Developmental Psychology
2011, Vol. 47, No. 6, 1553–1564

0012-1649/11/$12.00 DOI: 10.1037/a0025623

The Development of Memory Efficiency and Value-Directed Remembering Across the Life Span: A Cross-Sectional Study of Memory and Selectivity

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Although attentional control and memory change considerably across the life span, no research has examined how the ability to strategically remember important information (i.e., value-directed remembering) changes from childhood to old age. The present study examined this in different age groups across the life span (N = 320, 5–96 years old). A selectivity task was used in which participants were asked to study and recall items worth different point values in order to maximize their point score. This procedure allowed for measures of memory quantity/capacity (number of words recalled) and memory efficiency/selectivity (the recall of high-value items relative to low-value items). Age-related differences were found for memory capacity, as young adults recalled more words than the other groups. However, in terms of selectivity, younger and older adults were more selective than adolescents and children. The dissociation between these measures across the life span illustrates important age-related differences in terms of memory capacity and the ability to selectively remember high-value information.

Keywords: memory, life span cognition, selective attention, metacognition, cognitive aging

The ability to selectively encode important information is an essential skill to successfully navigate one's environment throughout the life span. Selectively attending to important information, and then later recalling this high-value information, can be conceptualized as strategic control of attention and memory (Castel, 2008). Although a considerable amount of research has examined how episodic memory and working memory capacity changes across the life span (e.g., Bialystok & Craik, 2006; McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010), very little research has directly examined the life span trajectory of the ability to selectively remember important information. This ability has numerous implications, such as focusing on key concepts when studying for an exam, remembering highly relevant information about a person that you recently met, remembering to buy the most important grocery items when shopping, or focusing on important information when considering retirement plans. Theoretically, the ability to selectively remember information requires attentional control, goal maintenance, and inhibition of less-relevant information—processes known to change considerably with age (e.g., Balota & Faust, 2001; Waszak, Li, & Hommel, 2010; Zelazo, Craik, & Booth, 2004). In the present study, we examined how the ability to selectively attend to information that differs in value changes across the life span. This approach allows for not only the measurement of memory capacity, but more critically, the efficient use of memory when presented with situations in which high-value information should be remembered at the expense of lower value information.

More specifically, in the present study, we wanted to determine whether *memory capacity* (defined here as the amount of information that can be remembered—a form of memory quantity) is enhanced from childhood to younger adulthood, with declines occurring after middle age (see Park & Payer, 2006; Park et al., 1996). Relative to memory capacity, the ability to be selective about what one remembers may come "online" at later developmental stages, and younger adults and older adults may learn to be more selective relative to children and adolescents. This would lead to a much later decline in memory efficiency, relative to memory capacity, with age—and a potential developmental dissociation between the two measures. Thus, results from a life span sample can elucidate the developmental transitions regarding memory capacity, and the ability to strategically encode high-value information.

There are likely several interrelated factors involved in the ability to selectively encode information, including inhibitory control, memory capacity, and metacognitive monitoring. A great deal

This article was published Online First September 26, 2011.

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David P. McCabe passed away unexpectedly on January 11, 2011. He was a good friend, an insightful collaborator, and will be dearly missed.

This work was partially supported by National Institute on Aging Grants AG10145, AG03991, and AG05681, and a UCLA Faculty Career Development Award. We thank the many people who were involved in data collection.

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of research shows that inhibitory control changes dramatically across the life span (e.g., Bedard et al., 2002; Cowan, Naveh-Benjamin, Kilb, & Saults, 2006; Dempster, 1992; Durston et al., 2006; Zelazo et al., 2004). Many studies have found an inverted-U function best represents the changes observed in inhibitory processes across the life span (e.g., Cepeda, Kramer, & De Sather, 2001; Dempster, 1992; Hasher, Stolzfus, Zacks, & Rypma, 1991; Zelazo et al., 2004). Given the frequent need to direct attention to high-value information in the real world, and maintain this information in memory, the concept of value-directed remembering is critical throughout the life span. Thus, this value-directed remembering approach may be a more ecologically valid method to study how people use memory when information differs in terms of importance, relative to other more traditional tests of short-term or episodic memory. The ability to strategically focus on high-value information involves some awareness about how one can successfully allocate attention to these items, and it may be possibly to find dissociations between the selective control of memory and how much information one can successfully remember.

Metacognition refers to people's beliefs and knowledge about how memory works, and it can play an important role when deciding what and how much information one can accurately remember (Koriat, 2007). The metacognitive aspects of selectively remembering information are pertinent to the present study, as participants must learn to selectively encode high-value items, at the expense of lower value items. Recent research has shown that younger adults can successfully implement "agenda-based" memory operations (Ariel, Dunlosky, & Bailey, 2009; Castel, 2008), functions that may be related to attention and executive control (Adcock, Thangavel, Whitfield-Gabrieli, Knutson, & Gabrieli, 2006; Plude, Enns, & Brodeur, 1994). Specifically, participants can learn to attend to information that has a higher payoff (in terms of point values). Selective attention to high-value information may be impaired in children with traumatic brain injury and autism (Hanten et al., 2004; Hanten, Zhang, & Levin, 2002) in school-age children with attention-deficit/hyperactivity disorder (ADHD; Castel, Lee, Humphreys, & Moore, 2011) and in older adults with Alzheimer's disease (Castel, Balota, & McCabe, 2009). However, some previous work suggests that there are strategic processes involved in selective encoding that are not directly related to measures of memory (Castel et al., 2009). These strategic processes may be more metacognitive in nature, and possibly involve monitoring and control functions that occur after the encoding stage, such as using feedback regarding performance to decide how many items one should attempt to focus on and encode on a subsequent list. Thus, a form of metacognitive awareness may be involved when monitoring past performance in order to update resource allocation strategies for future memory tasks, and this may play different roles depending on the age of the participant and awareness of memory capacity.

