The Relationship Between Inhibition and Working Memory In Preschoolers: Evidence For Different Inhibitory Abilities

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Abstract

The present cross-sectional study aims to explore the contribution of working memory (WM) in different inhibitory abilities (i.e., response inhibition and interference suppression) in 72 children who are between 3 and 5 years of age. The results showed that response inhibition tasks are influenced by both verbal and spatial WM, whereas the interference suppression task was not influenced by WM when the analysis controlled for age.

Keywords: Inhibition; Working Memory; Preschoolers

Introduction

The present study aims to explore the relationship between inhibition and WM in early childhood (i.e., between 3 and 5 years of age), which is a particularly important time for the development of higher order cognitive processes, which is referred to as the executive function (EF), that is involved in the control and modulation of cognition (Miyake & Friedman, 2012; Best & Miller, 2010; Garon, Bryson, & Smith, 2008).

Inhibition is conceptualized as the ability to deliberately inhibit dominant, automatic, or prepotent responses when it is necessary and/or requested (Miyake et al., 2000). In children, as well in adults (Friedman & Miyake, 2004; Nigg, 2000), different types of inhibition have been distinguished: cognitive inhibition, a process that operates at the level of thought and memories; response inhibition, a mechanism that acts at the level of behavior; and executive attention, a process that functions at the level of attention (Diamond, 2013). Although inhibition is conceptualized as a multidimensional ability, few studies have verified this assumption by examining its latent structure. Recently, two inhibition processes were found to be separate but associated dimensions in children between the ages of 36 and 48 months: the ability to suppress prepotent but inappropriate responses (response inhibition) and the ability to manage the interference of potentially conflicting features of the task (interference suppression; Gandolfi, Viterbori, Traverso, & Usai, 2014).

WM has been defined using different theoretical models: in the first models, working memory was described as a set of multiple specialized subcomponents of cognition (Baddeley & Hitch, 1974), while in the subsequent models the role of diverse attentional/executive process to elaborate information has become much more relevant (Engle, 2002). WM generally refers to the ability to hold and manipulate information mentally (Mesulam, 2000), whereas updating is conceptualized as the ability to encode incoming information and replace the information that is no longer relevant to the task (Morris & Jones, 1990). Working memory and updating are very closely associated notions or process, particularly when they are both involved in complex tasks that require information updating and/or manipulation (Garon et al., 2008).

Early in the course of development, the level of efficiency of inhibition and working memory influences children's performance in complex situations. Specifically, between 3 and 5 years of age, major improvements occur in both inhibition and working memory abilities (Garon et al., 2008). The capacity to suppress a dominant or automatic response within complex tasks (which differ in memory load, see Carlson, 2005; Hughes & Ensor, 2007), and the ability to hold information in one's mind after a delay, which is assessed by span tasks, develop significantly (Morra, Gobbo, Marini, & Sheese, 2011), during this period.

The relationship between inhibition and WM

Although some recent studies have shown that between the ages of 3 and 5 years inhibition and WM are distinct dimensions (Lee, Bull, & Ho, 2013; Usai, Viterbori, Traverso, & De Franchis, 2014; Miller, Giesbrecht, Müller, McInerney, & Kerns, 2012), it is not clear the nature of the association between these two dimensions (see, for example, Wright & Diamond, 2014). One possibility to investigate this relationship is to examine the role of WM in performing inhibition tasks.

As reported by Best & Miller (2010), many of the tasks that aim to assess inhibition also require WM (Garon et al., 2008; Simpson & Riggs, 2005), and the combination of the two processes within a single task may significantly enhance the difficulty to perform the task, particularly for young children (e.g., Carlson, 2005). Garon et al. (2008) distinguished between simple and complex inhibition processes according to their working memory demands. Simple inhibition tasks, such as Delay gratification, were those paradigms that had a low level of working memory demand; conversely, the Flanker task was considered to be a complex inhibition paradigm because it required the resolution of conflict between the dominant and subdominant responses and, consequently, involved greater levels of top-down control. The distinction between simple and complex inhibitory tasks is similar to the distinctions that were made by Gandolfi et al. (2014) between response inhibition and interference suppression: both classifications are based on the differences between univalent tasks in which only a single feature is presented, and the conflict is between two response options to the same stimulus and tasks in which many potentially conflicting dimensions are present, such as in the Flanker tasks. The presence of many conflicting features may require more WM abilities, thus the interference suppression tasks may be more influenced by the WM abilities than the response inhibition tasks, in which the cognitive load for children is confined to a conflict between the habitual response and a less familiar, arbitrary response, such as in the Stroop task.

