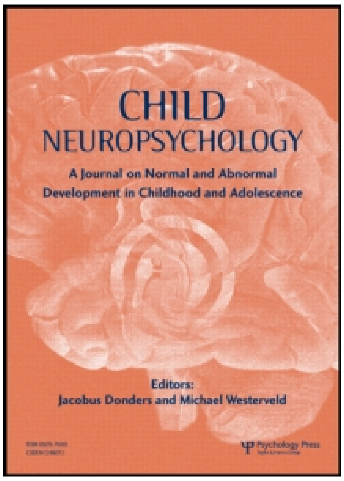

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INTERRELATIONS BETWEEN ATTENTION AND VERBAL MEMORY AS AFFECTED BY DEVELOPMENTAL AGE

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We analyzed the relationship between several measures of attention (e.g., sustained and divided attention) and measures of verbal memory (e.g., immediate and delayed memory) in children aged 8–17 years. The attentional measures were derived from several tests of attention: Trail-Making, Digit Cancellation, Digit-Symbol, and Digit-Span. The verbal memory measures were derived from the Rey Auditory Verbal Learning Test (AVLT). We found that most correlations between attention and the Rey AVLT measures were mediated by age. After removing the contribution of age, relationships were found between attentional and memory measures only in the younger age groups (8–12) but not in the older age groups (13–17). For the younger children different attentional tests predicted different aspects of verbal memory. Furthermore, boys and girls showed different patterns of attention-memory relationships. The theoretical and clinical implications of these findings are discussed.

Keywords: ***Attention; Verbal memory; Rey AVLT; Memory development.***

The study of developmental changes in memory and their relationship with other cognitive domains, particularly attention, has important theoretical as well as educational, diagnostic and remedial applications (Gathercole, 1998). Numerous studies of various age groups have found a clear and consistent developmental enhancement of immediate and delayed recall of simple and complex material in various modalities. Working memory as indexed by digit span has been shown to grow steadily with age (reviewed by DeMarie & Ferron, 2003; Dempster, 1981), and similar developmental trends have been found for recall and cumulative learning of word lists (Vakil, Blachstein, & Sheinman, 1998), nonword stimuli, visual patterns, visual sequences, and mazes (Gathercole, Pickering, Ambridge, & Wearing, 2004; Swanson, 1999). It is noteworthy that at certain ages, memory performance levels off. In a previous study, we reported that most memory measures stabilized after age 11 (Vakil et al., 1998). A similar finding was reported by Gathercole et al. (2004) regarding a visual patterns test, while other tests in their study leveled off at ages 14–15 years.

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Regarding memory development, several explanations have been offered to account for the clear developmental trend of improved memory performance: Growth in knowledge about the world in general, of knowledge of language, or an expertise in a specific domain (Schneider, 2002); the use by older children of better memory strategies (Gathercole, 1998); and changes in meta-memory (the person's awareness and knowledge of his or her memory capacities, when and how to activate memory strategies, and the self-monitoring of the learning process; Schneider).

Other explanations of memory development have emphasized the role of attentional processes. Several models of memory incorporate attention as a key component of different memory processes (selection, encoding, storage, and retrieval). The content of short-term memory reflects stimuli in the present focus of attention (J. R. Anderson, 2005); active rehearsal, needed for retention in short-term memory, requires attention (Cowan, Nugent, Elliott, Ponomarev, & Saults, 1999; Pashler, 1998); and attention has been found to affect episodic encoding (Naveh-Benjamin, Guez, & Marom, 2003). Attention is also required for memory retrieval: it acts either by activating memory representations and thereby facilitating their subsequent storage and retrieval (Cowan et al.; Gavens & Barrouillet, 2004), or it affects the process of selection between competing responses during the retrieval process (Roelofs, 2008). Attention is considered to be a part of the "Central Executive" component, a major part of working memory, as suggested by Baddeley's (2002) model. The "Central Executive" component is responsible for the control of flow of information, switching between tasks, selection of relevant stimuli and inhibition of irrelevant ones, which are functions attributed mainly to attentional processes (Alloway, Gathercole, Willis, & Adams, 2004; Travis, 1998). The involvement of attention in memory development may also be related to capacity limitations. The studies cited above indicate a consistent developmental increase in the number of stimuli that children can recall. Do these changes reflect a basic memory capacity that increases with age? Cowan et al. (1999) used a dual task paradigm in order to prevent participants from using mnemonic techniques while hearing lists of digits. They found that older children still recalled more verbal items than younger children and concluded that there is a "core memory capacity" that increases with age. Gavens and Barrouillet (2004) found that processing load affects working memory performance in children more than does task duration, emphasizing the role of capacity limitation in memory development.

Attention develops and matures with age, as attested by numerous studies. Betts, McKay, Maruff, and Anderson (2006) have found changes in sustained attention up to age 10 years. Klenberg, Korkman, and Lahti-Nuuttila (2001) have also found developmental changes in vigilance, selective and focused attention (up to age 10 years), and in tests of executive functions (up to age 11 years). In a norm-collection study of four frequently used attention tests (Trail Making, Digit-Symbol, Digit Span, and Digit Cancellation), we have reported that performance improved with age, with pronounced developmental changes in the younger ages (8–11 years) and stabilization of performance in older age groups (12–17 years; Vakil, Blachstein, Sheinman, & Greenstein, 2009). Manly et al. (2001) have reported developmental changes in attention tasks even up to the age of 16 years.

