

Life Span Changes in Visual Enumeration: The Number Discrimination Task

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Participants from 5 groups with mean ages of 6, 8, 10, 22, and 72 years were tested on a series of speeded number discriminations: 1 vs. 2, 3 vs. 4, 6 vs. 7, and 8 vs. 9. The primary measure of interest—response time slope as a function of number size—decreased with age for numbers in the 1–4 range. However, a U-shaped age function emerged in the 6–9 range, with larger slopes for children and senior adults, and the smallest slopes for young adults. These data suggest that different processes are involved in enumerating small and large numbers of items. It is argued that subitizing, the process for small numbers, makes only minimal demands on spatial attention and thus shows developmental improvements without any decline in old age. In contrast, counting, the process for large numbers, requires sophisticated coordination of spatial attention, which has previously been shown to first improve and then decline over the life span.

This article examines the ability of children, young adults, and senior adults to enumerate spatial arrays of identical items, as measured by a number discrimination task. Visual enumeration has been studied in its own right for more than 100 years (Jevons, 1871). More recently, enumeration has been studied extensively in two disparate areas: the attentional mechanisms involved in the perception of multiple-item displays (e.g., Beck, 1972; Folk, Egeth, & Kwak, 1988; Francolini & Egeth, 1979, 1980; Mozer, 1989; Rock, Linnett, Grant, & Mack, 1992; Sagi & Julesz, 1984; Trick & Pylyshyn, 1993, 1994b); and the development of number concept in children (e.g., Chi & Klahr, 1975; Gallistel & Gelman, 1991; Gelman & Gallistel, 1978; Klahr & Wallace, 1976; Starkey & Cooper, 1980; Svenson & Sjoberg, 1978; van Loosbroek & Smitsman, 1990). However, visual enumeration has not been studied systematically in late adulthood, nor have systematic comparisons been made across the life span. Such data could contribute both to theories of enumeration and to theories of life span development. To develop this argument, we will begin with a brief review of theories of enumeration, including one that has grown out of a more general theory of visual attention (Trick & Pylyshyn, 1994b). We will then consider how enumeration might be expected to change with age from this perspective.

Theories of Enumeration

Jevons (1871) observed that enumerating small numbers seemed to happen “all at once” with very little error. In con-

trast, enumerating larger numbers was laborious, sequential, and error prone. Most adults seemed to scan the display area by area, enumerating the items within an area, adding this sum into a running total, and then moving to the next items, a process that has since been termed *group and add* (Klahr & Wallace, 1976).

Subsequent research has revealed that these phenomenological differences are accompanied by different patterns of response time (RT). In a typical task, participants are presented with a spatial array of items and required to state the total number of items as rapidly and accurately as possible. RT is plotted as a function of the number of items, as shown in Figure 1. When there are only a small number of items (up to 3–5 for most adults), the slope of the RT function is shallow (40–100 ms per item). When there are larger numbers (5 or more), the slope is much larger (250–300 ms per item). This difference in slopes produces an “elbow” in the RT function.

Subitizing is the term given to the cognitive processes involved when the slope is shallow, and the *subitizing range* is thus the range over which this shallow slope remains linear. *Counting* is the term applied to the cognitive processes involved when the slopes are steeper, and the *counting range* refers to the numbers of items that are beyond the elbow in the RT function. (It is unfortunate that counting has become the term for this subfunction, since it is also commonly used to refer to performance over the entire range of numbers.)

