EUROPEAN JOURNAL OF COGNITIVE PSYCHOLOGY
2006, 18 (1), 51–69

Psychology Press
Taylor & Francis Group

Do working memory and susceptibility to interference predict individual differences in fluid intelligence?

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In the current study we examined the relationship between working memory capacity, inhibition/susceptibility to interference and fluid intelligence, measured by the Raven's Progressive Matrices (PM38), comparing groups of young (aged 18–35), young-old (aged 65–74), and old-old (aged 75–86) participants. Groups were administered two working memory tasks tapping into different mechanisms involved in working memory. The ability to control for irrelevant information was measured both considering memory errors (intrusion errors) in a working memory task and an index of susceptibility to interference obtained with a variant of the Brown-Peterson task. Regression analyses showed that the classical working memory measure was the most potent predictors of the Raven's score. Susceptibility to interference and intrusions errors contributed, but to a lower extent, to the Raven explained variance. These results confirm that working memory shares cognitive aspects with the fluid intelligence measure considered, whereas the role of inhibition to Raven scores is still in need of better evidence.

Working memory refers to the ability to temporarily maintain information for use in ongoing mental operations (Baddeley & Hitch, 1974). Since its introduction, Baddeley and Hitch's model has been exposed to several reconceptualisations. Some authors suggest that working memory has to be considered as a unitary system regulated by attentional resources (e.g., Engle, Tuholski, Laughlin, & Conway, 1999), while others stress the modality specific nature of some of its processes (Baddeley & Logie, 1999; Cornoldi & Vecchi, 2003). Nevertheless it is possible to draw some common points between the various models proposed (Miyake & Shah, 1999). Firstly, it is well-accepted that the working memory capacity is limited in nature and its limitations are due to different factors such as trace decay (Baddeley & Logie, 1999), susceptibility to interference (Engle et al., 1999; Hasher & Zacks, 1988; see also Elliott, Barrilleaux, & Cowan, 2006 this issue) and processing speed (Salthouse & Meinz, 1995; see also de Ribaupierre & Lecerf, 2006 this issue; Wilhelm & Oberauer,

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http://www.psypress.com/ecp DOI:10.1080/09541440500215962

2006 this issue). Secondly, the management of attentional resources is a distinctive feature of working memory functioning and it could be considered the point of conjunction between working memory and complex cognitive processes, such as reading comprehension (Daneman & Merikle, 1996; De Beni, Palladino, Pazzaglia, & Cornoldi, 1998), problem solving (Passolunghi, Cornoldi, & De Liberto, 1999; Passolunghi & Siegel, 2001), note taking (Kiewra & Benton, 1988), and fluid intelligence abilities (Engle et al., 1999; Kane et al., 2004).

Within this framework, working memory capacity appears as an important source of individual differences. Indeed, a large number of studies have shown that working memory capacity is useful in distinguishing learning-disabled children from normal students (Swanson & Ashbaker, 2000; for a review, see Swanson & Siegel, 2001) and older adults from younger adults (Jenkins, Myerson, Hale, & Fry, 1999). One of the researchers' aims has been to determine which aspects of working memory better account for these differences in performance. Individual differences in working memory can be conceptualised in terms of the ability to monitor attentional resources (Engle et al., 1999), the amount of available resources (Daneman & Tardif, 1987; Engle et al., 1999), and the efficacy of the inhibitory mechanisms (May, Hasher, & Kane, 1999). In the last few years, the latter explanation has gained greater relevance (Friedman & Miyake, 2004).

According to Hasher and Zacks (1988), inhibition is involved in different kinds of control functions that allow people: to determine which activated representations gain entrance into working memory, to suppress those representations that are no longer relevant for the current goal, and to prevent predominant but inappropriate responses (Hasher & Zacks, 1988; Hasher, Zacks, & May, 1999). When inhibitory mechanisms are inefficient, a broader range of information will enter in working memory. Information no longer relevant continues to remain active and the frequency of overt inappropriate responses and of irrelevant or marginally relevant momentary thoughts will increase (Hasher, Quig, & May, 1997). As a consequence working memory becomes saturated. Several studies have shown that older adults, as well as low working memory span young adults (Conway & Engle, 1994; Kane & Engle, 2000; Rosen & Engle, 1997, 1998), are less likely to inhibit irrelevant items and are more likely to retrieve them (e.g., Hamm & Hasher, 1992; Hartman & Dusek, 1994; Hartman & Hasher, 1991). Furthermore, Engle and colleagues have demonstrated that the performance of low span participants under interference conditions can be simulated by dividing the attention of high span participants, consistently with the idea that the attention-control ability is the source of individual differences between high and low working memory participants. Thus in these studies, the presence of interfering material in working memory is interpreted in terms of inefficient inhibitory mechanisms that produce proactive interference.

Several researchers, using the Brown-Peterson task, have shown larger proactive interference effects in older adults compared to younger adults (Lustig, May, & Hasher, 2001; May et al., 1999; Winocur & Moscovitch, 1983). Unfortunately, the data are not entirely consistent. Indeed some authors have shown a higher susceptibility to interference for the elderly (Schonfield, Davidson, & Jones, 1983), while others have not (Craik, 1977; Dobbs, Aubrey, & Rule, 1989). This inconsistency could be due to differences in the procedure used. The Brown-Peterson task requires listening to lists of words and subsequently recalling the words contained in the lists; in addition, between the encoding and the retrieval phases, participants are usually required to do a rehearsal prevention task that allows the prolonging of the retention interval. In some cases the interval duration can go beyond the typical interval for working memory tasks. This can also have a consequence on the age effects (Inman & Parkinson, 1983), since it has been shown that the elderly are less impaired in long term memory recall and by long term memory interference. Conversely one would expect older adults to show a poorer recall and a higher susceptibility to interference compared to younger participants when recall relies on the working memory components.

