Inhibition and Working Memory: A latent variable analysis during adolescence

Chiara Malagoli (chiara.malagoli@edu.unige.it)
Department of Educational Sciences (DISFOR), C.so A. Podestà, 2
16128, Genova, Italy

Maria Carmen Usai (maria.carmen.usai@unige.it)
Department of Educational Sciences (DISFOR), C.so A. Podestà, 2
16128, Genova, Italy

Abstract

Inhibition and Working Memory (WM) are two core dimensions of executive functions (EF). These processes seem develop until late adolescence (Huizinga, Dolan & Van der Molen, 2006; Crone, Bunge, Van der Molen & Ridderinkhof, 2006) but it is still quite unclear how these abilities do organize in this great time of changes for the human brain. The aim of the study is to investigate how inhibition and WM organize during adolescence. CFA results, consistently with literature, show that Inhibition and WM seem to cluster in separable factors and seem to be as well strongly related.

Keywords: Executive Function; Inhibition; Working memory, adolescence.

Introduction

The terms Executive Function (EF) is used to refer to a set of top-down processes that allow to regulate one's thoughts and behaviors (Miyake & Friedman, 2012). The abilities that refer to these processes are inhibitory control, planning, cognitive flexibility and working memory (WM).

Inhibitory control or Inhibition may be defined as «A deliberate overriding of a dominant or prepotent response» (Miyake & Friedman, 2012, p. 2) even though inhibition is a multi-componential construct itself and comprehends many different abilities such as managing impulses and interferences, both behavioural and cognitive (Diamond, 2013; Nigg, 2004). Due to this complexity, inhibition lately has been theorized as an ability that more than being a dimension per se may be a general factor of executive control that may also influence all the other abilities (Miyake & Friedman, 2012). Working Memory is the ability to hold in mind useful information while completing a task when the information is no longer present. It is possible to distinguish two type of WM, verbal and visuo-spatial WM (Baddeley, 1986; see Engle, Kane, & Tuholski, 1999 a for a review). Diamond (2013) lately reviewing the literature theorizes a bi-directional relation between Inhibition and WM, describing them as separate dimensions yet strongly related.

1.1 Why is important to have a good Inhibitory Control?

This ability has an important control and filter role that involve being able to manage thoughts, actions and, in general, interferences. Inhibition allows us to keep the attention focused, to suppress the override of a prepotent response or an, usually, automatic action in case of need or danger. Inhibition imply also the ability to regulate behavior and emotions, without this kind of control we would be at the mercy of impulses, and in constant danger of taking bad decision or to not be able to manage complex situations.

1.2 Development of Inhibition

The ability to inhibit responses has been observed in several studies since early childhood (Kochanska, Murray & Coy 1997; Diamond, 2002; Jones, Rothbart & Posner, 2003; Carlson, 2005; Garon, Bryson & Smith, 2008). Best and Miller (2010) report a significant peak of development in inhibitory processes in preschools years. In effect, in behavioural response inhibition task (e.g. Go-noGo) and also in more complex ones that involve also WM (e.g. the Stroop test), a successful performance is registered already by the age of four. From five to eight this ability registers a continuous growth, in particular in task in which inhibition and WM are combined (Gerstadt, Hong & Diamond, 1994; Carlson, 2005). Other studies document a significant increase in these abilities during childhood, in particular from three to four year of age (see Clark et al., 2013). Gandolfi, Viterbori, Traverso and Usai (2014) analyzing the organization of this construct in preschoolers and trying to investigate the latent structure of cognitive processes involved in inhibition in children from the 24 to 48 month, suggest that inhibitory processes are not yet differentiated before 36 months of age, after which a distinction between different inhibitory dimensions emerges.