These findings leave us with an important question: what aspects of attention are related to memory development and vice versa: the ability to focus, to sustain, or to divide attention, the ability to inhibit irrelevant information, and/or the size of the storage capacity? All these processes change and mature with age, are interconnected and probably affect one another. For example, changes in attention may result in the reduction of the processing demands of the task, freeing more space in storage capacity (DeMarie, Miller, Ferron, & Cunningham, 2004). These authors argue that capacity changes may also affect the ability to use efficient memory strategies (a younger child with a smaller capacity may need more effort when using more advanced memory strategies). More efficient strategies also free up capacity (Gathercole, 1998).

Attention and memory are also related to processing speed (Gavens & Barrouillet, 2004). Since some of the tests used in the present study employ performance time as the critical measure, it is important to consider this factor. Numerous studies have shown that processing speed increases with age and contributes a great deal to the performance of various tasks. Speed of rehearsal (rather than its quantity) affects the storage in short-term memory, indicating that there is a rapid decay of information in that store (J. R. Anderson, 2005). Increased speed may enable a faster switch between processing and storage of these decaying memory traces, thereby improving recall (Hitch, Towse, & Hutton, 2001). This rapid switch was found to contribute more to children's memory performance than capacity limitations (Towse, Hitch, & Hutton, 2002). Speed of rehearsal, speed of retrieval, and the use of rehearsal were the most salient measures that changed with age in phonological short-term memory (Gathercole, 1998). It has been argued that speed and capacity are related, since faster processing enables storage of a greater amount of information (DeMarie et al., 2004). Speed also enables faster and more efficient encoding (Luna, Garver, Urban, Lazar, & Sweeney, 2004).

The developmental course of attention and memory has usually been investigated in separate studies. However, Gomez-Perez and Ostrosky-Solis (2006) examined the development of both attention and memory measures across a wide age range (6–85 years). Factor analysis of their data revealed six factors; some of which are relevant to our study: Verbal Memory (learning and memory of world lists) and three attentional factors: Attention-Executive (visual search and fluency tests); Selective and Sustained Attention and Orientation (orientation, digit detection, mental control, immediate, and delayed recall of faces); and Attentional-Working Memory (forward and backward digit and spatial spans). An interesting finding of their study was that all attentional factors change faster than the memory factor: the attention score increased by one point every 6–7 years, whereas the memory factor score changed by one point every 16 years.

On two previous developmental studies, one on attention and the other on verbal memory, a parallel developmental course was observed. Vakil et al. (2009) reported normative data on four attention tests for children aged from 8 to 17 years old. Performance on the Digit Symbol, Number Cancellation, and Trail Making Test (TMT; part B) tasks changed with age up to 17 years, while Digit Span backward and TMT (part A) stabilized at 14 years, and Digit Span forward stabilized at 13 years. Furthermore, age changes were more pronounced in the early years (8–11). Normative data on the Rey Auditory-Verbal Learning test (AVLT) with the same cohort of children was also reported. Variety of verbal learning and memory measures improved with age, with the exceptions of proactive interference and delayed recall (Vakil et al., 1998).

The purpose of the present study is to explore the relations between different attentional measures and a variety of verbal memory measures during development. To the best of our knowledge, this is the first study that explores the developmental relationships between attention and verbal memory. As noted above, attention and memory are interrelated. Attention is involved in the processes of selection of stimuli for perceptual focus, memory encoding and retrieval, and limits on processing capacity. The questions posed here are whether a relationship exists between verbal memory and attention, and whether this relationship changes with age.

As discussed previously, the time courses of attention and memory development are quite similar: both show a steady development in early childhood and tend to level off in late childhood-early adolescence. As a cognitive process that modulates perception, attention may affect and limit memory performance. Since attentional processes are not yet stabilized in early ages (Betts et al., 2006; Rebok et al., 1997; Vakil et al., 2009), and mnemonic strategies develop gradually during the elementary-school period (Schneider, 2002), it is expected that attention processes should be more related to memory in younger than in older ages. This hypothesis seems especially relevant to the Rey AVLT, because it entails multiple presentations of the same word list. This might enable older children to use advanced mnemonic strategies that are already available to them. Younger children, lacking such strategies, might exert more effort (attention) in dealing with the material to be remembered.

The findings of this study may potentially provide a significant clinical and theoretical contribution to understanding the relationships between memory and attention processes at various ages.

In order to examine these questions the performance on the four attention tests (i.e., TMT, Digit Cancellation, Digit Symbol, and Digit Span and the verbal memory measures derived from the Rey AVLT will be examined. All these tests will be described in detail in the "Methods" section. Norms for these attention tests (Vakil et al., 2009) and the Rey AVLT (Vakil et al., 1998) have been previously reported. Both studies' results were based on the same child population as in the present study.