Another measure that is often considered as an expression of the efficient/inefficient inhibitory mechanism is the number of intrusion errors in a working memory task (De Beni et al., 1998). This measure is conceived of as the ability to manage information currently in the focus of working memory on the basis of its relevance to the task goal (Carretti, Cornoldi, De Beni, & Palladino, 2004; De Beni et al., 1998; Palladino, Cornoldi, De Beni, & Pazzaglia, 2001). It has been suggested that a poor performance in working memory tasks is associated with an increased number of intrusion errors and that the probability of intrusions of irrelevant items is a function of the degree of item activation: The more the items are activated (stressed intrusion), the more they are likely to be erroneously included in the set of items to be recalled (De Beni et al., 1998; Oberauer, 2001; Osaka, Nishizaki, Komori, & Osaka, 2002). Some authors have shown a specific increase in stressed intrusion errors in the older adults' performance (De Beni & Palladino, 2004; Palladino & De Beni, 1999); however, others have not (McCabe & Hartman, 2003; Schelstraete & Hupet, 2002).

Palladino et al. (2001) suggested a distinction between intrusion errors that arise from items belonging to the list currently being processed (i.e., intrusion of items that are in the focus of attention) and intrusion of items that belong to the previous lists (probably due to some proactive interference effect). Palladino et al. highlighted that young participants with reading comprehension difficulties made more intrusions of the first kind, concluding that they had a specific impairment in managing information in working memory. Also in the case of elderly participants, De Beni and Palladino (2004) showed that intrusions of items from the current lists were more frequent in the older adults' performance than other kinds of errors. These data suggest that interference from a preceding list or from the same list in a short-term memory task do not necessarily measure the same type of susceptibility to interference.

WORKING MEMORY, PROACTIVE INTERFERENCE, AND INTELLIGENCE

A common assumption of working memory models is that working memory is at the service of complex cognition (Miyake & Shah, 1999). The maintenance aspects of the working memory capacity together with its processing functions allow to store and manipulate information during complex cognitive activities. Engle et al. (1999) argued that individual differences in performance on complex span tasks are primarily due to differences in the central executive component of working memory, whereas in the case of simple span task performance they are primarily due to differences in domain-specific abilities such as chunking and rehearsal (in the case of verbal span tasks). This reflection was confirmed by a structural equation modelling analysis that demonstrated that a latent variable derived from the complex span task predicts general fluid intelligence performance (measured by Raven's and Cattell's tests), whereas the latent variable derived from the simple span tasks does not. Furthermore, Engle et al. (1999) found that in removing the variance common to the working memory latent variable and the short-term memory latent variable, the relationship between working memory and fluid intelligence was still significant. In addition, Kane et al. (2004) demonstrated that this relation was independent of the type of material used (verbal or visuospatial). They provided evidence that the increase in attentional resources necessary to carry out typical working memory span tasks causes the disappearance of domain specific differences, since all the working memory measures are loaded on a single general common factor (see also Cornoldi, 2006 this issue).

Taken together these findings suggest that the request of the executive control is critical to the utility of the working memory span in predicting complex cognition (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Cornoldi & Vecchi, 2003; Kane & Engle, 2002).

More recently, a meta-analysis conducted by Ackerman, Beier, and Boyle (2005) showed that working memory and fluid intelligence are not isomorphic constructs (see also de Ribaupierre & Lecerf, 2006 this issue) contrary to the hypothesis advanced by Kane and Engle (2002). In addition, Ackerman et al. did not confirm the complete amodal nature of the relationship between working memory and fluid intelligence since they found that the correlations between tasks that had an overlapping content for working memory and fluid intelligence were higher than for nonoverlapping tasks.

However, it is not clear which specific function of the central executive is involved in the relationship with fluid intelligence. In the past few years, in contrast with a unitary view of the central executive, data supporting the possibility of fractionating the central executive has been collected (Letho, 1996;

Miyake et al., 2000). Furthermore, it has been demonstrated that different executive functions make different contributions in explaining complex task performance (see Miyake et al., 2000).

From another viewpoint, Dempster and Corkill (1999) suggested that inhibitory mechanisms play an important role in predicting fluid intelligence performance. Their proposal was to show that differences in the Raven's performance could be due to the efficiency/deficit in controlling previously learned information or previously used rules. Thus a low scoring participant would be less susceptible to proactive interference than a high scoring participant. Though correlational studies with young participants have confirmed Dempster's hypothesis (Brewin & Beaton, 2002), the evidence collected with older participants is discrepant. As regards the relationship between fluid intelligence and age, there are numerous studies indicating that there are large adult age differences on the Raven test, with correlations normally ranging from about $-.49$ to $-.64$ (Babcock, 1994; Hooper, Hooper, & Colbert, 1984; Schultz, Kaye, & Hoyer, 1980). Several researchers have offered possible explanations for age-related differences in the Raven score, such as differences in memory (Bromley, 1953; Chown, 1961), in the ability to determine relevant dimensions of the problem (Anderson, Hartley, Bye, Harber, & White, 1986), and in the ability to ignore irrelevant dimensions (Hoyer, Rebok, & Sved, 1979).

An interesting contribution to the analysis of the relationship between working memory and fluid intelligence was made by Carpenter, Just, and Shell (1990). The authors developed two simulation models to specify the processes engaged in solving the Raven's Advanced Progressive Matrices problems (Raven, 1965): the FAIRAVEN and BETTERAVEN, which correspond respectively to the median or the highest performance. According to these authors, the FAIRAVEN needed the inclusion of the working memory construct, in order to store rules and partial products in an active state thus available for further manipulation. However, the BETTERAVEN performance was simulated adding the, so-called, ''goal monitoring module'' that allows the setting of strategic goals, monitoring of progress towards them, and adjustment of the goals if necessary. Thus, to reach the highest performance in the Raven test the working memory measure is to be considered necessary but not sufficient for the BETTERAVEN performance. They concluded that one of the main distinctions between higher scoring participants and lower scoring participants was the higher scoring participants' ability to successfully generate and manage their problem-solving rules in working memory.