The aim of the present study is to examine the role of WM abilities in performance on inhibitory tasks in preschool children. In particular, we are interested in exploring the contribution of WM in inhibitory tasks that assess the different dimensions of inhibition (i.e., response inhibition and interference suppression). We hypothesize that WM will have a greater influence on interference suppression tasks than response inhibition tasks.

Method

Participants

Participants were recruited by the researchers who contacted the families of children who attended two public preschools in a province in a northwestern region of Italy. The families of 92 three- to five-year-old children agreed to participate in this study.

Eight children were excluded due to an ascertained developmental disorder (7) or because their families had serious social difficulties and the public Social Services were in charge of the children (1); 12 children were subsequently excluded from the sample because they received a score that was lower than the fifth percentile or because they did not reach the basal score on the PPVT. The final sample consisted of 72 children (41 females), whose ages ranged from 39 to 63 months (M_{age}=50.87; SD=6.72). The sample was divided into three subgroups based on preschool class attendance: the first group was composed of 27 children, who were aged between 39 and 47 months (M_{age} 43.63; SD=2.73) and attended their first year of preschool; the second group was composed of 25 children, who were aged between 48 and 55 months (M_{age} 51.64; SD=2.50) and attended their second year of preschool; the third group was composed of 20 children, who were aged between 56 and 63 months (M_{age} 59.20: SD=2.31) and attended their last year of preschool (kindergarten).

Written parental informed consent was obtained before the participating children were admitted to the assessment sessions. According to the data that were provided by the parents, 29% of the final sample is represented by only-children. With regard to maternal education, 28% achieved a primary or middle school degree, 44% achieved a high-school degree, and 28% achieved an academic degree (bachelor and/or master/doctorate).

Procedure

The children were individually tested in a quiet room at their preschool during two 15-20 minute sessions. A trained researcher administered and scored all of the tests. A battery of inhibitory and working memory tasks, which varied in format and in response demands, was administered to the children in a standard order. Moreover, the Italian version of the Peabody Picture Vocabulary Test (Stella, Pizzoli & Tressoldi, 2000), which evaluates language competence (receptive vocabulary), was used as screener; age-based standard scores were calculated (Mean=100, SD=15).

Working memory tasks. In order to assess WM two traditional tasks were used that require the elaboration of verbal and visuospatial stimuli.

Backward Word Span (BWS). This is a traditional working memory task (Alloway, Gathercole, & Pickering, 2006; Carlson, 2005). This task requires the child to recall a sequence of spoken words in reverse order. Words were presented approximately once 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 maximum list length for which two sequences were correctly recalled was scored (expected range 0-9).

Mr. Cucumber (Case, 1985). This task is a measure of working memory in children (Morra, 1994). The examiner presents a large outline drawing of an extra-terrestrial character, to whom a number of colored stickers is attached at specific body parts (e.g., on the nose, on the left antler, etc.) for 5 seconds. The child is then shown a colorless drawing and is asked to indicate the positions of the stickers on the previously presented figure. There are three items per level (from 1 to 8 stickers, in ascending order). An item is scored as correct if the child points to all of the correct body parts and does not point to any incorrect body parts. One point is given for each consecutive level for which a child correctly indicates at least two items, and one third of a point (0.33) is given for each correct item that is beyond that level (expected range: 0-8).

Inhibition tasks. A set of different tasks were used to assess inhibition.

Circle Drawing Task (Bachorowski & Newman, 1985). This is a well-known measure of response (motor) inhibition of an on-going response that has been used for both adult (Wallace, Newman, & Bachorowski, 1991) and childhood (see, for example, Geurts, Verté, Oosterlaan, Roeyers, & Sergeant, 2005) assessments. The child must trace a 17 cm in diameter circle, with his or her finger, from a starting point to an ending point. The task is administered twice. During the first administration, neutral instructions ("trace the circle") were provided, and during the second administration, inhibition instructions were provided ("trace the circle again, but this time, trace it as slowly as you can"). Larger time differences indicate better inhibition (slowing down) on the part of the participant in regard to his or her continuous tracing response. The time that it took to trace the circle, in seconds, was recorded for each trial. Scores were calculated for the slowdown time, relative to the total time, through the use of the following formula: T2-T1/T2+T1, where T1 and T2 were the times that were recorded for the first and second trials, respectively (expected range: no limit-0-no limit).

Preschool Matching Familiar Figure Task (PMFT, adapted by Kagan, 1965). This task measures the child's ability to restrain impulsive responses (Kagan 1966; Rovet, 1980) and to compare the target with all of the pictures by shifting his or her attention from the target to each alternative. The child is asked to select the figure that is identical to the target picture at the top of the page from among different alternatives. In the form that has been adapted for preschoolers, this task involves five alternatives and is composed of 14 items. The number of errors (PMFT Errors; expected range: 0-56) was recorded.