Frontal lobe function may also play a key role in the selective encoding of high-value information, given the need to inhibit competing information and maintain task goals (Luciana & Nelson, 1998; West, 1996). There is a rich literature regarding frontal lobe development and impairments (Thomas et al., 1999; see also Stuss & Knight, 2002, for a review) and its relation to memory performance. The developmental time course of attentional control and related frontal lobe development should have a strong impact on selectivity, but perhaps less so on memory capacity, which may be more driven by hippocampal function (e.g., Raz et al., 2005; Stuss & Knight, 2002). If this is the case, then there may be important dissociations between these two measures (i.e., memory capacity and control regarding the encoding of high-value information) that may be especially pronounced during periods of substantial frontal lobe development and change (e.g., childhood, senescence). Thus, the present study provides a novel assessment of memory capacity and selective control, and could provide important insight regarding different developmental functions for these mechanisms. In the present study, we tested a large cross-sectional sample of healthy participants ranging in age from 5 to 96 years to assess how memory capacity and control may follow similar or different developmental trajectories.

The "selectivity task" differs from traditional measures of working memory in that it provides insight regarding how individuals selectively encode high-value information using strategic control. This novel task has been used in several studies with various populations (see Castel, Benjamin, Craik, & Watkins, 2002; Castel, Farb, & Craik, 2007; Hanten et al., 2007; Watkins & Bloom, 1999). In the present study, we used the selectivity task, asking participants to remember words paired with different values (i.e., points). The point value assigned to each item during encoding indicated the relative importance of each item. This procedure provides insight regarding the extent to which people use value-based information to guide the efficient use of memory (e.g., by intentionally recalling higher valued items). The task differs from traditional measures of episodic memory (e.g., a typical free-recall test) in that it examines how strategic control of attention can lead to the encoding of high-value information, often at the expense of lower value information.

In the selectivity paradigm, participants are presented with a series of word lists, with each word in the list having a distinct value ranging from 1 to 12 points. Participants are instructed to remember as many words as possible, with the goal of maximizing their score, which is the sum of the point values of each recalled word. After recall, participants are told their score and then are given a new list of words, again with instructions to maximize their score. Using a selectivity index (SI) developed by Watkins and Bloom (1999; see also Hanten et al., 2007), one can examine the ability to be selective, as well as how selectivity changes with task experience. This SI is based on the participant's score (the sum of the points that were paired with the recalled items, or the "value" of the recalled items), relative to chance and ideal performance. The equation accounts for the participant's score relative to an ideal score that represents recall of only the most highly valued words at that level of recall. For example, if a given participant remembered four words, and the points associated with the words were 12, 10, 9, and 8, that participants' SI would be considered quite high. The ideal score for four words is $12 + 11 + 10 + 9 = 42$, whereas the score of the participant in question is 39. A chance score is based on calculating the average value of the points (using a 12-word list, with numbers ranging from 1 to 12, the average would be 6.5) and multiplying that value by the number of words recalled (in this case, four). Thus, the SI in this case is $(39 - 26)/(42 - 26) = .81$. It is important to note that the index can range from $+1$ to -1. Perfect selectivity would result in an SI of 1.0, whereas selection of words with the lowest values (e.g., recalling the 1-, 2-, and 3-point words) would result in an SI of -1.0. A set of words recalled with no regard to their point values (i.e., showing no selectivity) would result in a selectivity index close to 0. Thus, the SI provides an efficiency index, which is based on one's actual score, relative to an ideal score, taking into account the number of words recalled.

Previous work using the selectivity task has shown that although healthy older adults recalled fewer words than younger adults, older adults enhanced their selectivity score (to levels similar to younger adults) by recalling high-value items (Castel et al., 2002). In addition, Castel et al. (2009) have shown that, despite recalling fewer items relative to younger adults, healthy older adults begin to develop a strategy (after about four lists) of focusing on the higher value items in order to maximize their score. This ability to be selective was found to be impaired in older adults with early signs of Alzheimer's disease (Castel et al., 2009). Using factor analyses with data from younger and healthy older adults, Castel et al. also found that low- and high-value items comprise distinct factors, suggesting that high-value items may load on a scale related to "high importance" span and that this capacity may be about five items for most age groups, but reduced for children with ADHD (Castel et al., 2011). Hanten and colleagues (2004, 2002 2004) also found deficits among children with brain injury and autism in terms of selectivity. Of significance to the present study, Hanten and colleagues (2007) observed that the number of words recalled and selectivity were independent in children, suggesting that perhaps different neural systems may contribute to memory capacity and the selective control of attention to high-value items. Thus, the SI provides a useful measure of memory efficiency that goes beyond simply measuring the overall quantity of recalled items (cf. Koriat & Goldsmith, 1996). These findings suggest an important distinction between memory quantity and efficiency may exist across the life span, and the present study represents the first direct and rigorous examination of this precise question.

The selectivity task can also provide a measure of how people learn which items to attend to across lists (i.e., with task experience). In this task, participants are presented with several lists, and after each list are given feedback about their score, which is the sum of the point values of the words that they recalled. In order to achieve an optimal score (via efficient use of memory), participants need to focus on or attend to the high-value items and recall them on the immediate memory test. The number of items presented in each list (i.e., 12) is greater than the typical memory span of an individual, so many participants learn that they cannot remember all of the items and, consequently, attempt to maximize their score by focusing on remembering only the most valuable items in each list. Participants typically learn to attend to high-value items, as reflected by the finding that the SI increases across successive lists and with task experience (Castel, 2008). The ability to selectively recall high-value items has been examined in children as young as 6 years old and has been shown to be impaired in children with traumatic brain injury (Hanten et al., 2004, 2007). However, to date, no study has directly compared how memory capacity and control/efficiency change across the life span in healthy individuals to determine whether these mechanisms follow similar or different developmental functions.

The present study provides a thorough examination of life span trends regarding memory capacity and the ability to efficiently control memory (i.e., selectivity). A large age range was sampled and tested using the selectivity task to determine whether memory and selective control are characterized by different developmental functions. Specifically, we compared the performance of six distinct age groups in the selectivity task in the present study: children (5–9 years of age), adolescents (10–17 years of age), younger adults (18–23 years of age), middle-aged adults (45–64 years of age), younger–old adults (young–old; 65–79 years of age), and older–old adults (old–old; 80–96 years of age; see Tse, Balota, Moynam, Duchek, & Jacoby, 2010, for a similar age grouping for older adults). Given the different mechanisms that may contribute to memory capacity and memory control, and how these abilities may emerge at different stages throughout the life span, the present study provides important insight regarding age-related differences in attentional control and the role of metacognition in a value-based memory task.