Objective of the study

To summarise, several authors found evidence of a relationship between resistance to interference and fluid intelligence scores (Brewin & Beaton, 2002; Dempster & Corkill, 1999). At the same time, recent research showed that people with high susceptibility to interference have lower working memory capacity (Friedman & Miyake, 2004; Kane & Engle, 2000). Thus, it is possible to argue that resistance to interference could represent a crucial aspect both in working memory task and in fluid intelligence measures. However, different measures of working memory and susceptibility to interference in working memory do not seem to tap identical processes.

The objective of the current study was to examine the independent role of working memory and susceptibility to interference in the Raven's test performance, deeply analysing which processes make working memory important for fluid intelligence. To this aim participants of different ages were compared. Groups were administered two working memory tasks tapping into different mechanisms involved in working memory functioning. In the first task (derived from De Beni et al., 1998), in which the procedure used was the same as in the most classical working memory tasks (like the listening span; Daneman & Carpenter, 1980), participants were required to simultaneously maintain and process information, selecting relevant items and suppressing irrelevant ones. In the second task, a modified version of the Brown-Peterson paradigm, participants were invited to recall a series of lists, and the effect of susceptibility to proactive interference on recall was also measured (Kane & Engle, 2000).

METHOD

Participants

Two age groups of participants, 30 young adults and 60 older adults took part in this study (see Table 1). The young participants were aged between 18 and 27 years (25 females and 5 males) and were University of Padova undergraduates; the older participants were aged between 65 and 86 years. The group of older adults was spilt into two groups: Participants with an age range of 64–74 years' old comprised the young-old group (n = 30; 23 females, 7 males), while participants older than 74 years were allocated to the old-old group (n = 30; 18 females, 12 males).

Participants were all Italian native speakers and volunteered to the study. Older adults were selected on the basis of a physical and a health questionnaire.

TABLE 1
Participants' characteristics (means and standard deviations) by age group

	Young		*Young-old*		*Old-old*	
	M	*SD*	*M*	*SD*	*M*	*SD*
Age	20.23	2.36	67.20	2.89	78.60	2.97
Education	14.23	2.35	7.57	3.44	6.53	3.62

Older participants were active in the cultural and social activities of the neighbourhood.

Educational level was significantly different across age groups, $F(1, 87) = 51.44$, $p < .001$, $p\eta^2 = .54$. Post hoc comparison using Tukey's method showed that young adults had a higher educational level than the young-old ($p < .01$) and old-old ($p < .01$). The difference between the young-old and the old-old was not significant. Since the difference in educational level was not relevant for the measures considered this variable was not taken into account in the following analyses.[1]

Materials

Categorisation working memory span task (De Beni et al., 1998). A modified version of the original working memory task was used. The materials consisted of six sets of stimuli, each composed of three series containing a growing number (from 4 to 6) of strings of words. Each string contained five words rated for familiarity by five independent judges. Strings contained zero, one, or two body-part nouns, which could be presented in various locations, including the final position. Of the total number of words (450) included in the task, 69 were body-part nouns (11 in final positions). An example of a string is the following: house, mother, *head*, word, **night**.

Subjects heard the strings of words presented at a rate of approximately 1 s per word and were required to tap their hand on the table whenever they heard a body-part word. At the end of the set subjects recalled the last word of each string in serial order. The total number of correctly recalled words was considered as being the measure of their working memory capacity.

The number of intrusion errors (i.e., nonfinal words incorrectly recalled) was computed distinguishing between intrusions of words belonging to previous lists and intrusions of words belonging to the current list. In the latter category we further distinguished the mean percentage of intrusions of stressed words (body parts) and nonstressed words (all other words).[2]

Moreover the total number of tapping errors was calculated, to be sure that all participants are carrying out a double task.

Proactive interference (PI) task. Three blocks, of four lists of words, composed the task (based on Kane & Engle, 2000). Words presented belonged to three different categories: animals, occupations, and countries. Each block consisted of three lists of eight words from the same category (e.g., animals) and the last one, which served as the ''release from PI'' list, from another category

[1] ANCOVA analyses conducted with education level as a covariate on the measures used confirmed this assumption, showing that it did not affect cognitive performance.

[2] The percentage of errors was calculated dividing the total number of intrusions by the total number of correct words recalled, thus considering the individual working memory capacity.

(e.g., countries). The lists were presented orally, with a rate of one word per second. Between the presentation of each list and the recall, participants performed a rehearsal-prevention task.

Upon hearing a letter paired with a two-digit number ranging from 10 to 90 (e.g., *G–36*), participants alternated between counting aloud from the letter and number for 16 s, starting with the pair provided (''G–36, H–37, I–38,'' etc.). Participants were instructed to count aloud quickly and accurately. At the end of the rehearsal prevention task, participants had 20 s to recall as many words as possible in any order, and they were encouraged to continue attempting to recall for the entire 20 s. A practice block with two lists from unrelated categories was administered.

The mean percentage of recalled words for each list summed across the three blocks was used as dependent variable. In addition, a measure of total recall was computed averaging the percentage of recall across the lists.

Moreover, in agreement with previous findings (e.g., Friedman & Miyake, 2004; Kane & Engle, 2000, Exp. 2; Wickens, Born, & Allen, 1963) we calculated for each participant two indexes of interference susceptibility, considering the recall in list 1 as baseline in the assessment of the proactive interference build-up. Susceptibility to PI for lists 2 and 3 was estimated using the formula [(list1– list2) / list1)], [(list1– list3) / list1)]. List 4 was used as a control for the appearance of the release of proactive interference.

