# Aging and Capacity in the Same-Different Judgment

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**ABSTRACT**

The same-different judgment was used in two experiments to investigate age-group differences in visual processing. Two targets next to fixation were presented; on half the trials the targets were the same, and on half the trials the targets differed by color, shape, or color and shape (redundant). Response times were lower for redundant trials than for color-only and shape-only trials; this redundancy gain was greater for older observers than for young observers. Capacity measures based on the integrated hazard functions indicated that young adults, but not older adults, experienced a slowing of processing (reduction of capacity) in the redundant condition. These capacity measures may provide a method for interpreting age-group effects in the presence of overall response-time differences.

At present, there is no grand unifying theory to explain age-related differences in cognition (Salthouse & Craik, 2000; Salthouse, 2004). Two global descriptions of age-group effects, each of which has a lot of explanatory power, are reductions in *speed* (*generalized slowing;* Cerella, 1990; Salthouse, 1992) and reductions in *capacity (Salthouse, 1988)*. Measuring speed or capacity is a non-trivial problem, although each possesses an ordinal relationship to output measures such as response time (RT) or accuracy. Recent research has used explicit models such as the diffusion model to map speed onto response time, in order to characterize age-group differences in rate of information acquisition (e.g., Thapar, Ratcliff, & McKoon, 2003). Capacity, however, is less well-defined; as Wenger and Gibson (2004) pointed out, that concept is susceptible to problems of circularity and reification (cf., Navon, 1984; Salthouse & Craik, 2000).

In general, processing speed should be positively correlated with capacity. Salthouse (1988; 1992) suggested some linking constructs; for example, capacity of working memory would be dependent on processing speed if multiple items are constantly refreshed to remain active. Also, capacity and speed become dependent when a task is time-constrained, i.e. when a task must be completed within a restricted time window (Verhaeghen, 2002). In some cases, however, although it seems paradoxical, it might be possible for speed and capacity to be non-dependent or separable. Under what conditions could we find a dissociation between speed and capacity?

We might find such a dissociation when capacity is conceptualized, not as a global measure, but as a measure of the system response in a particular operating space. In many cases, operating-space capacity is based on measures of performance across two conditions. For instance, the attention operating characteristic (AOC; Sperling, 1984), describes the tradeoffs between two components of a dual task, by plotting response accuracy in Task A vs. response accuracy in Task B at different levels of emphasizing Task A vs. B. The capacity as measured by an AOC is the area under the curve swept out by performance in the two tasks; an analogous measure is d' in signal detection theory. Both AOC and d' are based on accuracy; recently another measure of capacity, based on response time, has been formalized by Townsend (Townsend & Nozawa, 1995). The Townsend and Nozawa capacity measure is computed on response time in two different conditions, which can be roughly termed *single input* and *double input,* or *low-load* and *high-load*. In the current work, the Townsend and Nozawa (1995) capacity measure was applied to results from a *same-different judgment* (Nickerson, 1965; Miller, 1978; Proctor, 1981).

*The same-different judgment.* In this task, observers examine a pair of items and determine whether they match (*same*) or are mismatched (*different*). Theories have been developed to explain the difference in response time (RT) between *same* and *different* trials (e. g., Nickerson, 1965; Proctor, 1981), but for the present purposes, we will focus on response times across the various types of *different* trials. The key manipulation is the number of stimulus dimensions on which the targets differ. For instance, in Miller's (1978) study, stimuli were a pair of small squares presented on a computer screen, and three item dimensions were salient: brightness, size, and tilt. If the items differed, they could differ on one, two, or three dimensions. The most general result was that latency (RT) for a *different* response decreased as number of different dimensions increased.

The same-different task was first examined in a cognitive aging context by Scialfa and Thomas (1994), in an effort to explain mechanisms underlying age-group differences in visual search. Their same-different task used three relevant dimensions (*shape*, *color*, and size). For both young and older observers, the results replicated Miller (1978): *different* trial RT increased (and error rates decreased) as a function of number of different dimensions, and the differences were much larger between the one- and two-dimension conditions than between the two- and three-dimension conditions. The result of greatest interest for Scialfa and Thomas (1994) was the size of the redundancy gain for younger and older observers, measured as the difference between mean RTs for one and two dimensions of difference. There were 35-ms and a 116-ms redundancy gains for younger and older observers respectively. Did that result indicate that older adults showed a greater benefit for redundant dimensions, or did they exhibit a greater cost in the single-dimension condition? Scialfa and Thomas favored the "cost" interpretation, i.e. a comparative age-group deficit when the difference between the items was small. This deficit was interpreted as one factor underlying reduced visual search rate in older adults.