Several specific hypotheses were formulated on the basis of the present literature regarding memory capacity, and the ability to selectively attend to, and remember, important information. We predicted that memory capacity would be related to age to a certain degree, such that younger adults would display superior memory capacity relative to older adults. However, selectivity can be influenced by attentional control as well as metacognitive processes, such as the awareness of how to efficiently use limited memory capacity and effective strategy use. Previous research has shown that younger children often use several strategies, but not always effective strategies, when trying to encode information (Coyle & Bjorklund, 1997), and this may be related to an emerging sense of metacognition (Flavell, 1979). Thus, the ability to be selective may come "online" at later developmental stages, and younger adults and older adults, to a certain degree, may learn to be more selective relative to children and adolescents. This may be due to changes in frontal lobe capacity and inhibitory control, metacognitive monitoring, and/or the strategic allocation of attention to high-value information. A nonlinear life span developmental trend for memory capacity, with a peak in early adulthood, would suggest that younger adulthood is accompanied by intact and active reward/incentive systems that are engaged and responsive to incentives (Galván, 2010). However, for adolescents the prefrontal systems that are critical for the selective learning/memory component may still be relatively immature (Bunge, Dudukovic, Thomason, Vaidya, & Gabrieli, 2002; Luna et al., 2001), and this may lead to reduced motivational components of reward-directed behavior and poorer selectivity (Geier, Terwilliger, Teslovich, Velanova, & Luna, 2010). By contrast, in older adults, memory capacity begins to diminish considerably, but older adults may be able to "maximize" memory by strategically encoding fewer, but higher value, words (see also Castel, 2008). There is also evidence that, despite declines in overall memory performance, older adults can accurately predict what information they will later recall (Hertzog, Sinclair, & Dunlosky, 2010). This may suggest a much later decline in memory efficiency, relative to memory capacity, with age, and an observable and important developmental dissociation between the two measures. Thus, the results from a life span sample will provide insight into the specific developmental trends regarding memory capacity, and the ability to strategically encode high-value information.

Method

Participants

A summary of the sample size, mean age, percentage of male/female, and other background measures (where available) for each age group is presented in Table 1. The age groups differed in size, as in some cases data collection for the selectivity task was part of a longer study with different sample sizes. Given the need to recruit a wide array of participants across the life span, participants were recruited from major metropolitan areas in the United States as described in the following sections.

The child group was part of a larger, ongoing study of children with and without ADHD in a large metropolitan area in the western United States. However, none of the children in the present study had any ADHD diagnosis. Portions of the data on relatively healthy children without ADHD were part of a comparison group in previous research (Castel et al., 2011). All participants were administered a reading test to ensure a minimum threshold for reading ability. Those participants who fell below the cutoff were excluded from the present analyses. This procedure was previously discussed in Castel et al. (2011). The children were primarily recruited through advertisements mailed to local elementary schools, pediatric offices, and clinical service providers. Participants were excluded from the study if they had a Full Scale IQ < 70, or if they had ever been diagnosed with a pervasive developmental disorder, seizure disorder, or any neurological disorder that prevented full participation in the study. Participants were required to live with at least one biological parent no less than half time, and both parent and child were required to be fluent in English.

The adolescent group was part of a larger, ongoing study of neural development, consisting of participants 9–17 years old from a large metropolitan area in the western United States. Participants were recruited through advertisements in the community, schools, and various message boards. Participants were paid for their participation in the larger study.

The young adult group composed of undergraduate students from a private teaching and research university in the midwestern United States participated in return for course credit or were paid $10. The students reported to be in good health and did not report any neurological impairment or the use of medication that would alter cognitive function.

The middle-aged and older adult samples were recruited from an Alzheimer's center at a large research hospital in the midwestern United States, and a portion of these participants served as healthy control participants in previous research. All of these participants were seen by a physician and completed a battery of psychometric tests approximately once a year, and were screened by a physician for neurological, psychiatric, or medical disorders with the potential to cause dementia. The inclusion and exclusion criteria for a diagnosis of dementia have been described in detail elsewhere (e.g., Morris, 1993; Morris, McKeel, Fulling, Torack, & Berg, 1988) and conform to those outlined in the criteria of the National Institute of Neurological and Communications Disorders and Stroke—Alzheimer's Disease and Related Disorders Association (McKhann et al., 1984). Thus, it is important to note that all middle-aged and older adults in the present sample were thoroughly screened for dementia by a trained grouped of neurologists, so this sample represents an extremely healthy and likely high-functioning group of older adults (see the Mini-Mental Status Exam scores in Table 1).

Selectivity Task

In the present study, the selectivity task was used, in which words with different values (i.e., points) were to be remembered by the participant. Before participants began the selectivity task, they were told that they would be presented with lists of 12 words and that each word would be paired with a number (i.e., a point value) ranging from 1 to 12, which indicated how important it is to remember the word (e.g., much like a game in which the words are worth different amounts of money). Participants were told that each word and number would appear on the screen for 2 s, followed by another word and number. Participants were told that after they see each list of words, they will see the word "REMEMBER" on the screen, and that their job would be to remember as many of the words from that list as possible within 30 s with the goal of maximizing their score, which was the sum of the point values of each recalled word. They were told that they should pay attention to both the words and the numbers, even though it would be difficult to remember all of the words. Participants were told they just needed to say the word itself, and not the value of the word, and that the experimenter would record their response. They were told that the goal of the task was to earn as many points as possible by remembering as many of the high point value words as they could, although recalling any word would increase their score. To further emphasize the procedure, participants were told that this was like a "game" with words and points. For children, this was emphasized such that they were told that the more points that they earned,

Table 1
Sample Size, Mean Age, Percent Male, and Other Background Measures (Where Available and Appropriate) for Each Group