Raven's Progressive Matrices. In this standardised test (Raven, Court, & Raven, 1977) participants were presented with 60 matrices, grouped in five series of 12 matrices each. The matrices were similar to a puzzle with a piece missing from the bottom right corner. For each matrix six pieces that could fill in the missing part of the puzzle were presented. The participants had to choose the one that completed the figure showing consistency between different elements. They were not allowed to use paper to work out any of the problems and they were instructed to answer each question before moving to the next picture. No time limits were given. The total number of correct solutions was used as a measure of fluid intelligence.

RESULTS

The reliability of our experimental measures was assessed by calculating Cronbach's alpha over items. The reliability coefficients were satisfactory: categorisation working memory span task (correct recall), $\alpha = .98$; PI task (correct recall), $\alpha = .95$; Raven's matrices (PM38), $\alpha = .94$.

Post hoc analyses were conducted using either Dunnett's T3 or Tukey's HSD statistic. The post hoc method was adopted after considering whether or not measures violated the homogeneity of variance assumption, according to Levene's test. For all the analyses the alpha value was set at .05.

Categorisation working memory span task

Errors in the tapping task

To be sure that all the participants carried out the processing task (tapping on the table when a body part noun occurred), the rate of errors between groups of participants were compared. Results did not show any group effect (Table 2).

Correct recall

A one-way ANOVA on the total number of words recalled in the correct order was performed. The main effect of group was significant, $F(2, 87) = 153.20$, $p < .001$, $p\eta^2 = .78$. The group of young participants recalled a significantly higher number of words than the young-old and the old-old that differed significantly from each other (Table 2).

Intrusion errors

A 3 × 2 repeated-measures ANOVA with mixed design with group (young, young-old, old-old) as between-subjects factor and type of intrusion (same vs. previous list) as within factor was conducted. Results indicated a main effect of the type of intrusion, $F(1, 87) = 15.96$, $p < .001$, $p\eta^2 = .155$, but not of the group's age. Independently of the age, the frequency of intrusions from the same list was higher than intrusions from the previous lists. However, the significant interaction Group × Type of intrusion, $F(1, 87) = 3.64$, $p < .05$, $p\eta^2 = .08$, revealed that the age-related differences emerged

TABLE 2
Descriptive statistics (means and standard deviations) for all measures of the study by age group

	Young		*Young-old*		*Old-old*	
	M	*SD*	*M*	*SD*	*M*	*SD*
CWMS task						
% WM recall	77.62	13.46	36.44	12.85	23.33	11.19
% Intrusion of stressed words	0.95	1.59	1.28	2.87	4.43	9.03
% Intrusion of nonstressed words	2.31	2.47	2.14	3.78	5.36	10.02
Errors in the tapping task	4.57	2.90	2.83	2.60	3.63	3.26
PI task						
% Proactive interference recall	52.67	10.43	34.58	8.92	26.35	9.69
Errors in the rehearsal prevention task	1.27	1.93	2.50	2.45	3.27	2.49
Raven's Progressive Matrices						
% Raven score	86.78	7.55	53.67	17.14	40.44	15.86

Figure 1. Mean percentage of working memory intrusion errors by type of intrusions (same vs. previous list) and age group.

only when intrusion errors from the same list were considered. The groups of young and young-old differed significantly from the old-old group (Tukey's post-hoc analysis, $p < .05$). (See Figure 1.)

Moreover, we distinguished errors within the category of intrusion from the same list on the basis of activation of stressed and nonstressed items. Two one-way ANOVA tests were conducted to examine the effects of group (young, young-old, old-old) on the two types of intrusion calculated in percentage (stressed words and nonstressed words). There was a main group effect in the case of stressed intrusions, $F(2, 87) = 3.59$, $p < .05$, $p\eta^2 = .08$. A Tukey's post hoc analysis yielded a unique age difference: Old-old participants made significantly more intrusion errors for stressed words than the young adults ($p < .05$) (Table 2). On the contrary, the group effect was not significant for the nonstressed intrusions.

Proactive interference task

Errors in the rehearsal prevention task

The comparison of accuracy on the rehearsal prevention task yielded a main group effect, $F(2, 87) = 5.76$, $p < .01$, $p\eta^2 = .11$, with old-old adults committing a higher number of errors ($M = 3.27$, $SD = 2.49$) than the young adults ($M = 1.27$, $SD = 1.92$).

Correct recall

A repeated-measures ANOVA with group as between factor (young, young-old, and old-old) and list recall in percentage as within factor (list 1, list 2, list 3, list 4) was conducted.

The result showed a main effect for group, $F(2, 87) = 57.82$, $p < .001$, $p\eta^2 = .57$, and list, $F(3, 261) = 109.86$, $p < .001$, $p\eta^2 = .56$. Tukey's post hoc analyses yielded significant age differences: The young recalled a greater number of words than the young-old ($p < .001$) and the old-old ($p < .001$). Moreover participants recalled more words in list 1 than in the other lists. The Group × List interaction was significant, $F(6, 261) = 29.28$, $p <$ 001, $p\eta^2 = .40$. The interaction arises from the observation that the two groups of elderly showed, contrary to the young adults, an inverse pattern in the percentage of recalled words from list 2 to list 3. Tukey's post hoc analyses revealed that both the young-old and the old-old recalled, in percentage, more words in list 3 than in list 2 ($p < .01$). Moreover for the two groups of older participants the rate of recall from list 3 to list 4 did not increase significantly, showing a lack of release of proactive interference in the last list.

Significant age differences favouring young adults, and confirming the above results, were obtained on the total recall measure computed for the words recalled across the four lists, $F(2, 87) = 57.82$, $p < .001$, $\eta^2 = .57$ (Table 2).

Proactive interference indexes

A one-way ANOVA was used to examine the effects of group on the proportional proactive interference effect on list 2 and list 3 and on the prevention rehearsal task (Figure 2).