METHODS

The data analyzed in the present study are the normative Rey AVLT data and the normative attention tests data already published by Vakil et al. (1998) and Vakil et al. (2009), respectively. It is important to note that the memory and attention data were collected at the same time on the same participants. This gave us the unique opportunity to study the developmental course of the relationship between these two sets of tests scores.

Participants

Data collected on 812 children (416 boys and 396 girls) were used in this study. The age range of the sample population was from 8 to 17 years, divided into 10 age cohorts. The children's sample for the study was recruited from a population of children in 14 public schools in central Israel (i.e., the greater Tel Aviv area). Based on the teachers' judgment, children with learning disabilities, attention disorders, or those requiring special assistance in school were excluded. For more details about the participants, see Vakil et al. (1998, 2009). Based on our previous results (attention data: Vakil et al., 2009; Rey AVLT data: Vakil et al., 1998), we analyzed the data separately for two age groups (8–12, n = 394 and 13–17, n = 418), since each age group has a different profile of memory and attention measures. In each age cohort, the number of boys ranged from 35 to 59, and the number of girls ranged from 35 to 42. The total number of participants in each age cohort ranged from 70 to 100.

Tests and Procedure

Children were tested individually in a room allocated for this purpose, in their own schools, during school hours. The children participated voluntarily in the study. Furthermore, they were told that they could stop at any time if they wished to do so. This happened with just a few children who claimed that they were tired. The attention tests used in this study were administered at the same time as the collection of Hebrew norms on the Rey AVLT. Some of the attention tests were administered during the 20-minute delay in administration of the Rey AVLT, and the remainder following the Rey AVLT. The examiners in this project were 14 undergraduate psychology majors at Bar-Ilan University, who were trained to administer and score the tests.

The following tests were used.

Rey-auditory verbal learning test (AVLT; Rey, 1964). This frequently used test measures different aspects of learning and memory, including immediate and delayed recall, cumulative learning, learning rate, recognition, proactive and retroactive interference, primacy and recency effects, and recall of temporal order. The test is differentially sensitive to the effects of age, gender, intelligence, psychiatric condition, and brain trauma (Addington, van Mastrigt, & Addington, 2003; Vakil et al., 1998, 2004). The Hebrew version of the Rey AVLT was used (Vakil et al., 1998). Administration was standard, as described by Lezak, Howieson, and Loring (2004). The test consists of 15 common nouns, which were read to the participants, at the rate of one word per second, in five consecutive trials (Trials 1 through 5); each reading was followed by a free recall task. In trial 6, an interference list of 15 new common nouns was presented, followed by free recall of these new nouns. In Trial 7, without an additional reading, participants were again asked to recall the first list. Twenty minutes later, and again without an additional reading, participants were once more asked to recall the first list (Trial 8). Next, in Trial 9, they were given a list of 50 words (15 from the first list, 15 from the second list, and 20 new common nouns) and were asked to identify the 15 first-list words. To measure the ability to remember temporal order, an extra trial (Trial 10) was added to the standard administration: participants were presented with the 15 first-list words written in an order different from that originally presented. Participants were asked to write the words in their original order, and the correlation was calculated between the subject's response order and the original presentation order of the words.

Trail-making test (TMT; Reitan & Davison, 1974). This test has been defined as a test of visual scanning and tracking, processing speed, focused and divided attention, working memory, cognitive flexibility, and shifting of attention (Lezak et al., 2004). The test consists of two parts: Part A requires the individual to draw lines that connect consecutive digits, printed in a scattered pattern on a page. Part B requires drawing lines that connect sequences of letters and digits, alternatively (i.e., 1-A-2-B and so on). The times to complete each part and the numbers of errors are recorded. It has been argued that Part A measures visual scanning and tracking, motor speed, and focused attention, whereas Part B measures cognitive flexibility, set shifting, and divided attention (V. Anderson & Pentland, 1998). In a previous study, we found that significant developmental changes in the performance on Part A occur mainly across the 8–11 age groups, and changes in Part B take place mainly across the 8–12 age groups (Vakil et al., 2009). Administration was according to Lezak et al. (2004). The adult version was administered to all age groups, with the digits parts administered first (Form A), followed by the dual task (Form B). Time to completion was recorded in both cases. A difference score (Form B minus Form A) was also analyzed, in order to obtain a more specific measure of flexibility and switching ability, without the contribution of the speed component, as recommended by Holtzer, Stern, and Rakitin (2005) and Lezak et al. (2004).

Digit cancellation test (Diller et al., 1974; Lezak et al., 2004, p. 381). Cancellation tests are considered to measure focused, sustained, and selective attention, speed of information processing, short-term memory, and cognitive flexibility (V. Anderson & Pentland, 1998; Kelly, 2000). We have reported a positive relationship between age and speed of performance on this task, in addition to gender effects (girls performed faster than boys), and task complexity effects, especially in the 8–12 age groups (Vakil et al., 2009). The test was administered in two stages, in each of which participants were presented with an identical form. The form consists of 312 digits (3 mm size each) printed in random order and organized in 6 rows and 52 columns. A $1^1/_2$ cm horizontal space in the middle splits the six rows in two. The digits were printed on an A4 sheet of paper in a horizontal layout (see Vakil et al.). The participants were required to scan the form and cross out the digit “8” in the simpler version (Part A) of this test, and “3” and “5” on the more complex version (Part B). The time to completion together with omissions and commissions errors were recorded. In order to separate the speed component from the complexity component, a difference score (Part B minus Part A) was also analyzed.