Variable	Children	Adolescents	Younger adults	Middle-aged adults	Young–old adults	Old–old adults
N	88	21	34	65	78	33
Age (*M*, *SD*)	8.14 (1.09)	14.52 (2.40)	20.34 (1.07)	56.66 (5.47)	71.42 (4.42)	84.70 (4.89)
Education (*M*, *SD* in years)	1.41 (1.08)	7.89 (2.38)	—	15.27 (2.24)	15.00 (3.04)	15.53 (2.66)
IQ (*M*, *SD*)	111.47 (14.72)	—	—	—	—	—
Male (%)	61	43	44	26	42	30
Mini-Mental Status Exam	—	—	—	27.55[a] (4.28)	27.91 (2.36)	27.17 (3.27)

Note. Dashes indicate missing value.
[a] Based on an incomplete sample ($N = 11$).

the more stickers they could earn (this was done to ensure children were aware that larger point values were more important). The experimenter provided each participant with examples of the scoring procedure, such that participants were made aware that their score would equal the sum of the point values of the words they recalled (e.g., if you recall three words [*table*, *donkey*, and *apple*] and these words were paired with the 8-, 10-, and 12-point values, then your score would be 8 + 10 + 12, which is 30). After being invited to ask any questions they had about the procedure, participants were presented with the first list and recall session, after which they were once again prompted to ask any questions about the procedure. After participants finished recalling items from each list, they were informed of the point total earned for that list. The participant then began the next list, and eight lists were presented during the session. For children, the stickers were given out only at the very end of a longer experimental session that consisted of many different tasks with similar rewards, and thus children were not given the stickers during the selectivity task.

Materials and Design

The words were presented visually, one at a time in 2-s intervals on the center of a computer screen in white Times New Roman 48-point font on a black background. The words in each list were high-frequency concrete nouns that contained between four and five letters (e.g., *ball*, *table*, *nose*), and were selected such that both children and adults would be highly familiar with each word (see Castel et al., 2009, 2011, for similar materials, and Balota et al., 2007, for the database used to access characteristics of the words). The words were randomly sorted into eight lists of 12 words. Each participant was shown eight lists and engaged in recall after each list. In each list, each word was randomly assigned a unique number between 1 and 12, and arranged such that a different value was present in each serial position for each list (to ensure that the higher and lower value words were well distributed across serial positions). To ensure that this was the case, the mean value of each word for each serial position ranged from 6.2 to 6.8.

Data analysis. A series of analyses of variance (ANOVAs) were conducted to examine group differences. For each test, the equality of variance assumption was tested using Levene's test (Levene, 1960). Following the results of this test, the analyses were either considered acceptable and Tukey's honestly significant difference (HSD) post hoc tests were run to examine pairwise differences in the six groups or an alternative test, the Welch F test, was used to examine the overall group effect, and the Games-Howell post hoc test (Games & Howell, 1976) was used to examine pairwise comparisons. All variables were examined for normality and were found to reasonably fit a normal distribution. In addition, five cases containing outliers were removed from analyses because either the number of words recalled ($n = 2$) or the number of intrusions ($n = 3$) fell at least three standard deviations outside the mean. One excluded case was from the child group, two from the younger adult group, and two from the old–old group.

Results

The selectivity task provides several measures of memory performance, including memory capacity (mean number of words recalled), sensitivity to value (how well one successfully recalls words on the basis of the point value of the words), and efficiency (the selectivity index, or SI). The results are presented below in terms of (a) overall recall performance and measures from the selectivity task as a function of age group, (b) the degree to which each age group was sensitive to point value, (c) performance as a function of the first and second half of the task, and (d) an exploratory factor analyses to examine the possibility that low- and high-value items would comprise distinct factors in the present study for each age group (cf. Castel et al., 2009).

A. Recall and SI

The main predictions centered on how recall and selectivity may vary with development. To compare the cross-sectional developmental trends for memory capacity and selectivity, the mean number of words recalled and the SI are shown in Figure 1. As is apparent from Figure 1, there are important similarities and differences for these two variables in terms of the overall shape of the functions, as well as the potential age-group differences. To examine this in more detail, we consider the mean number of words recalled and then turn to the SI.

In terms of number of words recalled by each age group, it appears that there was a curvilinear developmental age-group trend, with memory peaking in the younger adults and then systematically decreasing across middle age to old-old adults (see Figure 1). There was a main effect of age group for the average number of words recalled, $F(5, 309) = 34.63$, $MSE = 0.76$, $\eta_p^2 = .36$, $p < .001$. Post hoc tests showed that the younger adult and adolescent groups recalled more words relative to all of the other groups. The child group differed from all other groups except for the young-old and old-old groups, which did not differ significantly from each other. These groups had lower scores than the middle-age group, which had significantly lower scores than the adolescents and younger adults.

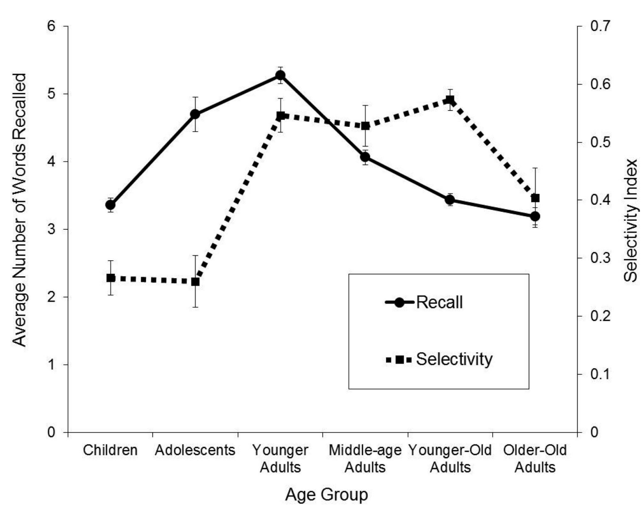

Figure 1. The average number of words recalled (on the left axis, represented as solid line in the graph) and the average selectivity index (on the right axis, dotted line) for the six age groups.