The main effect of group on the index computed for list 2 was significant, $F(2, 87) = 3.96$, $p < .05$, $p\eta^2 = .08$. Post hoc comparison using Tukey's test

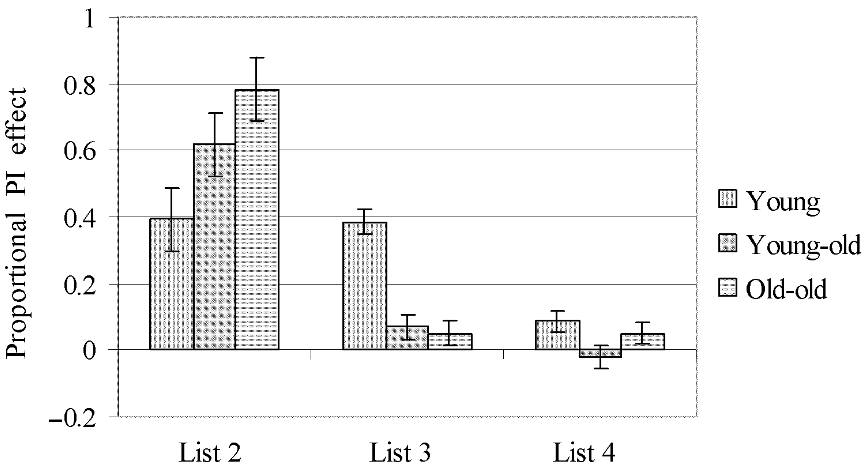

Figure 2. Proportional proactive interference (PI) effects on lists 2 [(list 1 – list 2) / list 1)], list 3 [(list 1 – list 3) / list 1)] and list 4 [(list 1 – list 4) / list 1)] by age group. Vertical lines depict standard errors of the mean.

yielded the following results. The old-old and marginally the young-old showed a higher susceptibility to interference than the young ($p < .05$ and $p = .07$, respectively). The mean difference between the young-old and the old-old was not significant.

The main effect of group was also significant on the index computed for list 3, $F(2, 87) = 24.30$, $p < .001$, $p\eta^2 = .36$, revealing a substantial difference favouring between the two groups of elderly participants, that did not differ from each other, compared to the group of young. Unexpectedly, neither the young-old nor the old-old participants present proactive interference on this index. This effect could be due to the lower percentage of words recalled by the elderly participants. In the case of the older participants' performance on list 2 was so poor that there was virtually no recall to interfere with performance on list 3. On the contrary the higher rate of words recalled on list 1, compared to words recalled on list 2, produced an interference effect.

If in one case (list 2 index) it is necessary for elderly participants, especially for old-old ones, to resist interfering items coming for list 1, this seems not the case for list 3. The resources consumed in storing words from list 1 could have limited, on one hand, the storage process for list 2 words and, on the other hand, the resistance to interference.

Another crucial aspect regarding these outcomes, which will be discussed further on, is the role potentially played by the secondary task on recall performance.

Raven's Matrices

A one-way ANOVA on the total number of correct responses on the Raven task yielded a main effect of age, $F(2, 87) = 85.06$, $p < .001$, $p\eta^2 = .66$, with significant main differences obtained for young and old-old adults and for young-old and old-old adults (Table 2).

Correlational analyses

Correlations were computed in order to examine the relationship among the following variables: the index list 2 of the PI task, the combined score of words recalled on PI task, working memory recall, working memory intrusion errors, the total number of correct responses in the Raven test, and age.

Though the crucial role of stressed intrusion errors in highlighting age-related differences, the working memory intrusion error (stressed and nonstressed) measures were collapsed to obtain a more robust index. In fact both these measures, taken independently, were necessarily weak due to the low number of observations and the high correlation between the two measures ($r = .86$) made plausible to merge the two types of measure. The same was not possible in the case of PI indexes since only the index computed for list 2

TABLE 3
Intercorrelations among measures used

	1	*2*	*3*	*4*
1. PI index (list 2)	—			
2. PI recall	−.60**	—		
3. WM recall	−.40**	.85**		
4. WM intrusion same list	.13	−.24*	−.30***	—
5. Raven	−.26**	.65**	.76***	−.15

$N = 90$. $^{**}p < .01$, $^{*}p < .05$. PI = proactive interference.

emerged as a proper measure of interference for the three age groups considered.

Correlations between the above mentioned measures were first computed within each age group to assess the measure of similarity between the three different patterns of results. Since results showed a similar pattern of correlations independently of the age group considered, we calculated a global correlation matrix for the whole sample (Table 3). The correlations ranged from small to large (Morse, 1998).

Working memory measures were highly correlated. On the contrary interference measures showed a lower relationship but in the expected direction: intrusion errors correlated negatively with the PI tasks. This confirms our hypothesis: Participants who suppressed irrelevant information more efficiently are the ones who are less sensitive to interference effects, recalling in percentage more correct words in the PI task. Moreover, the efficacy in suppressing irrelevant information from the contents of working memory is also significantly correlated with a higher working memory capacity. Globally, correlations showed that a lower susceptibility to interference is associated with a higher working memory capacity, higher scores on the Raven's test and a higher number of words recalled in the PI task. Nevertheless intrusion errors did not correlate with the PI index.

Regression analysis

Two distinct hierarchical regression analyses were used to examine the contribution of the two working memory tasks on the Raven's performance.

In a regression analysis the recalled words at the categorisation working memory span task and the words recalled on PI task (combined scores) were entered as predictors. Working memory measures accounted for 58% of the variance in the Raven's performance and the recalled words in the categorisation working memory span task ($\beta = .76$, $p < .001$) were the only salient predictor.