*RT distributions and the capacity coefficient*. Before discussion of the aging application of the current work, it is necessary to describe the models underlying the same-different task. The same-different task was used by Miller (1978) to investigate a parallel independent-channels model which he called the *analytic* model. In this model, each stimulus dimension is compared in a separate channel and the outcomes are pooled in an "or" function; the first *different* signal triggers a *different* response. According to a parallel independent-channels model, if there is no crosstalk or response pooling, then on every trial with two or more dimensions different (*redundant*), the first comparison process to produce a *different* signal should determine the response. This so-called statistical facilitation produces a straightforward prediction: mean response time in the redundant condition should be less than or equal to the mean response time for the one-dimension condition. This prediction is derived from the *Grice Inequality*, and is only violated when the system is much slower in the redundant condition than the one-dimension condition (Townsend & Nozawa, 1995). Therefore, this prediction does not provide a critical test of the parallel independent-channels model.

The first critical test for the parallel independent-channels model was provided by the *Miller Inequality* or race-model inequality (Miller, 1978; Townsend & Nozawa, 1995). Miller's inequality states that for the parallel independent-channels model, at every time t in the set of observations, the cumulative response time distribution for the redundant condition should never exceed the sum of the cumulative response times for the two single-dimension conditions. Miller's inequality is sensitive to deviations only at the lower end of the response distribution, because the cumulative for the redundant condition has the range 0 to 1, and the sum of the cumulatives for the single-dimension conditions has the range 0 to 2. If this inequality is violated, then the parallel independent-channels model is falsified; in Miller (1978), the inequality was indeed violated and it was concluded that information across dimensions was being combined in order to determine the response, possibly as a result of crosstalk or coactivation between channels. This analysis has been applied to other tasks including target detection, and findings have generally favored coactivation (Miller, 1982; Mordkoff & Yantis, 1993).

More recently, work by Townsend and associates (Townsend & Nozawa, 1995; Townsend & Wenger, 2004) has suggested an extension to Miller's work, using new measures of processing capacity, that may allow a way to quantitatively compare performance between redundant and one-dimension conditions in the same-different task. This theory requires examination of the response time distributions in order to infer system architecture, stopping rules, and overall capacity. A brief explanation of the capacity coefficient will be presented here; the full treatment is in Townsend and Nozawa (1995). Capacity is based on the RT hazard function, which is the (instantaneous) probability at time t of a response, given that a response hasn't occurred yet:

$$h(t) = p(t)/[1-F(t)], \quad (1)$$

where h(t) is the hazard function, p(t) is the density, and F(t) is the cumulative distribution function (Townsend & Ashby, 1983).

The integrated hazard function H(t) is computed as

$$H(t) = -\ln [1-F(t)]. \quad (2)$$

By analogy to physical systems, the h(t) term has been compared to power and the H(t) term has been compared to summed power or work; alternatively, H(t) can represent capacity (Townsend & Nozawa, 1995). H(t) increases monotonically from 0 to a theoretically-unbounded maximum, because -ln [1-F(t)] is undefined when F(t) = 1.

Capacity functions for different conditions (assuming a single process architecture) may be compared directly in terms of ordering for a given range of t, or alternatively, by constructing a capacity coefficient which is a ratio of capacities. The capacity coefficient in the current context is

$$C(t) = H_r(t)/[H_s(t) + H_c(t)] \qquad (3)$$

where the subscript *s*, *c* and *r* refer to *shape*, *color*, and *redundant* conditions, respectively.

The *capacity coefficient* has been used to compare performance across single- and double-input conditions in various applications, including dot detection (Townsend & Nozawa, 1995), face perception (Ingvalson & Wenger, in press; Townsend & Wenger, 2004; Wenger & Townsend, 2001), and temporal-order judgments (Miller, Kuhlwein, and Ulrich, 2004). When C(*t*) > 1, the system is said to exhibit super-capacity (processing speed increases when the number of inputs increases), C(*t*) = 1 indicates unlimited capacity (processing speed is unchanged when the number of inputs increases), and C(*t*) < 1 indicates limited capacity (processing speed decreases when the number of inputs increases). C(*t*) takes into account *statistical facilitation*, as described above. The relationship between the capacity coefficient and the Miller Inequality will be discussed later; in brief, for response times at which the Miller Inequality is violated, C(t) > 1 and the system is in a state of super-capacity.

**EXPERIMENT 1**

As stated above, Scialfa and Thomas (1994) found a larger redundancy gain for older than younger adults in the same-different task. They tested their hypotheses at the level of the mean; however, in the absence of a model, it was not clear whether the age-group difference in redundancy gain was consistent or inconsistent with cognitive slowing. This was partially due to the fact that statistical facilitation may cause a lower mean RT in the redundant condition solely as an artifact of the system architecture. The Townsend and Nozawa (1995) capacity coefficient, as discussed above, is invariant with respect to statistical facilitation, and thus allows the expression of whether the system speeds up or slows down when going from a single-dimension to a redundant condition. In this way, the capacity coefficient may be used to quantify the response of the system as the inputs are increased in number, and so may allow comparisons of this coefficient across age groups.