1.3 What we Know about Inhibition and WM during adolescence?

Prencipe et al. (2011), in order to evaluate changes and improvements across ages, analyze the performance of a large sample of children and mid-adolescents between 8 and 15 years of age at a battery of Inhibition and WM tasks and dividing the sample into age groups (8 and 9 year-olds, 10 and 11 year-olds, 12- and 13-year-olds, and 14- and 15-year-olds) results in WM capacity show the largest improvements at backward Digit Span relatively early in adolescence, between the two youngest age groups. This result is generally consistent with the findings of Hooper, Luciana, Conklin & Yarger (2004). In general studies of WM during adolescence come across variable results: some studies report level in terms of performance comparable to the one registered in adults already by early adolescence (Asato, Sweeney, & Luna, 2006; Crone, Wendelken, Donohue, van Leijenhorst & Bunge, 2006) while others show a more linear pattern in terms of gradual improvements through late adolescence (e.g. Hooper et al., 2004; Huizinga, Dolan & Van der Molen, 2006; Lamm, Zelazo & Lewis, 2006). Prencipe et al. (2011), point out how in backward digit span 10 and 11-year-olds in their study performed as well as typical adults (Janssen, Krabbendam, Jolles, & van Os, 2003; Kinsella et al., 1996).

1.4 WM and Inhibition which relation?

Cognitive Inhibition is important to support WM: to achieve a goal is very important to select carefully relevant information in order to let the goal guide our behavior decreasing the probability of being driven by an automatic response that could imply a failure in pursuing the goal. Moreover to relate ideas or events it is extremely important to be able to move the focus from one to another without being stuck only to one and also to be able to elaborate and combine facts in a creative way, resisting the impulse to repeat the same patterns in thinking. Lastly, inhibition is very important to filter internal and external distractions and to prevent our mental space to be overwhelmed by information, resisting to proactive interference and deleting no longer relevant facts or materials (Hasher & Zacks 1988; Zacks & Hasher, 2006).

2.This Study

The present work is aimed to investigate how inhibition and WM do organize during adolescence, in literature is documented how these abilities develop until the later years of this particular and unique developmental stage. For this reason the aim of the study is also to try different structural equations models in order to investigate if WM and inhibition cluster in a unitary dimension or if they are recognizable as separate dimensions connected by a strong relation or inter-relation. We hypothesize that all inhibition tasks would cluster into one factor and WM tasks into another, in fact this pattern has already been tested in adulthood (Miyake et al., 2000; Miyake & Friedman, 2012). As mentioned is still quite unclear how these aspects do organize in this great time of changes in the human brain, in particular we hypothesize that WM and Inhibition may result strongly related. In order to test these hypothesis we selected tasks created to investigate different aspects of inhibition, in agreement with the literature who suggests that different abilities are related to this construct (Nigg, 2004).

Participants

240 Adolescents, (158 females, 82 males) attending High school, age range 14 to 19.

Materials and Procedure

Method

We administered two individual 45-minutes sessions during school time, in a quiet room provided by the school. Flanker task, Go-NoGo, Antisaccade and Stop Signal Task were administered in the first session, while Symm-Span, ARSPAN and Mr Cucumber in the second one.

Inhibition Task:

Antissacade task (Adapted from Roberts, Hager & Heron, 1994). This task is a common measure of oculomotor inhibition. Participants practiced on 22 trials and then received 90 target trials. The dependent measure was a balanced index obtained by dividing the mean of all reaction times for each trial and the proportion of correct trials.

Flanker task (Eriksen,1974). This task is a cognitive measure of the ability of managing interferences. Congruent, incongruent and neutral trials were shown. A congruent trial is one in which the flankers are associated with the same response as the target, whereas in an incongruent trial, the flankers are associated with a competing response. The task was composed by a practice block of eight trials (two congruent, two incongruent and two neutral) and a test block of 48 trials (16 trials for each condition). The dependent measure was a balanced index obtained by dividing the mean of all reaction times for each trial and the proportion of correct trials.

Go-No Go task (Donders, 1969). The Go-No go is a classical inhibition paradigm meant to assess the ability to stop an automatic response. The task was composed by a practice phase of 20 trials and a test phase of 100 trials. Participant were asked to answer as fast as they could every time the “Go” stimulus appeared and received a feedback every time they pressed reporting their RT so they could realize how fast/slow they were. The dependent measure was a balanced index obtained by dividing the mean of all reaction times for each trial and the proportion of correct trials.

Stop Signal task (Logan, 1994). The task requires to stop a motor response while already activated. The experiment consists of two phases: a practice phase of 32 trials and an experimental phase of three blocks of 64 trials. In both phases, each trial starts with the presentation of the fixation sign, which is replaced by the primary-task stimulus after 250 msec. The dependent measure is the SSD index, which is an adjusted measure, based on the accuracy and the consequential adjustment of the delay.