In the second regression analysis the susceptibility to interference (list 2 PI index) and the intrusion measure (combined score between the stressed and nonstressed intrusions errors) were entered as predictors. Interference measures accounted for a very limited part of the variance (less than 1%) of the Raven's performance and only susceptibility to interference contributed significantly towards the Raven's performance.

GENERAL DISCUSSION

The current study is an attempt to understand the links between three important aspects of cognition, i.e., the working memory capacity, susceptibility to interference, and fluid intelligence (measured by the Raven's test) in function of age-related changes. To this aim we firstly compared groups of participants of different ages in tasks that are considered as representative of these cognitive processes. The following step was to establish the role of working memory and susceptibility to interference in explaining the variation in a task measuring fluid intelligence.

The group comparison results substantially replicated well-known findings with only slight differences. The working memory task differentiated clearly between groups: Both groups of elderly participants reached a very low level of correctly recalled words compared to the younger adults. Differences were also found within the group of the elderly, with young-adults outperforming the old-old group. Analyses on intrusion errors, measuring the efficacy of the inhibitory processes, showed that old-old participants were less able to control for irrelevant information in comparison with young adults and young-old (De Beni & Palladino, 2004). This was true only when intrusion errors from the same list were considered, suggesting that old-old adults are specifically impaired in controlling information in working memory. Moreover, this result was confirmed by the further analysis of the category of the ''same list'' intrusion errors. The differences between old-old group and the other two groups were found only in the case of highly activated words, i.e., stressed words (body nouns), but not for other kinds of intrusion, i.e., nonstressed words. Thus, these results support the idea that the older adults have difficulty in monitoring the permanence of information in working memory depending on its relevance (De Beni & Palladino, 2004). In the case of the elderly participants, their inhibitory mechanism seems to show a deficit especially for those items that were more active in memory (De Beni & Palladino, 2004; Palladino & De Beni, 1999). The lack of differences between the young and the young-old adults suggests that the age-related differences in the inhibitory mechanisms are not the crucial aspect in the decline of the working memory capacity (Gamboz, Russo, & Fox, 2002). However, the results concerning intrusion errors have to be considered with caution, since, especially in the case of the elderly groups, their row scores were rather low.

The recall in the PI task revealed again a poorer performance in the memory task for older adults compared to young adults; indeed both the groups of elderly participants obtained a performance always below 50%. Since the interval between the presentation of the stimuli and recall was set at 16 s, we can assume that recalling activities rely on primary memory (Floden, Stuss, & Craik, 2000), i.e., on the working memory capacity. Thus, the older adults' lower performance could be ascribed to their working memory capacity deficit, as suggested by the correlational analyses. However, in the case of this task, it is likely that other aspects negatively influenced the elderly participants' performance. Some authors have pointed out that the level of difficulty of the secondary task could be one of the crucial aspects in influencing the older adults' performance (Inman & Parkinson, 1983; Parkinson, Inman, & Dannenbaum, 1985). Indeed a more complex secondary task heightened the difficulty in successfully encoding information in memory, producing poorer memory traces. The encoding difficulty resulting from a more complex secondary task could also account for the low rate of intrusion errors in this task. In the case of the index of resistance to interference, our results highlighted significant differences for the index computed for list 2 in that the young differed significantly from the old-old but only marginally from the young-old group in the susceptibility to interference. In addition older participants showed a comparable level of susceptibility. However, the index computed in list 3 showed a heavy reduction in susceptibility to interference in both the elderly groups. In our opinion, this finding could be a product of the impressively low level of recall performance reached by the elderly groups in list 2. This could suggest that list 2 is better in highlighting age-related differences in susceptibility to interference. It is worth noticing that this hypothesis has been made in the case of results obtained with younger adults (see, for example, Friedman & Miyake, 2004).

Finally, as expected, in the Raven's test the young adults outperformed both groups of elderly participants. Furthermore, similarly with findings obtained in the working memory task, we found differences also within the elderly group with a better performance for the young-old adults in comparison with the old-old participants.

The second part of the study aimed to understand the relationship between these aspects of cognition. The literature reports correlations that vary remarkably in strength between working memory, fluid intelligence (measured with the Raven's test) and resistance to interference. In the present study, the regression analyses showed that measures expressing the ability to control for interference (PI index) and intrusion errors are weakly related with the Raven scores. In contrast, working memory capacity emerged as powerful predictors in explaining a significant and consistent part of the variance of fluid intelligence as measured by the Raven test. Despite the fact that the two working memory tasks we used, the categorisation working memory span task and the PI task, come from different paradigms and seem to rely on partially different functions, in the present study they seemed to share the largest part of the variance in the Raven test. Concerning the memory performance the categorisation working memory span test appeared a better predictor of fluid intelligence than recall in the PI task, whereas—with respect to susceptibility of interference—the proactive interference index appeared preferable to the intrusion measure. However the two measures of susceptibility to interference did not appear particularly powerful. Before concluding that susceptibility to interference is not a good predictor of fluid intelligence, further stronger evidence is necessary. In fact, our two measures, intrusions and PI, were based on a low number of observations and this could have affected the general pattern of data. More robust measures and a larger number of tasks could disambiguate more precisely the relationship between fluid intelligence (in this study measured only with the Raven task), working memory, and susceptibility to interference.

To summarise, our study confirmed the important role of working memory and highlighted the weak contribution of the ability to control for irrelevant interfering information in a measure of fluid intelligence, the Raven test.

REFERENCES

Ackerman, P. L., Beier, M. E., & Boyle, M. O. (2005). Working memory and intelligence: The same or different constructs? *Psychological Bulletin*, *131*, 30–60.

Anderson, J. W., Hartley, A. A., Bye, R., Harber, K. D., & White, O. L. (1986). Cognitive training using self-discovery methods. *Educational Gerontology*, *12*, 159–171.

Babcock, R. L. (1994). Analysis of adult age differences on the Raven's Advanced Progressive Matrices test. *Psychology and Aging*, *9*, 303–314.