Digit-symbol subtest of the WISC-R (Wechsler, 1991). This test taps processing speed, visual tracking and scanning, visual-motor coordination, focused and sustained attention, short-term memory, cognitive flexibility, rapid shifting, and the ability to learn a new task (V. Anderson & Pentland, 1998; Kinsella, 1998; Sattler, 1992). Perceptual and graphomotor speed and visual scanning efficiency have been found to contribute substantially to the variance in this test (Joy, Fein, & Kaplan, 2003). Recently, we found clear age and gender effects on this task, girls being faster than boys (Vakil et al., 2009). Administration was according to the WISC-R (Wechsler, 1991) protocol. The form consists of 4 rows of 25 empty boxes in each, with the first 7 boxes being used for a demonstration and practice trial. Participants were instructed to work as quickly as possible, using a pencil, and going from one box to the next from left to right. The relevant measure recorded was the number of correct symbols copied within 120 seconds.

Digit-span subtest of the WISC-R (Wechsler, 1991). This test measures auditory attention and short-term memory (Sattler, 1992). It has two parts: The Digits Forward sequence requires the individual to immediately repeat sequences of orally presented digits in the same order as presented; the Digits Backward sequence requires the immediate repetition of the digits in reverse order. The Digits Forward part requires more simple attention and mental tracking and presumably measures the storage component of working memory or attention (Kinsella, 1998). Using Baddeley’s (1986) working memory model, Gathercole (1999) suggests that while the Digits Forward task reflects processing in the phonological loop, the Digits Backward part relies more on the Central Executive component of working memory. In the present study, consistent with our previous normative study of attentional developmental (Vakil et al., 2009), we adopted Cohen’s (1993) classification of attentional tests into a variety of attentional factors. Cohen distinguishes between four attentional factors; Attentional Capacity, Sensory-Selective Attention, Response

Selection and Control, and Sustained Attention. Cohen includes the Digit Span forward test in the Attentional Capacity factor because it reflects the limits of the amount of information that can be simultaneously processed.

In our previous study, we found that changes in recall took place across ages 8–10 and 11–13, with no changes after age 14, with boys performing slightly better than girls (Vakil et al., 2009). Administration was according to the WISC-R (Wechsler, 1991) protocol. This task consists of two subtests: Digits Forward (starting from three digits and increasing on each trial by one digit, up to nine digits), and Digits Backward (starting from two and increasing by one digit up to eight digits). Digits were read aloud, one digit per second, and responses were noted. There were two sequences for each length, and then the following longer sequence was read. Each sequence was read only once. The Digits Forward subtest was administered first, followed by the Digits Backward subtest. The score for each series is the longest sequence correctly recalled. Consistent with Gathercole's approach we thought that a difference score (Digits Forward minus Digits Backward) would reflect more purely the central executive component of working memory.

RESULTS

As mentioned above, the analyses of the present study are based on normative developmental data, collected on the same children's cohort previously reported, for four attention tests (Vakil et al., 2009) and the Rey AVLT (Vakil et al., 1998). Although in the previous reports norms are reported for every age group from 8 to 17 years, in the present study, based on the developmental trajectory, the sample was divided into two age groups: younger (8–12 years) and older children (13–17 years). The means and standard deviations of the different Rey AVLT and attention tests are reported in Tables 1 and 2, separately for the two age groups.

The first question we attempted to address is the relationship between verbal memory and attention. In order to test this relationship, a Pearson Product-Moment correlation analysis was conducted. Due to the large number of correlations, and the concern regarding type I error, the significance level was set at .01. The results are presented in Table 3.

Table 1 Means and Standard Deviations of the Rey AVLT Measures.

	List A Trial 1	List A Trial 5	Total Learning	List B Trial 6	List A Trial 7	List A Trial 8 (Delay)	List A Trial 9 (Recognition)	Temporal Order
Ages 8–12 years								
Boys	6.5	11.8	49.4	5.8	10.3	10.4	13.9	.73
	(1.8)	(1.9)	(7.8)	(1.8)	(2.4)	(2.5)	(1.8)	(.21)
Girls	6.7	12.2	51.1	5.9	10.6	10.8	14.0	.77
	(1.7)	(1.9)	(8.3)	(1.9)	(2.4)	(2.4)	(2.3)	(.20)
Ages 13–17 years								
Boys	7.2	12.6	53.8	6.5	11.3	11.2	14.0	.75
	(1.7)	(1.7)	(7.1)	(2.1)	(2.3)	(2.4)	(1.6)	(.20)
Girls	7.6	13.0	55.5	6.6	11.6	11.9	14.1	.76
	(1.8)	(1.4)	(6.9)	(2.1)	(2.1)	(2.1)	(1.8)	(.20)

Table 2 Means and Standard Deviations of the Attention Measures.