Although subitizing and counting have been studied for a long time, there is still no consensus on what these data mean. According to one-process theories, subitizing and counting involve the same cognitive operations (e.g., Balakrishnan & Ashby, 1991). For example, Gallistel and Gelman (1991) propose that subitizing and counting differ only in the form of the mental representation used in selecting a number name. Subitizing is fast because rapid mappings can be made from preverbal to verbal representations for small numbers of items. The inaccuracy of the preverbal representation for large numbers makes it necessary for participants to rely on verbal representations, which

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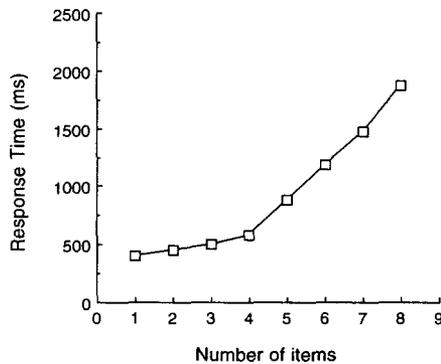


Figure 1. Idealized mean response time in a visual enumeration task as a function of the number of items.

are impeded by the slow process of subvocal number name retrieval (verbal counting).

There are also theories premised on different perceptual processes for subitizing and counting. Some of these capitalize on display characteristics that are confounded with number. According to *density* theory (Atkinson, Campbell, & Francis, 1976), there are phase sensitive spatial frequency units in the visual cortex that can be used to infer number, but only for small numbers of items (low densities). According to *pattern* theory (Mandler & Shebo, 1982), participants use the pattern of the items to infer number for small numbers of items: One item forms a point, two form a line, three usually form a triangle. By the time more than five items are present, each number no longer has a unique pattern associated with it.

Klahr and Wallace (1976) suggest that different processes are required for subitizing and counting because of limitations in visual short-term memory. Subitizing occurs for items within the capacity of the memory buffer (up to four or five items). Counting occurs when item number exceeds this capacity, meaning that the buffer has to be continually reloaded, requiring extra operations.

Although each of these theories has its unique limitations (Trick & Pylyshyn, 1994b), all fail to explain why attentional factors dictate whether subitizing occurs. Participants can subitize complex multiple contour objects of varying sizes; they can subitize O's in X distractors, and items of one color or orientation amidst a variety of distractor items. However, when spatial attention is required to resolve the item as a whole (as required for nested concentric items) or distinguish the items to be enumerated from distractors (as required to enumerate O's in Q's, items connected by a line, or items with a particular conjunction of orientation and color), then subitizing does not occur (Trick & Pylyshyn, 1993). For these stimuli, the slope discontinuity in the RT function, indicative of the change from subitizing to counting, is absent; RT slopes are uniformly high throughout the number range, as if the counting process were used for both large and small numbers of items.

The Fingers of INSTantiation (FINST) Theory of Enumeration

Only a theory that acknowledges the role of preattentive and attentive visual processes can account for these results. Before

an item can be enumerated, it must first of all be distinguished from its background and other items. Thus, enumeration begins with image analysis, and in particular, with the spatially parallel (preattentive) processes of feature detection and grouping. Display regions that differ from their surround in brightness or color are represented by their bounding contours; nearby and similar contours are grouped together into clusters. The available data indicate that only a small number of such clusters can be assigned reference tokens, which Pylyshyn (1989) has called FINSTs. The purpose of these reference tokens is to select certain clusters as future targets for the attentional focus; therefore they must be identified separately or "individuated." These tokens can then be used to compute spatial relations such as *connected*, *inside*, or *to the left of* (Pylyshyn, 1989; Trick & Pylyshyn, 1994b; Ullman, 1984), to track multiple target items as they move among identical moving distractors (Pylyshyn & Storm, 1988), and to move the attentional focus deliberately from one item to the next in a multielement display (Trick & Pylyshyn, 1994b).

Enumeration occurs when these reference tokens are used to produce a numerical response. If there are only a small number of items in a display, each item can be assigned a unique token. A number name can then be accessed by simply matching each assigned reference token to a name. Thus, subitizing requires one operation over and above the usual processes involved in selecting a small number of targets for attention—that of retrieving a number name for each assigned reference token so that the final correct numerical response can be produced. This response selection process seems to be the source of most of the subitizing slope because in studies where the measure is the requisite exposure duration to achieve a certain level of response accuracy, the slope all but disappears (Oyama, Kikuchi, & Ichihara, 1981). In such studies, participants choose their response after the timed portion of the trial has ended, and thus response selection processes are not reflected in the slope.