Baddeley, A. D., & Hitch, G. J. (1974). Working memory. In G. Bower (Ed.), *The psychology of learning and motivation* (Vol. 8, pp. 47–90). New York: Academic Press.

Baddeley, A. D., & Logie, R. H. (1999). Working memory: The multiple-component model. In A. Miyake & P. Shah (Eds.), *Models of working memory* (pp. 28–61). Cambridge, UK: Cambridge University Press.

Brewin, C. R., & Beaton, A. (2002). Thought suppression, intelligence, and working memory capacity. *Behaviour Research and Therapy*, *40*, 923–930.

Bromley, D. B. (1953). Primitive forms of response to the matrices test. *Journal of Mental Sciences*, *99*, 374–393.

Carpenter, P. A., Just, M. A., & Shell, P. (1990). What one intelligence test measures: A theoretical account of the processing in the Raven Progressive Matrices test. *Psychological Review*, *97*, 404–431.

Carretti, B., Cornoldi, C., De Beni, R., & Palladino, P. (2004). What happens to information to be suppressed in working memory tasks? Short and long term effects. *Quarterly Journal of Experimental Psychology*, *57A*, 1059–1084.

Chown, S. M. (1961). Age and the rigidities. *Journal of Gerontology*, *16*, 353–362.

Conway, A. R. A., Cowan, N., Bunting, M. F., Therriault, D. J., & Minkoff, S. R. B. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence*, *30*, 163–183.

Conway, A. R. A., & Engle, R. W. (1994). Working memory and retrieval: a resource-dependent inhibition model. *Journal of Experimental Psychology: General*, *123*, 354–373.

Cornoldi, C. (2006). The contribution of cognitive psychology to the study of human intelligence *European Journal of Cognitive Psychology*, *18*(1), 1–17.

Cornoldi, C., & Vecchi, T. E. (2003). *Visuo-spatial working memory and individual differences*. Hove, UK: Psychology Press.

Craik, F. I. M. (1977). Age differences in human memory. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (pp. 384–420). Englewood Cliffs, NJ: Prentice Hall.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior*, *19*, 450–466.

Daneman, M., & Merikle, P. M. (1996). Working memory and language comprehension: A meta-analysis. *Psychonomic Bulletin and Review*, *3*, 422–433.

Daneman, M., & Tardif, T. (1987). Working memory and reading skill reexamined. In M. Coltheart (Ed.), *Attention and performance XII: The psychology of reading* (pp. 491–508). Hove, UK: Lawrence Erlbaum Associates Ltd.

De Beni, R., & Palladino, P. (2004). Decline in working memory updating through ageing: Intrusion error analyses. *Memory*, *12*, 75–89.

De Beni, R., Palladino, P., Pazzaglia, F., & Cornoldi, C. (1998). Increases in intrusion errors and working memory deficit of poor comprehenders. *Quarterly Journal of Experimental Psychology*, *51A*, 305–320.

Dempster, F. N., & Corkill, A. J. (1999). Individual differences in susceptibility to interference and general cognitive ability. *Acta Psychologica*, *10*, 395–416.

De Ribaupierre, A., & Lecerf, T. (2006). Relationships between working memory and intelligence from a developmental perspective: Convergent evidence from a neo-Piagetian and a psychometric approach. *European Journal of Cognitive Psychology*, *18*(1), 109–137.

Dobbs, A. R., Aubrey, J. B., & Rule, B. G. (1989). Age-associated release from proactive interference: A review. *Canadian Psychology*, *30*, 588–595.

Elliott, E. M., Barrilleaux, K. M., & Cowan, N. (2006). Individual differences in the ability to avoid distracting sounds. *European Journal of Cognitive Psychology*, *18*(1), 90–108.

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. A. (1999). Working memory, short-term memory and general fluid intelligence: A latent variable approach. *Journal of Experimental Psychology: General*, *128*, 309–331.

Floden, D., Stuss, D. T., & Craik, F. I. M. (2000). Age differences in performance on two versions of the Brown-Peterson task. *Aging, Neuropsychology and Cognition*, *7*, 245–259.

Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: A latent-variable analysis. *Journal of Experimental Psychology: General*, *133*, 101–135.

Gamboz, N., Russo, R., & Fox, E. (2002). Age differences and the identity negative priming effect: An updated meta-analysis. *Psychology and Aging*, *17*, 525–531.

Hamm, V. P., & Hasher, L. (1992). Age and the availability of inferences. *Psychology and Aging*, *7*, 56–64.

Hartman, M., & Dusek, J. (1994). Direct and indirect memory tests: What they reveal about age differences in interference. *Aging and Cognition*, *1*, 292–309.

Hartman, M., & Hasher, L. (1991). Aging and suppression: Memory for previously relevant information. *Psychology and Aging*, *6*, 587–594.

Hasher, L., Quig, M. B., & May, C. P. (1997). Inhibitory control over no-longer-relevant information: Adult age differences. *Memory and Cognition*, *25*, 286–295.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension and aging: A review and new view. In G. H. Bower (Ed.), *The psychology of learning and motivation* (pp. 193–225). San Diego, CA: Academic Press.

Hasher, L., Zacks, R. T., & May, C. P. (1999). Inhibitory control, circadian arousal, and age. In D. Gopher & A. Koriat (Eds.), *Attention and performance XVII: Cognitive regulation of performance: Interaction of theory and application* (pp. 653–675). Cambridge, MA: MIT Press.

Hooper, F. H., Hooper, J. O., & Colbert, K. C. (1984). *Personality and memory correlates of intellectual functioning: Young adulthood to old age*. Basel, Switzerland: Karger.

Hoyer, J. W., Rebok, G. W., & Sved, S. M. (1979). Effects of varying irrelevant information on adult age differences in problem solving. *Journal of Gerontology*, *34*, 553–560.