In order to test the applicability of the capacity coefficient to cognitive aging, I partially replicated the single- and redundant-dimension conditions from Scialfa and Thomas (1994). Whereas the previous research examined the means of the RT distributions, in the current study, the entire RT distributions were examined. Capacity coefficients allowed the characterization of system performance as number of *different* signals increased from one to two. These coefficients were computed for each 1ms time bin in the observed RT distributions, and compared across age groups.

METHOD

*Observers.* Eleven older adults (M age = 69; range 64 – 73 yrs) and eleven young adults (M age = 20; range = 18 – 23 yrs), recruited from the community, participated. The older adults were members of the Sanders-Brown subject registry at the University of Kentucky and were paid $10 per 1-hour session; the young adults were university students receiving course credit. Observers passed a color-blindness test, and minimum visual acuity, measured at four feet, was 4/8 (equivalent to 20/40). All observers had a minimum of 12 years of education. A computerized version of the Mill-Hill vocabulary test was administered; mean scores were 16.5 (se = 1.4) and 12.9 (se = 1.35) for older and younger participants respectively, $F(1, 20) = 3.36$, $p > .05$. A computerized version of the WAIS digit-symbol test was also administered; mean response times were 1.4 sec (se = 0.08) and 1.1 sec (se = 0.05) for older and younger participants respectively, $F(1, 20) = 14.81$, $p < .01$.

*Apparatus.* The stimulus displays were controlled by a Pentium 4 computer, connected to a 17” monitor running at 120 Hz, at a screen resolution of 600 x 800, programmed with Eprime. A chin- and head-rest fixed eye position and maintained an eye-to-screen distance of 80 cm. The room had dim natural lighting.

*Stimuli.* Each trial consisted of a central fixation point (1.5 sec), followed by two targets 1.8 degrees to the left and right of the fixation point. Colors as specified in the RGB coordinate system were blue (0, 100, 255), red (255, 0, 0), and green (0, 160, 0), which corresponded to targets of approximately equal brightness. Shapes were hexagons, squares, and triangles subtending about 0.5 deg (sized for the appearance of equal size and brightness). Luminance of the targets was 30 to 69 cd/m2, and background luminance was 3.4 cd/m2.

The stimulus display was terminated by the manual response which was recorded on the keyboard, with the *m* key mapped to *same* and the *z* key mapped to *different*. (Response was not counterbalanced because critical tests were comprised of response times on *different* trials.) Accuracy feedback was displayed on each trial.

*Procedure.* Each observer completed a single session of the experiment, which began with 30 practice trials, followed by eight blocks of 72 trials each (576 total). Half of the trials were *same*, and half *different*, by either *shape*, *color*, or *redundant*. On the 288 *different* trials, 144 featured differences in *shape* and 144 featured differences in *color*; these events were independent resulting in 72 trials with a *shape* (only) difference, 72 trials with a *color* (only) difference, and 144 trials with a *redundant* difference. Trials were presented randomly to each observer.

RESULTS AND DISCUSSION

Error rates were less than 2.5% overall and were not analyzed further. Correct RTs were first compared between match and mismatch trials (Table 1). There was a main effect of matching, $F(1, 20) = 18.59$, $p < .001$, and a main effect of age group, $F(1, 20) = 22.61$, $p < .001$. These main effects were qualified by an Age Group x Match interaction, $F(1, 20) = 46.85$, $p < .001$ which was not removed by a log transformation (Cerella, 1990; Gottlob, in press). For younger observers, *same* responses were 32 ms faster than *different* responses, $F(1, 10) = 66.26$, $p < .01$. For older observers, *same* responses did not differ from *different* responses, $F(1, 10) = 3.03$, $p > .05$.

The next analysis was for mismatch trials only, with factors of difference type (*color*, *shape*, or *redundant*) and age group (Table 2). There were main effects of difference type, $F(2, 20) = 189.11$, $p < .001$ and age group, $F(1, 20) = 20.96$, $p < .001$, as well as an Age Group x Difference Type interaction, $F(2, 40) = 12.56$, $p < .001$, which was not removed by a log transformation. Pairwise comparisons with the Sidak correction (SAS Institute, 1989) showed that for each age group, *redundant* trials were fastest and of the single-dimension conditions, *color* was 55 ms faster than *shape* for the younger adults ($p < .01$ for all tests), and *color* was (non-significantly) 21 ms faster than *shape* for the older adults. Redundancy gain on raw RT was computed as $RT_r - [(RT_s + RT_c)/2]$ where the subscripts *r*, *s*, and *c* stand for *redundant*, *color*, and *shape* conditions respectively. Redundancy gain was 57 ms for younger adults and 91 ms for older adults. The meaning of the older adults' larger redundancy gain is not clear, however, because mean RTs were 592 ms and 749 ms for the younger and older adults, respectively (Table 1).