	Cancellation Part A One Target	Cancellation Part B Two Targets	TMT Digits	TMT Dual	Digit Symbol	Digit Span Forward	Digit Span Backward	TMT Dual-Digits	Cancellation Part B – Part A	Digit Span Forward – Backward
Ages 8–12 years										
Boys	100.8	132.3	36.4	90.6	55.9	7.5	5.8	52.7	31.5	1.7
	(33.3)	(54.7)	(16.6)	(47.3)	(16.6)	(2.3)	(2.4)	(35.1)	(30.8)	(2.3)
Girls	103.8	131.4	37.3	90.9	54.1	7.2	5.8	53.5	30.2	1.4
	(33.0)	(51.1)	(17.3)	(49.4)	(16.5)	(2.4)	(2.2)	(39.50	(36.4)	(2.0)
Ages 13–17 years										
Boys	93.9	120.6	36.3	89.0	61.3	7.3	5.7	52.9	25.9	1.6
	(34.9)	(55.7)	(19.0)	(50.3)	(17.3)	(2.2)	(2.1)	(38.7)	(28.4)	(2.3)
Girls	98.8	125.5	38.2	95.0	58.1	7.2	5.8	56.8	25.9	1.4
	(30.8)	(47.9)	(17.8)	(48.2)	(16.8)	(2.3)	(2.1)	(37.5)	(28.9)	(2.0)

Table 3 Correlations Between Attention Measures and Rey AVLT Measures, Across All Ages and Gender.

Rey AVLT ↓	Cancellation Part A One Target	Cancellation Part B Two Targets	TMT Digits	TMT Dual	Digit Symbol	Digit Span Forward	Digit Span Backward	TMT Dual-Digits	Cancellation Part B – Part A	Digit Span Forward – Backward
	–.11***	–.12***	–.11***	–.15***	.15***	.09*	.07	–.13***	–.08	.03
List A trial 5	–.13***	–.16***	–.11***	–.13***	.15***	.07	.08	–.13***	–.12***	–.01
Total Learning (Trial 1 through 5)	–.18***	–.19***	–.14***	–.13***	.21***	.12***	.11**	–.18***	–.14***	.03
List B trial 6	–.16***	–.16***	–.11***	–.15***	.15***	.14***	.13***	–.13***	–.07	.02
List A trial 7	–.13***	–.15***	–.09**	–.13***	.15***	.10**	.08	–.13***	–.12***	.03
List A trial 8 (20 min. delay)	–.11***	–.12***	–.07	–.13***	.14***	.09*	.10**	–.14***	–.11**	–.003
List A trial 9 (recognition)	–.01	.01	.04	–.003	.01	–.02	.01	–.03	.02	–.03
Temporal order	–.10**	–.10**	–.08	–.12***	.13***	.10*	.04	–.12***	–.05	.06

*$p < .01$. **$p < .005$. ***$p < .001$.

As can be seen in Table 3, 53/80 (66%) of the possible correlations between the attentional tests and the Rey AVLT measures reached significance. The only exception was the Rey AVLT recognition trial, which did not correlate with any of the attentional tests. Some of these correlations might simply reflect the contribution of age, as they both progress with maturation. Our next goal, therefore, was to analyze the contribution of age to these relationships, by conducting a partial correlation analysis, controlling for age effects. The results are presented in Table 4.

As can be seen from Table 4, only 12/80 (15%) of the possible correlations between the attentional tests and the Rey AVLT measures now reached significance. Two attentional tests stand out in their relationships with the Rey AVLT measures, after partialing out age effects: the Digit Span (forward and backward), and TMT measures: TMT Dual task and the TMT difference score (Dual-Digits). Digit Span measures correlated with List B Trial 6, whereas TMT measures correlated with List B Trial 6 as well as with Trial 1 and Total words recalled of List A. Digit Symbol and both cancellation tasks were not correlated with any of the learning measures of the Rey AVLT. However, they were related to the temporal order score of the Rey AVLT, as were the TMT Dual and difference scores.

The use of a different statistical approach consisting of a series of stepwise regression analyses, confirmed the significant role of age as a mediator between the attentional and memory measures. On each of these analyses, one Rey AVLT measure was the predicted variable and the different attentional measures and age were the predicting variables. Age remained the only significant predicting variable for all the Rey AVLT measures (β values ranging .25 to –.34, R^2 ranging .06 to –.14, $p < .001$), with the exception of recognition and temporal order measures, for which neither age nor the attentional measures reached significance.

Partial correlation analyses were performed between the attentional and Rey AVLT measures, this time separately for males and females, based on previous reports of female superiority in verbal learning and memory as noted in several studies (see Lowe, Mayfield, & Reynolds, 2003). We have also reported gender differences on attentional tasks (Vakil et al., 2009) and on the Rey AVLT (Vakil et al., 1998). As can be seen in Table 5 the relationship between attention and Rey AVLT measures in girls concerns only List A learning, whereas for the boys the relationship is manifest only in List B. For both groups, many attentional tasks are associated with the temporal order measure.

We reported earlier that age was the only significant predicting variable for all the Rey AVLT measures. At this stage we attempted to detect which attentional measures better predict verbal memory. To this end a series of linear regressions were conducted separately for the younger (8–12 years) and the older (13–17 years) children's groups, to examine possible similarity in their profiles of relations between verbal memory and attention. The attentional measures used were grouped into three sets constituted by measures among which intercorrelation did not exceed $r = .70$. Only the data for the younger group are presented on Table 6 because none of the attention measures reached significance in the older children group.