Counting occurs when the number of items exceeds the number of available reference tokens, and it is necessary to reuse the same tokens. This requires moving the attentional focus through the display in a deliberate and strategic fashion, reassigning the reference tokens in each new area, and mentally "marking off" the already enumerated items so the attentional focus does not visit them again (Ullman, 1984). Counting also requires extended memory functions (e.g., temporarily storing the current total) and mental addition (e.g., incrementing a counter). Both of these processes are subject to error, even in adults. For example, when enumerating a large number of items it is easy to "get lost" in the display, and thus miss or recount items, or have to start all over; the "marking" process is one source of error. Second, it is easy to forget the running total, or to make a mistake in addition, especially when there are disruptions to working memory. For example, it is very difficult to enumerate large numbers of items when someone is pronouncing number names in the background. Counting is thus a more complex process than subitizing, and consequently, more time consuming and error prone.

Predictions for Enumeration over the Life Span

Elderly participants and children typically have a higher mean RT than college-aged participants in any speeded task

(Wickens, 1974). The more pertinent measure for this study is the slope of the RT function in the subitizing and counting ranges. How might subitizing and counting slopes be expected to change with age? Subitizing involves registering the targets as items, individuating them, and selecting the appropriate number name response. With the exception of response selection, most of the current literature suggests that these processes change little with age. For example, visual feature search is comparable in children, senior adults, and young adults (Plude, Enns, & Brodeur, 1994) and even very young infants can distinguish between two and three items when pattern and density factors are controlled (e.g., Starkey & Cooper, 1980; van Loosbroek & Smitsman, 1990). Therefore, the reported decline in the subitizing slope during childhood (Chi & Klahr, 1975; Svensson & Sjoberg, 1978) may reflect improving efficiency in retrieving number names from memory and matching them to individuated items in order to select a response. Once the process of retrieving number names from memory is overlearned, however, there is no reason to expect it to deteriorate with normal aging, and consequently, no reason to expect the subitizing slope to increase again for senior adults. Thus, the subitizing slope should decline with age to adulthood, and then stabilize.

The counting process involves a number of operations in addition to those of subitizing, including moving the attentional focus from location to location. Life span studies indicate that both younger and older participants are often less efficient than young adults in performing attentional tasks (Plude et al., 1994). For example, both groups require more time to move the attentional focus in response to an abrupt onset cue (Brodeur & Enns, 1994), they have steeper RT slopes in visual search tasks that require the combining of separate features (Trick & Enns, 1995), they have more difficulty filtering out extraneous material when making a response (D'Alosio & Klein, 1990; Enns & Akhtar, 1989), and they are less likely to make use of strategic inhibitory operations when moving the attentional focus (Connelly & Hasher, 1993). The literature on life span changes in attention, together with the FINST-based account of the role of attention in counting, would thus predict that counting slopes should be higher for both elderly participants and children than they would be for young adults.

In this study, we used a number discrimination task to study the processes of enumeration. The key feature of this task, relative to the standard task in which participants must give one of many verbal number responses, is a large reduction in response uncertainty. In number discrimination, participants decide between only two responses: numerosities n or $n + 1$. Although this task yields the same basic pattern of RT over the number of items, RT slopes tend to be somewhat lower (cf. Folk et al., 1988; Trick & Pylyshyn, 1994b), consistent with the hypothesis that standard enumeration slopes are inflated by response uncertainty. Given that we are not interested here in the effects of response uncertainty, and that other life span studies of attention tend to use a small number of response alternatives, number discrimination was the task of choice.