Inman, V. W., & Parkinson, S. R. (1983). Differences in Brown-Peterson recall as a function of age and retention interval. *Journal of Gerontology*, *38*, 58–64.

Jenkins, L., Myerson, J., Hale, S., & Fry, A. F. (1999). Individual and developmental differences in working memory across the life span. *Psychonomic Bulletin and Review*, *6*, 28–40.

Kane, M. J., & Engle, R. W. (2000). Working-memory capacity, proactive interference, and divided attention: Limits on long-term memory retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*, 336–358.

Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic Bulletin and Review*, *9*, 637–671.

Kane, M. J., Hambrick, D. Z., Wilhelm, O., Payne, T., Tuholski, S., & Engle, R. W. (2004). The generality of working memory capacity: A latent variable approach to verbal and visuo-spatial memory span and reasoning. *Journal of Experimental Psychology: General*, *133*, 189–217.

Kiewra, K. A., & Benton, S. L. (1988). The relationship between information processing ability and notetaking. *Contemporary Educational Psychology*, *13*, 33–44.

Letho, J. (1996). Are executive function tests dependent on working memory capacity? *Quarterly Journal of Experimental Psychology*, *49*, 29–50.

Lustig, C., May, C. P., & Hasher, L. (2001). Working memory span and the role of proactive interference. *Journal of Experimental Psychology: General*, *30*, 199–207.

May, C. P., Hasher, L., & Kane, M. J. (1999). The role of interference in memory span. *Memory and Cognition*, *27*, 759–767.

McCabe, J., & Hartman, M. (2003). Examining the locus of age effects on complex span tasks. *Psychology and Aging*, *18*, 562–572.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. (2000). The unity and diversity of executive functions and their contributions to complex ''frontal lobe'' tasks: A latent variable analysis. *Cognitive Psychology*, *41*, 49–100.

Miyake, A., & Shah, P. (1999). *Models of working memory*. Cambridge, UK: Cambridge University Press.

Morse, D. T. (1998). MINSIZE: A computer program for obtaining minimum sample size as an indicator of effect size. *Educational and Psychological Measurement*, *58*, 142–153.

Oberauer, K. (2001). Removing irrelevant information from working memory: A cognitive aging experiment with the modified Sternberg task. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *27*(4), 948–957.

Osaka, M., Nishizaki, Y., Komori, M., & Osaka, N. (2002). Effect of focus on verbal working memory: Critical role of the focus word in reading. *Memory and Cognition*, *30*(4), 562–571.

Palladino, P., Cornoldi, C., De Beni, R., & Pazzaglia, F. (2001). Working memory and updating processes in reading comprehension. *Memory and Cognition*, *29*, 344–354.

Palladino P., & De Beni, R. (1999). Short term and working memory in aging: Maintenance and suppression. *Aging, Clinical and Experimental Research*, *11*, 301–306.

Parkinson, S. R., Inman, V. W., & Dannenbaum, S. E. (1985). Adult age differences in short-term forgetting. *Acta Psychologica*, *60*, 83–101.

Passolunghi, M. C., Cornoldi, C., & De Liberto, S. (1999). Working memory and intrusions of irrelevant information in a group of specific poor problem solvers. *Memory and Cognition*, *27*, 779–790.

Passolunghi, M. C., & Siegel, L. S. (2001). Short-term memory, working memory, and inhibitory control in children with difficulties in arithmetic problem solving. *Journal of Experimental Child Psychology*, *80*, 44–57.

Raven, J. C. (1965). *Advanced Progressive Matrices, Sets I and II*. London: H. K. Lewis.

Raven, J. C., Court, J. H., & Raven, J. (1977). *Standard Progressive Matrices*. London: H. K. Lewis.

Rosen, V. M., & Engle, R. W. (1997). The role of working memory capacity in retrieval. *Journal of Experimental Psychology: General*, *126*, 211–227.

Rosen, V. M., & Engle, R. W. (1998). Working memory capacity and suppression. *Journal of Memory and Language*, *39*, 418–436.

Salthouse, T. A., & Meinz, E. J. (1995). Aging, inhibition, working memory, and speed. *Journals of Gerontology: Series B. Psychological Sciences and Social Sciences*, *50B*, 297–306.

Schelstraete, M., & Hupet, M. (2002). Cognitive aging and inhibitory efficiency in the Daneman and Carpenter's working memory task. *Experimental Aging Research*, *28*, 269–279.

Schonfield, A. E. D., Davidson, H., & Jones, H. (1983). An example of age-associated interference in memorizing. *Journal of Gerontology*, *38*, 204–210.

Schultz, N. R., Kaye, D. B., & Hoyer, W. J. (1980). Intelligence and spontaneous flexibility in adulthood and old age. *Intelligence*, *4*, 219–231.

Swanson, H. L., & Ashbaker, M. H. (2000). Working memory, short-term memory, speech rate, word recognition and reading comprehension in learning disabled readers: Does the executive system have a role? *Intelligence*, *28*, 1–30.

Swanson, H. L., & Siegel, L. (2001). Learning disabilities as a working memory deficit. *Issues in Education*, *7*, 1–48.

Wickens, D. D., Born, D. G., & Allen, C. K. (1963). Proactive inhibition and item similarity in short-term memory. *Journal of Verbal Learning and Verbal Behavior*, *2*, 440–445.

Wilhelm, O., & Oberauer, K. (2006). Why are reasoning ability and working memory capacity related to mental speed? An investigation of stimulus–response compatibility in choice reaction time tasks. *European Journal of Cognitive Psychology*, *18*(1), 18–50.

Winocur, G., & Moscovitch, M. (1983). Paired-associate learning in institutionalized and non-institutionalized old people: An analysis of interference and context effects. *Journal of Gerontology*, *38*, 455–464.