Turning to the main results regarding SI, consistent with the general predictions, there was a strong effect of age groups on SI.[1] There was a significant effect for age group in SI, $F(5, 97.93) = 21.03$, $p < .001$. The post hoc tests for group comparison revealed that children and adolescents had comparable performance, which was considerably lower than the young adults, middle-aged adults, and the young-old adults, which did not differ from one another—unlike the results for recall performance. However, relative to the younger-old group, the old-old group did exhibit lower SI. Thus, although recall was strongest in younger adulthood, the SI showed a different trend, with selectivity remaining stable across adulthood, and then declining slightly for the oldest age group. The different patterns of association across development revealed by these two measures suggest that memory capacity and the strategic control of memory are meaningfully different. In addition, to determine the degree to which selectivity and recall may be related, or represent distinct processes, a correlation between the number of words recalled and SI was conducted. These two measures were not significantly correlated ($r = .05$, $p = .38$). However, as would be expected given the design, the number of words recalled was strongly related to overall average score ($r = .89$, $p < .001$). These findings suggest the divergent validity of SI from measures of memory capacity.

We analyzed the overall average total score for each group, although total score performance does not necessarily provide any distinctly new information relative to the total number of words recalled and the SI, given that total score and number of words recalled are highly related. In terms of the average number of points accumulated via recall (i.e., score), there was a main effect of age group for the average score, $F(5, 309) = 38.51$, $MSE = 50.34$, $\eta_p^2 = .38$, $p < .001$. As a participant's average score is highly correlated with the number of words recalled, a curvilinear trend was also found for age group and average score, with average score peaking in younger adults. Tukey's HSD post hoc tests for group comparison showed that the younger adult group has significantly higher scores than all other age groups. The children had the lowest average scores, and differed from all other groups except for the old–old group. The adolescent group had significantly higher scores than the child and old–old groups, and did not differ from the middle-aged or young–old groups. The middle-aged group had significantly higher scores than the young–old group.

In addition to examining developmental trends across age groups, we examined age as a continuous predictor of the outcome variables of interest by centering age and testing in separate linear, quadratic, and cubic functions in multiple hierarchical regressions. For the average number of words recalled, a cubic regression produced the best fit, with the overall model accounting for 36% of the variance, $F(3, 308) = 57.41$, $p < .001$. Standardized beta weights for the final model with age, age squared, and age cubed were -1.50, -0.69, and 1.40, respectively (all $ps < .001$). A similar fit was found for age in the prediction of average overall score, $F(3, 308) = 55.63$, $p < .001$, $R^2 = .35$, as a cubic trend was also found to be the best fitting model, with age, age squared, and age cubed all significantly predicting score in the final model ($\beta = -1.14$, $\beta = -0.73$, and $\beta = 1.20$, respectively) (all $ps < .001$). For the prediction of SI, a quadratic trend fit best, $F(2, 309) = 37.10$, $p < .001$, with the final model accounting for 19% of the variance. Age and age squared each significantly predicted SI ($\beta = 0.34$ and $\beta = -0.26$, respectively, both $ps < .001$).

B. The Overall Effect of Value on Recall

Figure 2 displays the mean probability of recalling a word based on the point value of each word for the six age groups. An averaging, or smoothing, technique was used in Figure 2 (see Jones & Roediger, 1995) that takes into account the mean of neighboring point values. Overall, participants' recall was sensitive to point value, with higher value words being recalled more often than lower value words. The shape or slopes of these functions for each age group provides insight regarding the degree of selectivity, or sensitivity to value. To examine how the age groups were similar and different in terms of an effect of value on recall, we conducted a 6 (group) × 12 (word point value) repeated measures ANOVA. A main effect was found for group, $F(5, 309) = 34.77$, $MSE = 0.06$, $\eta_p^2 = .36$, $p < .001$. A main effect was also found for point value, $F(11, 299) = 79.12$, $\eta_p^2 = .74$, $p < .001$, indicating that overall, memory performance was influence by point value. The interaction of group and point value was also significant, $F(55, 1515) = 4.04$, $\eta_p^2 = .13$, $p < .001$, suggesting that the groups differed in the degree to which point value influenced recall, and this trend is illustrated in Figure 2. Given the large number of possible comparisons present in this interaction, we restricted our post hoc analysis to the comparison of values 1 and 12 by comparing the young adult group with other groups, using repeated measures ANOVA. These analyses determined that the young adult group had significantly greater differences in the probability of recall for words worth the least (value = 1) and greatest (value = 12) compared with the child, adolescent, and older–old groups. All other groups did not significantly differ from the younger adult group in this comparison.

C. Performance by Task Half

It was important to examine whether people improved in the task and to determine the degree to which people could learn to strategically focus on high-value items, especially after some experience with the task. It was expected that most groups should improve in selectivity with task experience and learn to strategically focus on higher value words in subsequent lists. In order to examine group performance across the task, we analyzed performance across the first half and second half within each group (Lists 1–4 = Half 1, and Lists 5–8 = Half 2) and conducted a repeated measures ANOVA to examine age group performance on each half. We combined the lists into task half for additional power, as was done in Castel et al. (2009). For the number of words recalled, there was a main effect of age group, $F(5, 309) = 34.63$, $MSE = 1.53$, $\eta_p^2 = .36$, $p < .001$. The number of words recalled was also found to vary by task half, $F(1, 309) = 7.31$, $\eta_p^2 = .02$, $p = .007$, such that slightly more words were remembered in the second half of the task relative to the first half (3.86 vs. 3.73, respectively). The interaction of group, point value, and

[1] The Levene's (1960) test revealed inequality in error variances between the age groups ($W = 7.65$, $p < .001$). Therefore, we ran Welch's variance weighted ANOVA. For post hoc group comparisons, the Games and Howell test was used to address the case of unequal variances.