Method

Participants

A total of 98 participants were tested, representing five different age groups: 6-year-olds ($M = 5$ years 9 months, $SD = 1.8$ months; $n = 9$, 5

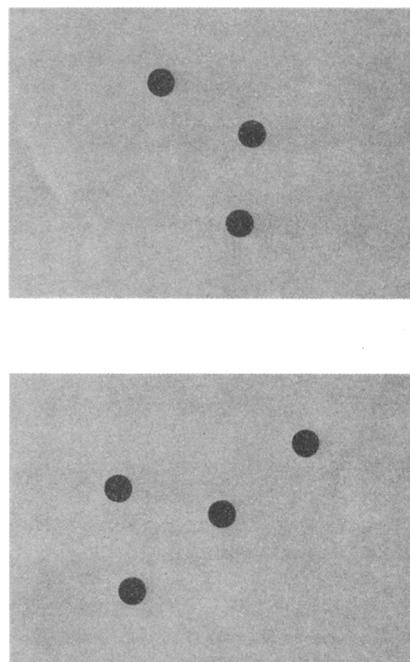


Figure 2. Examples of visual displays in the three versus four discrimination condition.

boys and 4 girls); 8-year-olds ($M = 8$ years 3 months, $SD = 5.1$ months; $n = 18$, 11 boys and 7 girls); 10-year-olds ($M = 10$ years 5 months, $SD = 9.8$ months; $n = 27$, 15 boys and 12 girls); 22-year-olds ($M = 21$ years 8 months, $SD = 31.1$ months; $n = 20$, 10 men and 10 women); and 72-year-olds ($M = 71$ years 11 months, $SD = 67.4$ months; $n = 24$, 7 men and 17 women). The children were all volunteers from public schools in the Vancouver and Richmond school districts; the young adults were members of the University of British Columbia participant pool and received partial course credit; the senior adults were recruited through advertisements in the local paper and were paid \$10 an hour for their participation. All participants were healthy, all had normal or corrected-to-normal vision, and none of the senior adults had received a diagnosis of glaucoma or cataracts. Subjects were not tested if they could not reliably count nine items in the practice trials, or if they did not complete all conditions of the number discrimination task.

Apparatus and Stimuli

The experiment was conducted on a Macintosh computer using the VScope software (Enns & Rensink, 1992), which permits response timing accurate to within 8.3 ms. The items to be enumerated were black dots (0.8° visual angle) on a gray background screen ($9.6^\circ \times 6.4^\circ$ visual angle) viewed from 50 cm. Items were located on an imaginary grid of six columns by four rows and were jittered by $\pm 0.5^\circ$ to prevent the appearance of item colinearity. The maximum and minimum possible distance between items was thus 0.6° and 2.6° , respectively, in the horizontal and vertical directions. Two sample displays from the 3 versus 4 discrimination are presented in Figure 2.

Procedure

Participants indicated whether there were n or $n + 1$ dots in the display by pressing one of two adjacent keys labeled with the appropriate digits. The key for the smaller number was on the left; the key for the

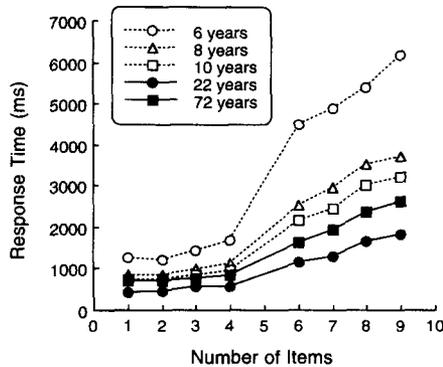


Figure 3. Mean correct response time in the number discrimination task as a function of the number of items and age of the participants.

larger was on the right. Participants were instructed to respond as quickly as possible without making errors.

Each trial began with a 720-ms interval during which a small fixation cross was presented. Then the spatial array of dots was presented until the participant responded or until 7.8 s had elapsed. Timing began at the onset of the display and ended with the response. There was no post-display mask, but a visual feedback symbol (0.5°) was presented for 720 ms at the center of the screen (+ for correct and - for incorrect).