Fish Task (Gandolfi et al., 2014; Viterbori, Gandolfi, & Usai, 2012). This task evaluates the child's interference suppression ability through the use of an adaptation of the flanker paradigm (Eriksen & Eriksen, 1974). This is a forced-choice task in which children are required to point to where a centrally located target fish is oriented, while ignoring the presence of interfering stimuli (other fish). There are 16 trials: 2 training trials, 8 congruent trials where the target and the interfering stimuli are oriented in the same direction, and 8 incongruent trials where the target and the interfering stimuli are oriented in opposite directions. The congruent and incongruent trials are randomly presented. The accuracy on the incongruent trials is scored (range: 0-8).

Results

Descriptive statistics for all of the inhibitory measures, by age, are shown in Table 1.

No outliers (values>3.0 standard deviation) were identified. The missing values for all of the measures ranged from 0% to 6%.

All of the dependent variables displayed adequate distributional characteristics, and there was no substantial skewness or kurtosis. Separate analyses of variance (ANOVAs) were performed to explore the effects of gender, maternal education and age on the EF tasks. No differences were found between males and females. The level of maternal education significantly influenced performance on the PMFT, $F(2,71)=4.26$, $p<.05$, $\eta^2=.110$, and on the Mr. Cucumber task, $F(2,71)=3.64$, $p<.05$, $\eta^2=.097$; children whose mothers had the lowest level of education performed significantly worse than all of the others on the PMFT and worse than children whose mothers had the highest level of education on the Mr. Cucumber task (post-hoc Tukey test, $p<.05$). A main effect of age was significant for all of the executive tasks (Table 1): on the Fish Task, performance differed significantly between each age level that was considered, whereas on the other tasks, the 5-year-olds performed better than the 3-year-old children, but the 4-year-old children did not differ from the others (post-hoc Tukey test, all ps<.05).

To investigate the association between the different tasks, a partial correlation analysis that controlled for age was performed (Table 2). The zero-order correlation shows that most of the executive tasks relate to one another. Correlations with age were significant and ranged from .29 to .44. When controlling for age, the pattern of significant associations is reduced; the inhibition tasks correlate with one another. Moreover, the CDT is positively associated with the BWS, and the PMFT correlates with the Mr. Cucumber task.

Table 1: Descriptive statistics of EF tasks and ANOVA by age level.

Tasks and ANOVA by age	Age Level	N	Mean	SD	Min	Max
Circle Drawing Task (CDT)	1	27	.06	.19	-.37	.41
	2	25	.18	.30	-.36	.70
	3	20	.33	.29	-.10	.86
	Tot.	72	.17	.28	-.37	.86
Preschool Matching Figure Test (PMFFT)	1	27	22.59	5.79	12	36
	2	25	19.60	5.54	10	33
	3	20	16.40	5.78	5	25
	Tot.	72	19.83	6.17	5	36
Fish Task (FT)	1	27	1.19	1.60	0	6
	2	25	2.84	4.59	0	14
	3	20	6.90	6.64	0	16
	Tot.	72	3.35	5.03	0	16
Backward Word Span (BWS)	1	27	.63	1.11	0	3
	2	25	1.08	1.22	0	4
	3	20	1.70	1.22	0	3
	Tot.	72	1.08	1.24	0	4
Mr. Cucumber (MC)	1	26	.87	.51	0	2
	2	25	1.20	.51	1	2
	3	20	1.37	.54	0	2
	Tot.	71	1.13	.55	0	2

To determine whether the two different WM measures contributed significant unique variance to the outcome variable of the inhibitory tasks, over and above the effect of age, a series of two-step hierarchical multiple linear regression analyses were conducted with the enter method. All of the necessary assumptions of the regression were met, and the order of entry was maintained constant (age, first step; WM tasks, second step). Results are reported in Table 3.

Table 2: Zero-order (lower triangle) and partial correlation by age (upper triangle) among EF tasks.

	CDT	PMFT	FT	BWS	MC
CDT	-	-.351**	.351**	.246*	.197
PMFT	-.417***	-	-.282*	.165	-.290*
FT	.424***	-.399**	-	.226	.176
BWS	.339**	-.313**	.381**	-	.143
MC	.283*	-.395***	.314**	.299*	-
Age	.288*	-.403***	.421***	.444***	.389**

***p<.001; **p<.01; *p<.05.

Table 3:Relationship between WM and inhibitory measures: Hierarchical linear regression analysis.