Table 6 indicates first that Cancellation A and B predicted all the Rey AVLT measures except Trial 1 and recognition. Second, both Trail Making subtests and Digit Symbol predicted Trial 1. Total Learning (which includes all five learning trials) was best predicted by Cancellation A and B, as well as by Trail Making B and Digit Symbol.

Table 4 Partial Correlations, Controlling for Age, Between Attention Measures and Rey AVLT Measures, Across All Ages and Gender.

Rey AVLT ↓	Cancellation Part A One Target	Cancellation Part B Two Targets	TMT Digits	TMT Dual	Digit Symbol	Digit Span Forward	Digit Span Backward	TMT Dual-Digits	Cancellation Part B – Part A	Digit Span Forward – Backward
List A trial 1	–.02	–.02	–.07	–.10**	.04	.05	.03	–.09*	–.01	.02
List A trial 5	–.03	–.05	–.05	–.07	.03	.02	.05	–.06	–.06	–.03
Total Learning (Trial 1 through 5)	–.05	–.07	–.07	–.11***	.06	.06	.06	–.11**	–.06	.01
List B trial 6	–.09	–.07	–.05	–.09*	.06	.11**	.09*	–.09	–.02	.02
List A trial 7	–.04	–.06	–.04	–.08	.04	.06	.05	–.08	–.06	.02
List A trial 8 (20 min. delay)	–.01	–.03	–.01	–.07	.03	.05	.07	–.09	–.03	–.01
List A trial 9 (recognition)	.01	.02	.04	.00	–.01	–.03	.01	–.02	.03	–.04
Temporal order	–.10*	–.09*	–.07	–.12***	.12***	.07	.03	–.12***	–.05	.05

*$p < .01$. **$p < .005$. ***$p < .001$.

Table 5 Partial Correlations, Controlling for Age, Between Attention Measures and Rey AVLT Measures, Separately for Males and Females Across all Ages.

Rey AVLT ↓	Cancellation Part A One Target	Cancellation Part B Two Targets	TMT Digits	TMT Dual	Digit Symbol	Digit Span Forward	Digit Span Backward	TMT Dual-Digits	Cancellation Part B – Part A	Digit Span Forward – Backward
Males (n = 416)										
List A Trial 1	–.01	.02	–.07	–.05	–.01	.03	–.00	–.03	.04	.03
List A Trial 5	–.02	–.02	–.09	–.08	.02	–.03	–.01	–.06	–.01	–.01
Total Learning	–.01	–.00	–.06	–.07	.02	.00	.00	–.06	.01	.00
List B Trial 6	–.10	–.06	–.08	–.13*	.09	.16***	.14**	–.12	.01	.02
List A Trial 7	–.03	–.03	–.08	–.05	.06	.03	.02	–.02	–.02	.01
List A Trial 8 (Delay)	–.02	.01	–.05	–.07	.05	.03	.05	–.07	.01	–.02
List A Trial 9 (Recognition)	.00	.03	–.00	–.02	–.02	–.01	–.04	–.03	.05	–.03
Temporal Order	–.08	–.09	–.11	–.15**	.12	.05	.02	–.14*	–.07	.03
Females (n = 396)										
List A Trial 1	–.05	–.07	–.09	–.16**	.12	.07	.06	–.15**	–.05	.02
List A Trial 5	–.05	–.09	–.02	–.07	.05	.07	.09	–.07	–.09	–.02
Total Learning	–.11	–.15**	–.08	–.17***	.12	.13	.10	–.17***	–.12	.04
List B Trial 6	–.07	–.08	–.03	–.06	.04	.05	.04	–.06	–.05	.02
List A Trial 7	–.04	–.09	.01	–.11	.02	.09	.05	–.15**	–.09	.06
List A Trial 8 (Delay)	–.02	–.06	.02	–.08	.01	–.00	.07	–.11	–.07	.09
List A Trial 9 (Recognition)	.02	.03	.08	.01	–.01	.00	.05	–.02	.02	–.06
Temporal Order	–.12	–.09	–.03	–.09	.13*	.11	.04	–.11	–.02	.09

*$p < .01$. **$p < .005$. ***$p < .001$.

Table 6 Summary of Regression Analyses for Rey (AVLT) Measures on Attention Measures (β Values) for Ages 8–12 Years.