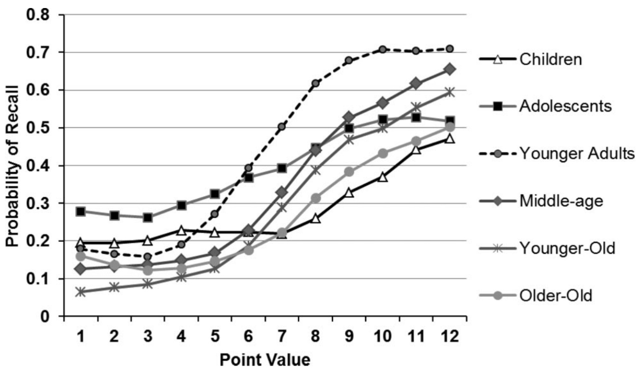

Figure 2. The average probability of recall as a function of the point value of the word for all lists for the six age groups.

half was also significant, $F(5, 309) = 7.85$, $\eta_p^2 = .11$, $p < .001$, indicating that age groups differed in the degree to which experience with the task influenced recall. As shown in Figure 3A, all groups recalled a greater number of words in the second half of the task compared with the first half, with the exceptions of the child and adolescent groups, both of which showed a slight decline in words recalled. A linear mixed model analysis allowed for an estimated intercept and slope for recall across the eight lists to be generated for each group. Consistent with the analyses for task half, both children and adolescents decreased in performance across lists ($B = -0.09$, $SE = 0.02$ and $B = -0.08$, $SE = 0.04$, respectively), and the estimated slopes did not differ from each other. All other groups displayed positive slopes, which significantly differed from the two younger groups ($p < .05$), but did not significantly differ from one another. This could have been a result of proactive interference or possibly a trade-off with being more selective, an issue that is discussed more specifically in the General Discussion section.

Examining selectivity across the task half, a main effect of age group was found, $F(5, 309) = 19.12$, $MSE = .12$, $\eta_p^2 = .24$, $p < .001$, as was a main effect for list half, $F(1, 309) = 62.76$, $\eta_p^2 = .17$, $p < .001$, such that selectivity significantly increased on the second half of the task relative to the first half (.50 vs. .38, respectively). A significant Group × Half interaction was also found, $F(5, 309) = 2.30$, $\eta_p^2 = .04$, $p = .045$. Figure 3B illustrates that all groups improved in SI across the task. As with words recalled, we conducted a mixed model analysis to examine potential changes in performance across all eight lists. The estimated slope (change in SI across lists) for the old-old group ($B = 0.06$, $SE = 0.01$) was significantly greater than children's ($B = 0.03$, $SE = 0.01$); however, no other significant differences were found among other group comparisons at the $p < .05$ level. Interestingly, even the two groups that showed fewer words recalled in the second half (the child and adolescent groups) also showed an increase in SI in the second half, which may suggest that these two groups learned to be selective, but at the cost of memory quantity. Additionally, the younger, middle-aged, and older adults showed an increase in SI, as well as an increase in number of words recalled across task half, possibly suggesting that a successful strategy was used early that did not compromise the total number of words recalled on later lists.

D. Exploratory Factor Analysis

According to the value-directed remembering framework (Castel, 2008), participants selectively encode items according to their (higher) value. If this is the case, and participants are limited in terms of how many items they can encode, low- and high-value items should comprise distinct factors. This has been shown in a previous study of younger and older adults, and children with and without ADHD (Castel et al., 2009, 2011). To examine the underlying structure of recalled word values, the average recall level of items of each value, 1–12, were submitted to an exploratory factor analysis (EFA). EFA reduces a large number of observations to a smaller number of factors based on similarities among those observations. In the present context, factor analysis can be used to examine whether the 12 items of differing values in each list could be empirically reduced to fewer factors and, furthermore, whether low- and high-value items created separate factors that could be distinguished from one another. We conducted an initial EFA on the entire sample, using principal components analysis and a varimax rotation, keeping factors with eigenvalues greater than one.

In the overall sample, the EFA distinguished two factors that accounted for a total of 52.16% of the variance in recall performance. The stronger of the two factor loadings for each item is highlighted in bold text in Table 2. In order to achieve sufficient

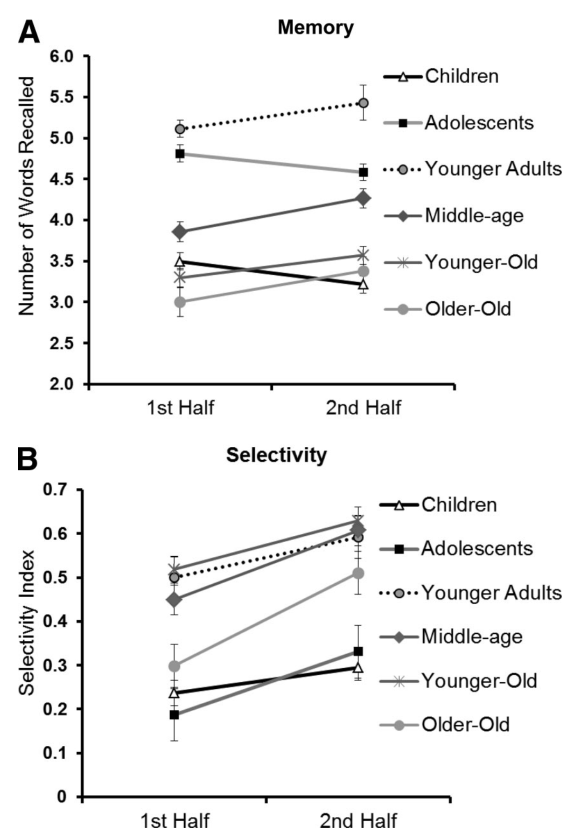

Figure 3. A: Average number of words recalled as a function of task half (Lists 1–4 vs. Lists 5–8) for the six age groups. B: Average selectivity index as a function of task half (Lists 1–4 vs. Lists 5–8) for the six age groups.