There were four different discrimination conditions presented in a counterbalanced order: 1 versus 2; 3 versus 4; 6 versus 7; and 8 versus 9. Each condition included 40 trials, divided into two blocks of 20 trials. All participants were given a practice block of trials in each condition before the test trials began. This was sufficient for all participants to report complete understanding of the task. Instructions for the children began with handheld cards displaying different numbers of dots and culminated with a block of practice trials.

Participants were run individually by a female research assistant in a small room, under normal room lighting. The experiment required 30 min for all but the 6-year-old group. For these participants, the experiment was administered in two sessions, on different days. Most of the first session was devoted to familiarizing the participants with the research assistant, the computer, and the number discrimination task. On the second day there was more practice and testing. Only data from children who participated in both of these sessions was included in the study; as a result there were not as many 6-year-olds as in the other age groups.

Results

Mean correct RT is shown in Figure 3 and mean percentage accuracy in Figure 4. Standard errors are given in Appendix A. Before discussing these results in terms of our predictions, it is necessary to confirm that the RT and error data from this number discrimination task were consistent with previous enumeration studies.

We noted first that, overall, RT tended to increase with the number of items, even within a single discrimination condition. Nonetheless, for the statistical analyses, performance for n and $n + 1$ were averaged in each condition so that any differences between right and left hand did not confound the effect of number. RT slopes were calculated separately for the subitizing and counting ranges. In the 1–4 range, the mean RT for the 1 versus 2 condition was subtracted from the mean RT in the 3 versus 4 condition, and divided by two. A similar estimate was derived

for the 6–9 range, and the resulting slopes are presented in Table 1.

As expected from the results of standard enumeration studies, slopes in the 1–4 range were significantly smaller than those in the 6–9 range in each age group, $F(1, 8) = 16.0$, $MSE = 42,238$; $F(1, 17) = 34.3$, $MSE = 28,850$; $F(1, 26) = 89.6$, $MSE = 14,821$; $F(1, 19) = 40.9$, $MSE = 9,580$; and $F(1, 23) = 105.0$, $MSE = 10,470$, for the youngest to oldest age groups, respectively, all $ps < .01$. This suggests that participants were in fact subitizing in the small number range and counting in the higher range. Indeed, the number discrimination slopes for the 22-year-olds in this study were remarkably similar to estimates from standard enumeration studies (e.g., Klahr, 1973: 66 ms in the 1–4 range and 268 ms in the 6–9). Therefore, it is reasonable to conclude that the number discrimination task in this study was tapping the same basic processes measured in standard enumeration tasks.

Tests of Predictions

Several analyses were performed to examine the effect of age on the number discrimination slopes in the 1–4 and 6–9 ranges. First, an overall test of RT slopes indicated significant main effects of age, $F(4, 93) = 7.9$, $p < .01$, $MSE = 18,123$, and number range, $F(1, 93) = 226.4$, $p < .01$, $MSE = 17,597$, along with a marginally significant Age \times Number Range interaction, $F(4, 93) = 2.1$, $p < .08$, $MSE = 17,597$. This test of an interaction, however, is far more general than our specific predictions. To test these more directly, we analyzed the developmental aspects separately from the aging aspects.

When the three groups of children were compared with the young adults, there were significant effects of age, $F(3, 70) = 8.2$, $p < .01$, $MSE = 21,112$, and number range, $F(1, 70) = 149.9$, $p < .01$, $MSE = 19,939$, and a marginally significant Age \times Number Range interaction, $F(3, 70) = 2.5$, $p = .07$, $MSE = 19,939$. Age had significant effects in both the 1–4 and 6–9 ranges considered separately, $F(3, 70) = 3.2$, $MSE = 6,568$ and $F(3, 70) = 5.9$, $MSE = 34,483$, respectively, both $ps < .05$, as has been reported previously (e.g., Chi & Klahr, 1975; Svenson