	List A Trial 1	List A Trial 5	Total Learning	List B Trial 6	List A Trial 7	List A Trial 8 (Delay)	List A Trial 9 (Recognition)	Temporal Order
Set 1								
Cancellation A	–.007	–.20**	–.20**	–.16*	–.15*	–.17*	–.10	–.16*
TMT A	–.19**	–.07	–.09	–.43	–.006	–.02	.11	.03
Digit forward	.07	–.06	.03	.08	.03	–.01	–.04	.09
Digit backward	–.006	.05	.06	.08	.11	.14*	.06	–.003
Set 2								
Cancellation B	–.03	–.22**	–.24**	–.17**	–.22***	–.21**	–.05	–.21**
TMT A	–.20**	–.09	–.09	–.05	.006	–.02	.08	.04
Digit forward	.06	–.06	.02	.08	.01	–.02	–.03	.08
Digit backward	–.006	.04	.05	.07	.09	.13	.06	–.02
Set 3								
Cancellation A	.10	–.11	–.04	–.12	–.04	–.03	.01	.02
TMT B	–.17*	–.08	–.17*	–.07	–.06	–.09	.006	–.11
Digit forward	.04	–.08	–.001	.08	.01	–.02	–.45	.07
Digit backward	–.04	.03	.01	.07	.08	.10	.04	–.06
Digit Symbol	.20*	.14	.19*	.03	.12	.16	.08	.14

*$p < .01$. **$p < .005$. *** $p < .001$.

DISCUSSION

The present study sought to explore the relationships between the development of verbal memory, as measured by the Rey AVLT, and several attentional measures. As reviewed in the introduction, several researchers (Cowan et al., 1999; Gavens & Barrouillet, 2004; Towse et al., 2002) argue that memory development is dependent on attentional mechanisms and the increase of processing and storage capacity. The most significant finding in the present study is that the relationship between attention and memory is age dependent. Age is a very significant mediator of these relationships; controlling for the effects of age eliminated most of the associations initially found between attention and memory. Nevertheless, there are several relationships between specific memory and attention measures that remain even when the effect of age is taken into account. Interestingly, these relationships obtain only for the younger age group (8–12 years) and not in the older age group (13–17 years). For the younger children different attentional tests predicted different aspects of verbal memory. Furthermore, the specific memory and attention measures that remained related are different for boys and for girls.

Our finding that the relationship between attention and memory is age-dependent, suggest that these relationships change during development. As reviewed in the introduction, attention processes and capacity limitations affect several memory processes (e.g., Alloway et al., 2004; DeMarie et al., 2004). Attention is a basic cognitive process that continues to develop in younger ages and thus may affect other cognitive processes and abilities. When attention processes mature — around ages 10–11 (Klenberg et al., 2001) or 12 (Vakil et al., 2009) — memory processes may become less dependent on attention or less associated with it. A somewhat similar pattern of findings was reported by Tsujimoto, Kuwajima, and Sawaguchi (2007). In their study, they found relationships between measures of working memory (both visuospatial and auditory) and response inhibition measures in 5- to 6-year-olds; however, these relationships did not show up in the 8- to 9-year-olds. The authors suggest that these three tasks tap different neural structures in the lateral prefrontal cortex; with age, these structures mature and the functions they support dissociate. These findings are similar to ours, except for the fact that we also found significant relations at later ages. The fact that we examined different learning and memory processes might explain the age differences when dissociations between attention and memory emerged.

Thus, according to the partial correlation procedure in the girls' group, it was found that verbal memory measures primarily of List A (Trial 1, total words recalled, and Trials 7–8) were associated with attention measures (e.g., TMT difference score and Digit span). Some of these attentional processes are considered to reflect executive functions. For example, the difference score of the TMT has been found to account for a large proportion of variance in executive functions measures (Cheung, Mitsis, & Halperin, 2004). Therefore, it seems that the young girls in our study might have used effortful strategies while learning the words. This interpretation is supported by studies that examined gender differences in memory and indicated that memory performance activates different brain areas in males and females. In a functional Magnetic Resonance Imaging (fMRI) study of auditory working memory in adults, Goldstein et al. (2005) found that females showed a stronger activation of the prefrontal regions compared with males. There were no differences in memory performance, and the authors hypothesized that females activated these areas more strongly in order to prevent distraction. Alternatively, they suggested that the stronger brain activation found in females reflects activation of a single brain region, whereas males recruited a wider range of brain regions. A similar finding was reported by Ragland, Coleman, Gur, Glahn, and Gur (2000). They found that performance on the Logical Memory subtest of the Wechsler Memory Scale and the California Verbal Learning Test correlated more strongly with increased regional cerebral blood flow (rCBF) in the mid-temporal area in adult women, as compared to men. Nyberg, Habib, and Herlitz (2000), using Positron Emission Tomography (PET) neuroimaging, report stronger activation of the anterior cingulate gyrus during an episodic memory task in women than in men, possibly indicating more involvement of attention and executive processes. It is important to note that the differences in brain functioning exist despite lack of differences in performance, indicating perhaps that women exert more effort in performing these tasks. It seems, therefore, that the correlations found in the girls' group between learning List A and attention tasks indicate an increased effort and possible use of advanced mnemonic strategies invested by the young girls. This might also explain the superiority of girls over boys in verbal learning and memory, as reported in our Rey AVLT normative study (e.g., Vakil et al., 1998).