Table 2
Factor Analysis of Total Words Recalled as a Function of Point Value for all Groups Combined, the Younger Combined (Children, Adolescents, and Younger Adults), and Older Combined Groups (Middle-Aged, Young–Old, and Old–Old Adults), Showing the Two Primary Factors Underlying Recall Performance

	All groups		Children, adolescents, and younger adults		Middle-aged, young–old, old–old adults	
Point value	V1–V6	V7–V12	V1–V6	V7–V12	V1–V7	V8–V12
Value 1	**.67**	−.15	**.70**	.09	**.51**	−.44
Value 2	**.69**	−.15	**.79**	.01	**.53**	−.38
Value 3	**.70**	−.17	**.73**	−.15	**.74**	−.14
Value 4	**.72**	−.17	**.71**	−.11	**.73**	−.22
Value 5	**.74**	.02	**.72**	.03	**.74**	.02
Value 6	**.58**	.36	**.57**	.50	**.51**	.13
Value 7	.50	**.50**	.45	**.60**	**.59**	.22
Value 8	.07	**.73**	.18	**.79**	.22	**.60**
Value 9	.03	**.79**	.07	**.85**	.16	**.67**
Value 10	−.14	**.70**	−.06	**.77**	−.11	**.69**
Value 11	−.25	**.72**	−.19	**.81**	−.10	**.69**
Value 12	−.34	**.58**	−.18	**.64**	−.28	**.64**
% variance	27.31	24.84	27.55	30.43	24.59	22.01

Note. The stronger of the two factor loadings for each item is in bold text.

power, and to examine age-related differences, it was necessary to create two "combined" groups: The younger group comprised of the children, adolescents, and younger adults, whereas the older group comprised the middle-aged, young–old, and old–old adults. The factor loadings can be interpreted as the strength of the relationship between that item and the factor, in much the same way that a correlation coefficient would be interpreted. As shown in Table 2, the first factor included items of Values 1–6, and the second factor included items of Values 7–12. Thus, based on the pattern of recall across all individuals, there was a clear division between the six highest value items and the six lower value items. A two-factor solution was then applied to the two age groups. As shown in Table 2, the findings from the overall sample are consistent with the factor loadings for the two age groups, with one minor difference: The older group displayed slightly fewer items (Value 8–Value 12 compared with Value 7–Value 12 for the younger group) in the higher value factor. This likely reflects age-related differences in memory performance that was evident in the task, but it is important to note that both groups showed a similar division in terms of two distinct factors related to high and lower values.

General Discussion

In the present study, we examined how a life span sample performed on an incentive-based memory selectivity task in order to determine whether there were different developmental functions for memory capacity and memory selectivity/control. In general, the results suggest that overall memory capacity and the ability to selectively encode high-value items are empirically distinct, and appear to follow different developmental trajectories. As can be seen in Figure 1, whereas memory capacity peaked in young adulthood, the ability to selectively remember high-value information improved from childhood to young adulthood, and remained stable from middle to old age, with some decline in very old age. The dissociation between memory capacity and selectivity provides insight regarding distinct mechanisms that can guide memory efficiency. Although memory capacity develops with age, and reaches its peak in younger adulthood, the ability to focus on high-value information appears to show a different trend. It may be that the strategic and metacognitive skills needed to use memory in an efficient fashion come online later in development and remain relatively intact as one ages, and this can then supplement changes in memory capacity, allowing older adults to focus on high-value items despite reductions in memory capacity.

Importantly, it appears that all groups in the present study "learned" to become selective with task experience, suggesting that each group understood the task instructions and implemented some degree of value-directed remembering. In addition, all groups were able to maximize their score with successive study-test cycles, and this may be due to the use of feedback and monitoring performance. However, we cannot assume that similar factors/processes underlie these performances. In terms of differences in age groups, older adults may learn to adopt a "less-is-more" approach to the task with experience, as they are aware of deficits in overall memory capacity (a form of metamemory). Adolescents and children may be more inclined to attempt to encode as many words as possible, but this approach could potentially lead to poor selectivity if certain high-value words are forgotten at the time of test. Thus, metacognition, and more specifically, awareness of memory capacity, may play a key role in the present task, and this could be one reason for the different developmental functions for memory capacity and selectivity. In addition, there may be important trade-offs with memory capacity, such that when one attempts to focus on higher value items, this comes at the cost of remembering fewer items. Some evidence of this potential trade-off could be observed in the adolescent group, who showed an increase in SI in the second half of the task, but relative to the other groups showed a decline in number of words recalled in the second half. Thus, although all groups showed a modest gain in SI with task experience, for adolescents (and, to a lesser degree, the younger–old group) this gain may have come at the cost of remembering fewer words. This may suggest that for these individuals, greater/additional attentional resources are needed to maintain adequate goal maintenance, and to ensure that high-value words are given priority processing, relative to the lower value words.

These findings have important implications for theories of cognitive control, frontal lobe development, and models of memory. Early childhood and adolescence is accompanied by development of the frontal lobes and memory capacity into early adulthood (Luciana & Nelson, 1998; Welsh, Pennington, & Grossier, 1991), and this change may lead to good memory capacity but not necessarily good metacognitive skills (Flavell, 1979; Shin, Bjorklund, & Beck, 2007). Adolescence has also been associated with greater risk taking, due to various changes in the accumbens relative to frontal development (e.g., Galván et al., 2006; Galván, Hare, Voss, Glover, & Casey, 2007), which could lead to more risk taking or overconfidence in memory (Shin et al., 2007). In the present study, these changes could result in the relatively poorer SI in children and adolescents compared with younger adults. At the other end of the developmental spectrum, it is well documented that the volume of the frontal cortex declines in late adulthood (Raz et al., 2005). However, it is interesting to note that in the present task, older adults were still able to perform well in terms of selectivity, but not capacity (see also Castel et al., 2002), possibly compensating for declines in memory by using a form of "selective optimization with compensation" (see Baltes & Baltes, 1990; Hess, 2000; Riediger, Li, & Lindenberger, 2006). In this framework, Riediger and Freund (2006) suggest that a form of "motivational" selectivity may involve two forms: (a) focusing on high-value or important information while also (b) restricting the access of lower value or more peripheral information. This seems relevant to the present finding, as some older adults were able to successfully focus on high-value information, while inhibiting the encoding of lower value information. However, children and adolescents were not as successful in this regard, as well as the oldest adults, possibly due to declines in frontal lobe function and lack of sufficient metacognitive monitoring.