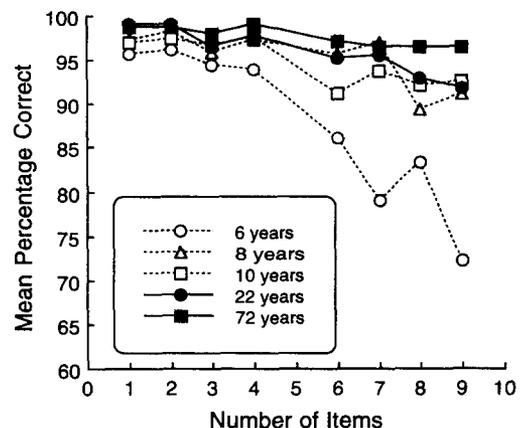


Figure 4. Mean percentage accuracy in the number discrimination task as a function of the number of items and age of the participants.

Table 1
Mean Response Time (RT) Slopes (Milliseconds per Additional Item) in the Number Discrimination Task, in Raw Form, and Corrected for Accuracy

Age (years)	Number discrimination task							
	1-4 range				6-9 range			
	Raw	SEM	Corrected	SEM	Raw	SEM	Corrected	SEM
6	159	48	185	51	547	80	892	188
8	106	24	114	25	438	56	603	89
10	85	12	87	14	399	29	430	37
22	62	7	68	9	260	32	301	39
72	51	11	54	11	354	26	374	30

Note. Corrected RT slopes were obtained after first dividing the mean correct RT for each condition by the proportion of correct responses in that condition (after Akhtar & Enns, 1989).

& Sjoberg, 1978). The fact that the age effect was marginally larger for counting than for subitizing might reflect floor effects in the subitizing range or a differential rate of age-change for the processes involved in subitizing and counting.

The critical comparison for our aging hypotheses involved the 22- and 72-year-olds. Here the Age × Number Range interaction was significant, $F(1, 42) = 5.9, p < .05, MSE = 10,067$, along with a marginally significant age effect, $F(1, 42) = 3.6, p = .06, MSE = 10,462$, and significant number range effect, $F(1, 42) = 135.8, p < .01, MSE = 10,067$. It was predicted that there would be little difference between the two age groups in the 1-4 range, but that the elderly participants would have higher slopes in the 6-9 range. Indeed, simple effects tests (Howell, 1987) revealed no difference in the slopes of younger and older adults in the 1-4 range ($p > .10$). However, older adults had significantly larger slopes than younger adults in the 6-9 range, $F(1, 50) = 16.8, p < .01, MSE = 5,734$.

Enumeration accuracy was very high for all but the youngest participants, as is shown in Figure 4. Across the four discrimination conditions, accuracy was significantly influenced by Age, $F(4, 93) = 14.5, p < .01, MSE = 47$; Number, $F(3, 279) = 61.9, p < .01, MSE = 18$; and an Age × Number interaction, $F(12, 279) = 6.6, p < .01, MSE = 18$. Age-related differences in accuracy became increasingly large as the numbers of items increased.

Speed-Accuracy Trade-offs?

It is possible that some participants were more inclined than others to trade speed for accuracy. One way to deal with this issue is to create a corrected measure of RT that incorporates accuracy. Akhtar and Enns (1989) suggested dividing RTs by the proportion correct to compensate for any tendencies to trade speed for accuracy. The results of estimating these "corrected" slopes are also shown in Table 1.