Unlike the girls, whose attention measures were associated with memory measures extracted from List A, in the boys' group, learning of List B (Trial 6) was associated with the attention measures (e.g., TMT difference score, both Digit Span measures). It has been argued that performance on Trial 6 is sensitive to the effects of proactive interference (e.g., Vakil et al., 1998). Effort and attention are needed to avoid this kind of interference, both during encoding and retrieval (Kane & Engle, 2000). It has also been found that activity in the prefrontal cortex serves to protect the content of working memory from interference (Postle, Brush, & Nick, 2004). Comparing the boys' and girls' groups, it appears that effort and attention were activated during different components of the Rey AVLT learning: Whereas girls allocated attention and effort during the learning of the first list, the boys' efforts were concentrated on minimizing the distracting effects of proactive interference that took place in the second list. It is important to note that in the normative studies on attention (Vakil et al., 2009) and verbal memory (Vakil et al., 1998) only the main effect for gender emerged, which was interpreted as reflecting a quantitative difference between boys and girls. The present findings suggest that there are qualitative differences between boys and girls expressed in a different profile of relations between memory and attention.

The findings of no relations between memory and attention in the older age groups (13–17) indicate that memory development in these age groups depends on factors other than attention: possibly more efficient strategies, wider knowledge base, language development, and more developed meta-memory (Gathercole, 1998; Ottem, Lian, & Karlsen, 2007; Schneider, 2002). It is well established that memory strategies and meta-memory develop rapidly during the elementary-school period and late childhood (Schneider, 2002; Schneider, Kron, Hünnerkopf, & Krajewski, 2004). Regarding neural maturation, it has been established that synaptic density and gray matter develop and increase during development. The first areas to show increase in synaptic density and gray matter volume are the primary sensory and motor cortices; then similar changes take place in the temporal and parietal associative areas, and finally in prefrontal and lateral temporal areas. It is argued that the last areas to mature mediate such functions as complex language, attention, inhibition, and executive functions (Amos & Casey, 2006). Gray matter volume in frontal areas reaches a peak at ages 10–12 years; it then undergoes pruning after adolescence

(Blakemore, 2008; Blakemore & Choudhury, 2006; Bunge & Wright, 2007). Relationships between prefrontal activity and executive functions have been found in several studies (see Yurgelu-Todd, 2007). White matter volume also increases during development and is also related to attention and cognition (Barnea-Goraly et al., 2005).

A different way of viewing the results was to apply a linear regression (as compared to partial correlation) to two age groups (as compared to the whole group). This approach enables us to assess the relative contribution of each attentional measure as a predictor for a variety of verbal memory measures. Consistent with the results obtained with partial correlation, for the older children's group, none of the verbal memory measures was predicted by the attentional measures. In contrast, for the young children's group different attentional measures predicted different verbal memory measures derived from the Rey AVLT. Immediate memory was significantly predicted by the TMT (digits and Dual) and by Digit Symbol, while the following verbal learning trials (with the exception of recognition) were consistently predicted by Cancellation (A and B). According to Cohen's (1993) multicomponent attentional model, the TMT represents the Response Selection and Control component while the Digit Symbol and the Cancellation tests represent a Sustained Attention component. Based on this model our results can be interpreted as indicating that immediate memory (i.e., first trial of the Rey AVLT) is associated with the Response Selection and Control component of attention and the following trials are associated with Sustained Attention. The fact that Digit Symbol made the same predictions as the TMT rather than Cancellation is inconsistent with Cohen's model.

The fact that specific memory measures were predicted by particular attention measures could provide us with an insight into the underlying cognitive processes of these memory measures. Total learning measure is a summary that sums up all first five trials. As such it reflects immediate memory as well as learning processes. Thus, it is not surprising that this measure was associated with several attentional measures. The temporal order measure extracted from the Rey AVLT (Vakil et al., 1998) is associated with most of the attention measures. A possible interpretation of this finding is that memory for temporal order has been shown to be associated with the functioning of the frontal lobes (Shimamura, Janowsky, & Squire, 1990). As mentioned above, many of the attention measures are also associated with the functioning of the frontal lobes as well.

The results of the present study indicate that different theories of memory development may speak to different ages: those that emphasize attention (and speed) are probably more relevant to younger age groups, and those involving "higher" cognitive processes (e.g., mnemonic strategies, meta-memory) are more relevant to older children and adolescents. This interpretation requires further research.

From a theoretical point of view, the most robust finding in the present study is that measures of verbal memory and attention were associated with each other primarily in the younger age group and much less so in the older age group. This finding is consistent with the "differentiation-dedifferentiation" hypothesis (e.g., Li et al., 2004). According to this hypothesis, in childhood cognitive abilities are undifferentiated, then go through differentiation at adulthood and again become undifferentiated in old age. One of the clinical implications of these findings is that attentional difficulties in younger children could be expressed (and misdiagnosed) as memory difficulties. Furthermore, specific attentional difficulties could be associated with specific verbal memory difficulties.

In conclusion, many of the relations initially found between the memory and attention measures are mediated by age. Furthermore, associations between memory and attention measures that obtained are found primarily in early age groups (8–12) but not in later age groups (13–17). In addition, boys and girls show a different pattern of results, with the girls' acquisition and retrieval performance more correlated with attention and processing speed, whereas boys' attention and effort related more to coping with proactive interference.

From a theoretical perspective, these findings provide us with an insight into the complexity of attention and memory interrelations and how they are modified by age. From a clinical perspective, these findings suggest that attention performance at an early age but not at a later age could predict memory performance, and vice versa. A challenge remaining for further studies is to determine whether the pattern of relationships between attention and memory reported here exists in other cognitive domains as well.

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