The present task allows for an important comparison and dissociation between memory capacity and the ability to selectively encode high-value information. Although the evidence from the present study suggests different developmental functions for these abilities, this may also map on to the difference in the development of frontal and medial-temporal structures in the brain. For example, one issue is whether the patterns found for memory capacity and selectivity mirror hippocampal and prefrontal cortex development, respectively, and/or the connections between systems. Neuropsychological memory models developed by Moscovitch and Winocur (1992; see also Moscovitch, 2000) suggest that the frontal lobes and hippocampus are critically involved in executive control and memory tasks. More specifically, they outline the "working-with-memory" hypothesis, which suggests that the frontal areas are more involved with mediating strategic processes that support memory encoding and monitoring, whereas the hippocampus "works" with the frontal cortex to bind and retain information. Thus, the different developmental trends found for selectivity and memory capacity may represent differences in the functionality and connections between frontal and hippocampal regions, and these connections are what change with age. This provides an important potential link regarding life span development, behavioral changes in selective encoding and memory, and neuropsychological changes in "working-with-memory," which may reflect differences in the development of the frontal cortex and hippocampus.

In terms of theoretical accounts of memory capacity and the strategic control of encoding operations, the exploratory factor analysis revealed two distinct factors related to recall of high- and low-value items. Generally, the six highest value items loaded on one factor and the six lowest value items loaded on another, and this trend was present for the younger groups, and also for the older adult group (although slightly reduced for the higher value factor). A similar trend has been found for children, and younger and older adults in other studies (Castel et al., 2009; Castel et al., 2011). This factor structure can also be seen, to a certain some extent, by a visual inspection of Figure 2, which shows a relatively flat recall function for low-value items for all groups, with a sharp increase in recall somewhere between items of Values 5–7. The present findings from the EFA suggest that perhaps there is both a capacity limitation and a strategic component to the ability to encode high-value items. People are strategic in terms of focusing on higher value items, which may reflect accurate metacognitive monitoring, and this high-value factor may represent the capacity of a memory store that is exclusive for high-value information (e.g., a "high-value" memory buffer). However, in general, the results from EFA should be treated with some caution given the need to combine the different groups to achieve sufficient power.

The ability to selectivity remember important information likely involves several stages, including the encoding of high-value items (and ignoring lower value items), storage of high-value items, and strategic retrieval of high-value information. Although it seems likely that selective encoding may play an important role, and participants may become more selective about what they try to encode in later lists, it remains an open question regarding how encoding, storage, and retrieval contribute to overall selectivity. Castel et al. (2002) used an adapted procedure in which the value of each item was presented only after participants' read each word, ensuring some general encoding of each item, and this resulted in somewhat lower overall selectivity relative to when items and value were present simultaneous (like in the present study). Also, we tested memory used in immediate free recall, and future research could examine whether there are age-related differences for long-term memory of high-value information, and whether different tests of memory (recognition, cued recall, or saving/priming) might yield insight regarding the role of storage and retrieval dynamics that might influence selectivity and value-directed remembering.

Point values were used in the selectivity task to indicate which words were worth more, and this was made clear to children by indicating that the greater number of points they earned, the more stickers they could obtain at the end of the study. In addition, participants were told that points were like a form of currency or money, such that it was important to attend to words paired with high values. These instructions were included to indicate that higher points were more desirable (and to avoid confusion that lower value might indicate priority), and more generally to ensure participants understood task instructions. However, this does raise the point of how motivation could influence performance, and perhaps using different reward structures (especially rewards that are salient/relevant to specific age groups) could yield insightful results. In addition, all participants were given the same presentation rate when studying each word, but this rate of 2 s per word could create potential challenges for children and older adults to effectively encode information, relative to younger adults. In the present study, we felt it was important to keep the task parameters constant to allow for direct comparison across all age groups. Future research (see also Castel, 2008) should assess how relevant rewards, adjusted presentation rates, self-paced study (e.g., Ariel et al., 2009), or the selection of high-value information (e.g., McGillivray & Castel, 2011) might have important effects on how people attend to what is either objectively or subjectively defined as "high-value information." In addition, it would be interesting to examine how selectivity is related to memory performance for a list of words without values to determine whether having to attend to value presents a trade-off with encoding operations, and to more fully examine individual differences.

It is important to note that the older adults in the present sample were thoroughly screened for dementia (Morris, 1993) by a trained grouped of neurologists, so this sample likely represents an extremely healthy and high-functioning group of older adults. Although this may not represent a typical random sample of older adults, due to the nature of the sample it is possible to ensure that the developmental changes that are reported in the present study are due to healthy aging, as opposed to pathological aging and dementia in the older–old group (see also Tse et al., 2010). In addition, the present design was cross-sectional, whereas (in some ways) a longitudinal design would allow for stronger conclusions regarding how selectivity *changes* with age (as opposed to examining age-*related* change). However, we feel that any potential cohort effect would be relatively minimal given the nature of the task and that the use of a longitudinal design, with repeated testing sessions, might actually lead to practice effects with regard to selectivity. Although training effects would be an interesting future direction, the present study attempts to map the developmental trends regarding memory capacity and selectivity, providing useful insight for further work in this domain that could include a more diverse sample, such as children with learning disabilities or patient groups that may potentially benefit from training schedules.

In summary, the present study shows that different developmental functions exist regarding memory capacity and the ability to strategically encode high-value information. There are very few studies in which developmental changes regarding the ability to selectively remember information are examined, and the present study provides novel insight regarding age-related differences in the ability to selectively attend to high-value information, and how this might change across the life span. Future research could address age-related differences in the role of encoding, storage, and retrieval operations in value-directed remembering, and how selectivity involves metacognitive monitoring that is learned with both feedback and task experience. In addition, there may also be transfer of these skills to other domains, which would provide important insight regarding the degree to which selectivity is a domain-general or task-specific skill. The present study demonstrated that memory capacity (or memory quantity) and the selective and strategic control of memory (selectivity or memory efficiency) follow different developmental functions, and this dissociation has important applied and theoretical implications for the study of memory, selective attention, and metacognition. Learning to attend to important information, sometimes at the expense of less valuable information, is a critical skill that requires the strategic control of memory, and there are important age-related differences in this ability.

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Received August 12, 2010
Revision received June 30, 2011
Accepted July 19, 2011 ■