Working Memory task

The two following WM tasks are widely used as complex measures of WM capacity, while the third and last one is a more classic visuo-spatial span measure.

Symmetry Span task (SymmSpan)- Kane et al. (2004). This span is composed by two different visual task performed at the same time. The first one consists in recalling a sequence of square that appear on the screen while the second one consists in judging if some figures are symmetric or not. Dependent variable was the absolute span score the SSPAN score: the sum of all perfectly recalled sets. So, for example, if an individual recalled correctly two squares in a set size of two, three squares in a set size of three, and three squares in a set size of four, their SSPAN score would be five (2 + 3 + 0).

Reading Span task (RSPAN) (Daneman & Carpenter, 1980). This span is structurally identical to the previous one, but is made up with different stimuli. In fact the tasks consists in recalling a sequence of letters that appear on the screen while judging if some phrases make logical sense or not. As mentioned in the previous task we used the RSPAN score.

Mr Cucumber (Case, 1985). This is the only non-computerized test. The task requires to recall the position of stickers on a target image by pointing with the finger on a figure without any sticker on. A point is given for each level fully correctly recalled, one third of a point (0.33) is given for each correct item beyond that level. The test must be discontinued if the participant fail all the three item of the same level. Dependent measure is the score obtained (expected range 0-8).

Statistical Analysis

In order to validate our hypothesis we performed a latent factor analysis with two different model: a one factor model where Inhibition and WM are clustered in a unitary factor and a two factor model in order to test the hypothesis of two separate abilities strongly related. Descriptive statistics and zero-order (Pearson) correlations among measures were calculated. Outliers values at more than three standard deviation of the mean were 27 and were excluded from the analysis. In addition nine values were excluded from memory scores because they did not respect the task instruction to keep the percentage of symmetries/ phrases correctly judged to at least the 75%. In total the values excluded represent the 1.8% out of the full sample.

Two CFAs, based on covariance matrices, were conducted using EQS 6.1 software (Bentler, 2006).

The fit of each model to the data was evaluated by examining multiple fit indices (Schermelleh-Engel, Moosbrugger, & Műller, 2003): the χ^2 statistic, the root mean square error of approximation (RMSEA), the standardized root mean squared residual (SRMR), Bentler's comparative fit index (CFI), the non-normed fit index (NNFI) and the Akaike Information Criterion (AIC). In addition a measurement of invariance across gender and age was performed, in order to verify the reliability of the model and to test differences between the groups. In order to perform this particular analysis through age, the sample was first divided into two age groups: a first group from 14 to 16;11 years of age (n 120, 37 males- 83 females, mean age 15.7±11.8) and a second group from 17 to 19 (n 107, 42 males-65 females, mean age 18.3±9.3). Then we proceeded by testing different levels of invariance, running separated models (see van de Schoot, Lugtig, & Hox, 2012) in which different parameters were progressively constrained; then, as the models could be considered nested, we used the chi-square test and other goodness-of-fit indices to compare the models (see also Lee et al., 2013).

3. Results

Descriptive statistics and correlations are summarized in table 1.1 and 1.2.

Table 1.1
Descriptive Statistics

	Mean	*Sd*	*Skewness*		*Kurtosis*	
Antisaccade	731.6	279.4	1.5	0.2	3	0.3
Flanker	488.8	58.9	0.7	0.2	0.4	0.3
Go-NoGo	450.5	93.1	1.5	0.2	3.3	0.3
Stop SSD	397.8	176.9	0.4	0.2	-0.6	0.3
Symm_Span	17.4	8	0.3	0.2	-0.5	0.3
RSPAN	20.1	12.5	0.6	0.2	-0.1	0.3
Mr Cucumber	6.5	1159	-0.8	0.2	0.4	0.3

Note: Stop SSD= Stop Signal Delay index; Symm_Span= Visuo-Spatial Span Measure; RSPAN= Phonological-Span Measure

All tasks seem to show a significant correlation pattern that reflects an association among the tasks. This result confirm that Inhibitory task and WM task are related both with each other and also in terms of inter-Correlation between different dimensions.