When the five age groups were compared on these corrected slopes, the Age × Number Range effect was significant, $F(4, 93) = 5.1, p < .01, MSE = 42,858$, along with significant main effects of age, $F(4, 93) = 12.9, p < .01, MSE = 39,143$ and number range, $F(1, 93) = 172.7, p < .01, MSE = 42,858$. The developmental analysis revealed that differences between chil-

dren and young adults were now even more pronounced: There were significant effects of age, $F(3, 70) = 12.3, p < .01, MSE = 47,828$; number range, $F(3, 70) = 117.1, p < .01, MSE = 52,775$; and Age × Number Range, $F(3, 70) = 5.2, p < .01, MSE = 52,775$. However, the aging analysis now revealed only a marginally significant Age × Number Range interaction, $F(1, 42) = 3.1, p = .08, MSE = 13,577$, and a main effect of number range, $F(1, 42) = 122.6, p < .01, MSE = 13,577$. Nonetheless, tests of simple effects revealed the same pattern as in the uncorrected data: 22- and 72-year-olds did not differ significantly in the subitizing range ($p > .10$), while they did in the counting range, $F(1, 84) = 4.1, p < .05, MSE = 14,125$. Thus, the analyses of corrected slopes corroborated the analyses based only on RT. Where the results were not as strong, this seemed to be due to increased within-group variability, as shown in Table 1.

Discussion

A different life span pattern of performance was observed for number discrimination in the subitizing range (1-4 items) than in the counting range (6-9 items). The RT slope associated with enumerating an additional item in the small number range dropped with age between 6 and 22 years and then did not decline significantly thereafter, although the 72-year-old age group had the smallest slope estimates of all. This might be expected if the process that was changing with age involved matching individuated display items with number names retrieved from memory. Once this process was automatized, there would be no reason to expect it to deteriorate with age.

In contrast, RT slopes in the larger number range declined into young adulthood, but then increased in old age. Given that the position of the attentional focus has been shown to be important in the counting range (Trick & Pylyshyn, 1994a), and that other studies have shown children and elderly adults to be less efficient at shifting attention (Akhtar & Enns, 1989; Brodeur & Enns, 1994; Connelly & Hasher, 1993; D'Aloisio & Klein, 1990), it seem plausible that attentional factors may be responsible for this change. However, the counting process involves many other operations. It is possible that the U-shaped function may instead (or in addition) reflect a failure of memory functions in the youngest and oldest participants. These

participants may have difficulty with the operations of storing and retrieving the running total, or in performing mental addition. Moreover, until children begin to add with assurance, they certainly could not be expected to count as adults typically do, using the group-and-add process. If "group and add" were not performed then the attentional focus would have to be moved more often—from item to item instead of group to group. Nonetheless, at this point, given that the processes involved in seeing and attending display items logically precede the stages of working memory and mental addition, and that these lower-level functions are already known to yield U-shaped life span trends, it is parsimonious to conclude that attentional factors are primary candidates for the U-shaped life span trend in counting slopes.

Implications for Theories of Enumeration

At the very least, these data suggest that subitizing and counting involve different processes. This rules out *one-process* theories (e.g., Balakrishnan & Ashby, 1991; Gallistel & Gelman, 1991) because if the same process was being used for all numbers of items, then a variable should not have a different effect on one end of the number range than on the other. Yet, the present data indicate that participant age is such a variable.

Consider the data from the perspective that different representations are used to access the number name response for subitizing and counting (Gallistel & Gelman, 1991). If subitizing involves a direct mapping from a preverbal to verbal representation, and counting merely requires an increasing series of number name retrievals, there would be no reason to expect that subitizing would stay the same or even improve with age, at the same time that counting deteriorated.

Most *two-process* theories also have difficulty accounting for the present results. For example, neither density nor pattern theory specify how the enumeration of large numbers of items is accomplished, or even why there is an RT slope in the subitizing range, so it is unclear what developmental predictions these theories could make. Moreover, these theories fail to predict when subitizing will occur in adults. For example, when density is eliminated as a cue to number by embedding the items to be enumerated in distractor items, subitizing can still occur (Trick & Pylyshyn, 1993). When pattern cues are removed by always presenting the items in a linear configuration (the configuration for two), subitizing is still evident (Atkinson et al., 1976; Frick, 1987), and participants are no slower or more error-prone (Trick, 1987). Mandler and Shebo (1982) go so far as to suggest that large numbers of items can be "subitized" if participants see displays repeatedly and learn the item patterns. This could be taken to suggest that the elderly participants should be the fastest counters of all, given their lifetime of counting experience. As has been shown, they are not.