Dependent variables	Circle Drawing Task F(3,70)=4.19 $p<0.01$ R^2adj=.12 $R^2\Delta$=.08*		
Independent variables	B	SE	Beta
Age	.012	.005	.278
Age	.004	.006	.098
Backward Word Span	.055	.029	.242
Mr. Cucumber	.088	.063	.172
Dependent variables	Preschool Matching Figure Test F(3,70)=6.661 $p<0.01$ R^2adj=.20 $R^2\Delta$=.09*		
Independent variables	B	SE	Beta
Age	-.343	.100	-.380
Age	-.191	.115	-.212
Backward Word Span	-.641	.597	-.132
Mr. Cucumber	-3.007*	1.294	-.273*
Dependent variables	Fish Task F(3,70)=7.185 $p<0.001$ R^2adj=.21 $R^2\Delta$=.06		
Independent variables	B	SE	Beta
Age	.323	.082	.430
Age	.208*	.095	.276*
Backward Word Span	.850	.494	.209
Mr. Cucumber	1.323	1.070	.144

The WM tasks significantly increased the amount of variability that was explained for two of the dependent variables (i.e., the CDT and the PMFT) but not for the Fish task, which was only significantly predicted by age. The R^2 deltas are indeed significant for the CDT and PMFT, and they indicate that when the WM variables were added as predictors, the amount of variability that was explained significantly increased.

Discussion

The aim of the present study was to examine the role of WM abilities in different tasks that evaluate diverse aspects of inhibition (i.e., response inhibition and interference suppression; Gandolfi et al., 2014).

The results reveal that a significant increase in EF task performance occurs in the age range that was considered. In agreement with many authors, we found significant improvements, both in terms of the ability to deal with the interference and the ability to inhibit a dominant or automatic response (see, for example, Carlson, 2005; Hughes & Ensor, 2007; Jones, Rotbart, and Posner, 2003; Kochanska, Murray, and Coy, 1997; Kochanska, Murray, Jacques, Koenig, Vandeceest, 1996). At the same time, our results show an enhancement in WM abilities (Gathercole, 1998; Gathercole, Pickering, Ambridge, & Wearing, 2004; Reznick, 2007; also see Morra, Gobbo, Marini, and Sheese, 2008) for both verbal and spatial tasks (Garon et al., 2008).

In regard to the main objective of this study, verbal and spatial WM appears to be associated with both response inhibition and interference suppression, although to a different extent, depending on the type of inhibitory abilities that is considered. However, age was a significant predictor of all of the inhibition measures when it was considered alone in the regression models; moreover when age was controlled the association between the two WM tasks was no more significant (see Simmering & Perone, 2013).

In the case of CDT, which is a measure of response inhibition in early childhood (Gandolfi et al., 2014), when WM scores were added as predictors in the second regression model, the amount of variance that was explained increased, although neither age, nor verbal or spatial WM, when taken separately, contributed significantly to this model.

The WM scores also significantly increased the amount of variance that was predicted by the PMFT task, which evaluates the ability to control an impulsive response (Rovet, 1980) and could be considered as a response inhibition task. When all of the independent variables are considered together, only the Mr. Cucumber scores significantly contributed to the increase in variance that was explained by the model.

Different from the other inhibitory tasks, in the case of the Fish task, the WM scores in the regression model did not modify the amount of variance that was already explained by age.

In summary, WM was a significant predictor of response inhibition, whereas surprisingly, it did not appear to influence one's ability to control visual interference when age is taken into account.

Behavioral and electrophysiological evidence revealed mixed results regarding the relationship between working memory and interference control. Working memory load interferes with adults' ability to filter out irrelevant distractors (Pratt, Willoughby, & Swick, 2011); on the other hand, there is evidence of a significant conjunction between response inhibition (the go/no-go and stop tasks) and WM tasks, but not for the flanker task, in the left inferior frontal gyrus (McNab et al., 2008).

A plausible explanation for the absence of a significant contribution by the capacity of WM in flanker task performance may be found in the stronger effect of age, which may have masked the association between these variables. Recently, Cowan, Ricker, Clark, Hinrichs and Glass (2014) noted that during the developmental changes that occur in WM, which are maturational in nature, a loss of the variance portion that is specific to WM development when the general effect of age is partialized occurs.

A further explanation that is supported by Gandolfi et al.'s (2014) results takes into account the notion that the flanker task may rely more heavily on a different type of inhibition, the resistance to perceptual interference, which may share less common neural or cognitive resources with WM than the response inhibition tasks (McNab et al., 2008).

Another explanation may be found by assuming a non-linear relationship between WM and interference control; nevertheless, further research on young children is certainly necessary (also see, Roderer, Krebs, Schmid, & Roebers, 2012).

In conclusion, although some limitations need mentioning (small sample size, reduced assessment battery), this study demonstrated that WM abilities may influence performance on tasks that measure response inhibition but not interference suppression in children between 3 and 5 years of age. Further studies are needed to better clarify the relationship between interference suppression and WM over the course of development.

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