Table 1.2

Zero order and partial correlation controlled for age (upper triangle)

	Antisaccade	*Flanker*	*Go-NoGo*	*Stop SSD*	*Symm_Span*	*RSPAN*	*Mr CuCumber*
Antisaccade	-	.192	.204**	-.058	-.171	-.098	-.215**
Flanker	.269**	-	.353**	-.147	-.135	-.051	-.300**
Go-NoGo	.283**	.392**	-	-.284	-.216	-.115	-.196
Stop SSD	-.087	-.170*	-.296**	-	.075	.070	.019
Symm_Span	-.187**	-.163*	-.247**	.070	-	.245**	.217
RSPAN	-.101	-.045	-.118	.075	.250**	-	.136
Mr CuCumber	-.230**	-.315**	-.274**	.049	.208**	.139*	-

** Correlation is significat at 0.01 (2-tails).

* Correlation is significat at 0.05 (2- tails).

Confirmatory Factor Analysis (CFA)

To determine the EF structure, we tested two factor models representing the two different theoretical hypothesis: a one-factor model and a two factor model. The fit indices for these models, summarized in Table 2, are good for the two-factor model. Parameters for the one-factor model are generally adequate or mediocre in the case of NNFI and CFI. Based on the goodness of fit and AIC values, the two-factor model appears to better fit the data than the more parsimonious, single-factor model.

Table 2

Models	*χ2*	*df*	*RMSEA*	*SRMR*	*CFI*	*NNFI*	*AIC*
a One factor	21.339	14	0.052	0.52	0.926	0.889	-6.661
b Two Factors: Inhibition and Working Memory	**16.071**	**13**	**0.035**	**0.46**	**0.969**	**0.95**	**-9.929**

Note. RMSEA, Root mean square error of approximation; SRMR, Standardised root mean squared residual; CFI, Comparative Fit Index; NNFI, Non-normed fit index; AIC, Akaike's information criterion; Note: Stop SSD= Stop Signal Delay; Symm_Span= Symmetry complex span; RSPAN= Reading Span; EF=Executive function single-factor ; WM= working memory.

Figure 1

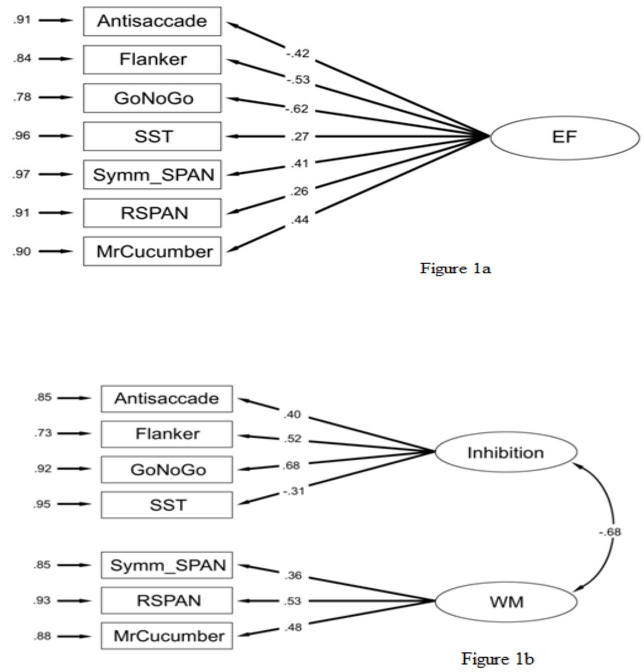

Figure 1. Two-factor model with inhibition and WM showing the relation between these two factor and the result at IGT. In the figure standardized factor loadings, correlation between factors and error terms are shown. Note: SST=Stop Signal Task; Emo_GoNoGo= Emotional Go_NoGo; Symm_Span= Symmetry complex span; RSPAN= Reading Span; IGT= Iowa Gambling Task; EF=Executive function single-factor ; WM= working memory. The standardized factor loadings are the numbers next to the straight, single-headed arrows; the correlations between the factors are those next to the curved, double-headed arrows. The error terms are shown near the observed variables at the end of the smaller, single-headed arrows.

