, *M*-capacity is theoretically and operationally distinct from both working memory and updating. The confusion of constructs in the literature (processing capacity/working memory/updating) and the frequent lack of a precise definition do not advance our understanding of how processing capacity is affected in children with learning difficulties, such as language impairment; nor do they clarify the role of EF in atypical development.

In the TCO, *M*-capacity serves to maintain activation of relevant schemes whereas updating changes the content of focal attention (i.e., *M*-centration). This is essentially like a movie director who changes the focus of the camera operator to different scenes or actors but does not affect the storage capacity of the camera. Within language, updating is necessarily a sequential process due to the nature of the stimuli, which may help to explain why children with language impairment are disadvantaged particularly in this domain. Theoretically and practically, this distinction between activation of relevant schemes (or *M*-capacity) and changing of the content of focal attention (or updating) is important to understand how different cognitive processes interact during goal-directed activity. For example, our findings are consistent with, and help to clarify, the procedural-deficit hypothesis, which suggests that deficits in procedural memory underlie language impairment (Lum, Conti-Ramsden, Page, & Ullman, 2012; Ullman & Pierpont, 2005). Difficulties with updating should affect procedural learning, which largely requires sequential retention of schemes, more than it affects declarative learning.

Practical Implications

According to the TCO, success on a task is dependent on whether the *M*-capacity of the child matches or is greater than the mental demand of the task (estimated through task analysis). Language-learning tasks that are more difficult are likely to make children with language difficulties give up or at least pay poor attention to the task at hand. This would enforce poor learning, which in turn would reduce the likelihood that new skills or knowledge would be acquired and would cause a negative cycle of greater deficits. In a practical sense, the distinction between misleading and facilitating situations has an immediate relevance for understanding behavior in children. Young children may have difficulty with effortful inhibition because they are more likely to have trouble distinguishing the relevant from the irrelevant—a skill that comes with experience and learning. In addition, a bypassing strategy is not available to young children due to their low *M*-capacity or limited executive know-how. As a result, misleading situations/tasks initially might constitute poor learning contexts, although practice in such contexts also is important.

Our findings highlight the need to consider task demands of a problem-solving situation to understand how different cognitive processes interact—something others have also advocated (Hanson & Montgomery, 2002; Miller et al., 2012; Montgomery, 2002a, 2002b). The demands of a learning situation or environment can be estimated using task analysis that takes into account the cognitive resources required. A task analysis would not only assist in targeting developmentally appropriate content, but it would also help to determine the optimal developmental timing for interventions for children with language impairment. Our findings suggest that considering inhibitory demands of a learning situation (e.g., need to minimize or eliminate irrelevant information) may be important when working with young children and children with language impairment. This is one reason why issues such as whether a task is misleading or facilitating, saliency of cues, consistency of cues, and previous learning must be taken into consideration.

Limitations and Directions for Future Research

The present study clearly demonstrates the utility of theory-guided examination of language in relation to cognitive resources, so as to attempt to explain mechanisms that underlie language competence and impairment. Nonetheless, we acknowledge as a limitation of the current study its lack of inclusion of latent variable modeling. This type of statistical technique requires large sample sizes, something difficult to achieve when working with atypical populations.

To confirm that EF is a mediator of language competence (not just structural language) and to determine other mediating factors that might exist, further research is needed that focuses on specific aspects of structural language (e.g., syntax) as well as on broader communicative competence like pragmatics and social discourse. In addition, data from longitudinal and intervention studies would help to clarify associations between different cognitive processes and language skills. In the current study, a wide age range of children was examined, but sample size did not allow us to investigate the crucial issue of whether the mediating effect of EF might differ at different points of development (e.g., is updating and/or shifting more important at older vs. younger ages or vice versa?). Although not a focus of the current study, there is much discussion in the literature regarding the existence of subtypes of language impairment (e.g., Simkin & Conti-Ramsden, 2006; Whitehouse, Line, Watt, & Bishop, 2009). Simultaneous consideration of *M*-capacity, *I* (inhibition), and EF when examining potential subtypes of language impairment could help to reliably define specific subgroups of language impairment.

Conclusions

The current study supports a model of *M*-capacity and *I* (inhibition) as attentional resources, both of which are distinct from EF and are needed in cognitive performance. As predicted, *M*-capacity has a direct relationship with language competence, but (at least in our data) *I* does not. Rather, inhibition appears to associate with language competence through its relation with *M*-capacity. These results also support updating (recentration) but not shifting (decentration) as an important domain of general EF that regulates use of both *M* and *I* in the language domain.

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