A short-term memory-based model (Klahr & Wallace, 1976) fares somewhat better with the present data, since the U-shaped life span trend for counting could be related to a similar trend in short-term memory ability. However, this theory makes no explicit predictions for the life span changes in subitizing (improvement and then stabilization) and also cannot explain the wide variety of attentional effects found in previous studies.

Only the FINST theory of enumeration is both consistent

with the present data on age and able to predict the observed dissociations between subitizing and counting. For example, item heterogeneity (Frick, 1987), articulatory suppression (e.g., being obliged to say "the, the, the" while enumerating; Logie & Baddeley, 1987), and the position of the attentional focus at the onset of a trial (Trick & Pylyshyn, 1994a) all have little impact on subitizing but have large effects on counting. Conversely, some variables exert a greater influence on subitizing than on counting, such as the discriminability of the items to be enumerated, and the configuration of multiple contours in the display (Trick & Pylyshyn, 1993, 1994b). The present data thus contribute to this picture by showing that participant age involves a similar dissociation between subitizing and counting.

Implications for Theories of Life Span Development

The clear message of these data for theories of life span development is that there is diversity in the pattern of change seen across life, even for the cognitive components of tasks that are as simple as discriminating between visual displays differing by only a single item. This is consistent with a life span orientation of open-ended change caused by a plurality of mechanisms, including both biological and environmental ones (Baltes & Reese, 1984; Plude et al., 1994), and it is inconsistent with mechanistic bio-decrement models that view change narrowly as growth, followed by maturity and eventual decline.

In a recent review of life span changes in selective attention (Plude et al., 1994), a complex pattern of differential development was observed for some well-known components of visual attention. Reflexive visual orienting, involving eye and head movements and only the "mind's eye," showed a remarkable degree of stability across the life span. Visual filtering of task-extraneous stimuli, on the other hand, showed large improvements at the early end of life with considerable preservation of these functions into old age. In contrast, both visual search and voluntary attentional orienting showed the classic U-shaped functions of improvement in childhood followed by decline in old age.

The present patterns for subitizing (developmental improvement with no associated decline in old age) and counting (developmental improvement with a decline in old age) are thus consistent with the analysis suggested by the attention-inspired account of enumeration (FINST theory). That is, cognitive tasks that rely on relatively more primitive visual operations are less likely to show an aging-related decline than are tasks that rely on more sophisticated operations. There may be more than one reason for this. For example, relatively sophisticated operations tend to be acquired and developed somewhat later in life, putting them in a more tenuous position with regard to principles of both biological maturity and learning. As such, the U-shaped trend may be simply another instance of the LIFO principle (last in, first out), noted by other lifespan researchers. Another possibility is that more complex cognitive operations depend heavily on those regions of the brain that are most susceptible to the deleterious effects of aging. A firm statement on this possibility, however, will require more data than is currently available on the links between behavioral tasks and localized brain activity.

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Appendix

Mean and Standard Error Response Time in Milliseconds For Each Number
in Each Age Group

Number	Age (years)									
	6		8		10		22		72	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
1	1,253	110	837	36	725	44	435	10	693	42
2	1,206	80	847	33	725	41	448	12	696	32
3	1,421	65	991	60	830	43	558	18	758	33
4	1,675	85	1,119	73	961	67	573	19	836	50
6	4,503	246	2,525	128	2,173	123	1,140	50	1,621	83
7	4,887	159	2,944	143	2,441	116	1,303	73	1,945	99
8	5,388	220	3,509	132	2,995	77	1,646	93	2,361	172
9	6,190	172	3,713	218	3,215	142	1,836	100	2,620	103

Note. Responses for 1, 3, 6, and 8 items were made with the index finger of the left hand; responses for 2, 4, 7, and 9 items were made with the index finger of the right hand.

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