The error-term squares are considered to be estimates of the unexplained variance for each task. The factor loadings were all significant (t values>2). We will only discuss the two-factor model parameters, as the two-factor model showed the best fit to the data. The estimate of the correlation between the latent variables was quite large (-.68). The 90% confidence interval for the correlation was [-0.79 ,-0.53]. The proportion of variance in the individual task scores explained by the latent variables varied across tasks. The R^2 values were .475 concerning the Go-NoGo task, .277 concerning the visuo-spatial span measure, .275 concerning the balanced index for the Flanker task, .230 concerning the MR Cucumber span measure, .163 with reference to the antisaccade and .127 relatively to the Phonological span measure. Gender and age invariance testing was conducted for the best-fitting two-factor model only. Configural invariance was already assumed by identifying a two-factor solution in females. Configural invariance and metric plus covariance between the latent factors models were invariant and showed a good fit, while constraining the intercepts resulted in a deterioration of the model's fit: when the intercept of males are constrained to be equal to those of females the chi-square significance improve, suggesting a difference among the two groups. In order to perform this analysis the sample was divided into two age intervals: The first one from 14 to 16;11 years of age while the second from 17 to 19 years of age. The invariance configural model replicated on the 17-19 sample group seem to show stronger reliability in terms of goodness of fit. R^2 show that also factorial weights in terms of variance change, this suggest a different organization in terms the influence that specific abilities may gain along the years.

4.Discussion

Results show that all inhibitory task cluster in one factor, moreover according to Pearson correlation all inhibitory tasks result also to be related to each other (see table 1.1). This find suggests a unitary nature of inhibition in opposition to previous studies in adulthood (e.g. Nigg, 2000; Friedman & Miyake, 2004) and in childhood (Gandolfi et al., 2014). In fact also in this stage of development it seems that even if the task implied in this study do elicit different sub-abilities they actually seem to be connected to the same macro ability: Inhibition. Most of the variability seem to rely on the Go-No Go, a task that elicit a more behavioural and simple kind of inhibition, the inhibition of an automatic response, an ability that is also one of the first to register a good performance even in early age (see Best & Miller, 2010) and one of the skills that is more connected to the adaptive function of voluntary control: being able to stop an overriding automatic response in every-day life may be quite important both in terms of social adaptability and self-preservation. The ability to manage interferences is the second index that seem to explain the second larger portion of variability of the response data around the mean, this ability is another core dimension of inhibition, because scaffold also the ability to stay focused and to not get distracted by irrelevant information. These results seem to reveal that in adolescence, as in adulthood, these abilities are core dimension in inhibitory control. On the other hand antisaccade and stop signal delay indexes seem to explain less portion of the global variability. This find may be due to the fact that antisaccade task relies on more basic processes that may be more difficult to control voluntarily . The analysis of invariance through gender show that the model fits both datasets, until strong invariance: this finding suggests a difference among the two groups in terms of quickness and accuracy: males may be more reactive than females, and especially in terms of RT may differ from females. On the other hand the analysis of invariance through age group seems to show some differences : the configural invariance replicated on the 17-19 sample group seems to show stronger reliability in terms of goodness of fit, this result may be due to the fact that we tried to test on our sample the model tested in adulthood by Miyake et al. (2000) and Miyake and Friedman (2012), given that it makes sense that data registered in younger adolescents cluster in a model that is not as stable as the first one. R^2 show that also factorial weights in terms of variance change in the two models, this suggest a different organization in terms the influence that specific abilities may gain along the years.

5.Conclusions

Data confirm the separability of inhibition and WM, even though these abilities result as well strongly related. This find is consistent with results reported in previous research in adulthood (Miyake et al., 2000; Miyake & Friedman, 2012; Diamond, 2013). Moreover the model is invariant across gender and age.
Data also seem to show a unitary dimension of inhibition in adolescence, this find is not consistent with previous research in childhood (Gandolfi et al. 2014) and in adulthood (Miyake et al., 2000; Miyake & Friedman, 2012; Diamond; 2013). This find may be due to the specific task implied in this study: most of the rely mainly on the ability to inhibit responses (behavioural inhibition) and not on other kind of inhibition (see Nigg, 2000; Miyake et al., 2000; 2012).

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