For the next analysis, the distributions of correct RT for the mismatch conditions were submitted to the integrated hazard function analysis of Townsend and Nozawa (1995). For each observer, RTs over 1500 ms were removed (< 5% of observations). Then, integrated hazard functions [$H_n(t)$, subscripted by condition] for the three mismatch conditions were computed for each ms time bin between 0 and 1500 ms and the capacity coefficient [$H_r(t)/(H_s(t)+H_c(t))$] was computed for each ms time bin. The *total capacity* was the integrated capacity between two endpoints using a bin size of 1 ms: the lower endpoint was the maximum of the 5$^{th}$ RT percentiles for the three conditions, and the upper endpoint was the minimum of the 95$^{th}$ RT percentiles for the three conditions. These integration endpoints were chosen so that spurious observations would not have an undue influence on the capacity measures. Total capacity was divided by the range of integration in ms to yield *mean capacity*. *Peak capacity* was defined as the maximum point for capacity within the integration range, after the capacity curve was filtered with a 51ms smoothing window. These parameters were computed on the basis of individual observers, and compared across age group (Table 3). Figure 1 shows representative cumulative RT distributions, integrated hazard functions, and capacity coefficients for a single older and young observer.

As Table 3 indicates, the older adults showed a greater mean capacity than the younger adults, with approximately the same difference (~ 473 ms) between first and last observation. For younger adults, mean capacity over the observed response times was significantly less than 1, $t(10) = -4.32$, $p < .01$. This indicated that the younger adults had limited capacity with respect to processing two difference inputs instead of one. In contrast, the older adults' mean capacity was not different from one, $t(10) = -1.93$, $p > .05$, which indicated unlimited capacity; i. e. the system processed two difference signals with no loss of capacity with respect to processing a single difference signal. This finding indicates that even though the older adults' responses were slowed compared to the younger adults', the redundancy gain was actually enhanced for the older adults. Peak capacity was comparable across age groups; its value of approximately 1.4 indicated that both groups of observers were exhibiting super-capacity for a portion of the RT distribution.

<TABLE 1> <TABLE 2> <TABLE 3> <Figure 1>

The results indicated that overall, older observers' capacity (processing speed) remained fixed as the system went from processing one difference signal to two; their mean-RT reduction of 91 ms therefore represented a "pure" redundancy gain. For younger adults, on the other hand, moving from one to two difference signals entailed a reduction in capacity, so even though mean RT declined by 57 ms, the system slowed as it processed two inputs instead of one. Taken together, it appears that both groups experienced a redundancy gain as measured in mean RT, but only the young adults incurred a cost in going from one input to two, as measured by processing speed.

One possible reason that the older observers processed two signals with no reduction in speed compared to one signal may have been that their relatively-longer RTs promoted the pooling of inputs or (equivalently), allowed more time for crosstalk to take place. Also, it has been shown that older observers are reduced in sensory uptake speed compared to young observers (e. g., Cerella, Poon, & Fozard, 1982; Gottlob &

Madden 1998; Verhaeghen, 2002); this may cause older observers to “prefer” redundant difference signals. One way to manipulate both processing time and sensory demands is to make the discrimination more difficult by increasing target similarity. If either of these factors are responsible for the age-group differences in the capacity coefficient, then we may see increases in the coefficient in both age groups when the task is more difficult.

## EXPERIMENT 2

### METHOD

*Observers.* Twenty older adults (M age = 69; range 64 – 75 yrs) and twenty young adults (M age = 19; range = 18 – 23 yrs), recruited from the community, participated. The older adults were members of the Sanders-Brown subject registry, and the young adults were university students. Older observers were paid $10 per 1-hour session; younger observers received course credit. Observers passed a color-blindness test, and minimum visual acuity, measured at four feet, was 4/8 (equivalent to 20/40). All observers had a minimum of 12 years of education. A computerized version of the Mill-Hill vocabulary test was administered; mean scores were 16.9 (se = 1.45) and 12.6 (se = 0.60) for older and younger participants respectively, $F(1, 34) = 12.78$, $p < .01$. A computerized version of the WAIS digit-symbol test was also administered; mean response times were 1.4 sec (se = 0.06) and 1.0 sec (se = 0.06) for older and younger participants respectively, $F(1, 34) = 46.10$, $p < .01$.

The apparatus and procedure were identical to that in Experiment 1 except that the stimuli were changed to increase target similarity. The shapes were circles, hexagons, and octagons, with similar areas. The colors were specified such that all three colors formed an equilateral triangle in RGB space. Violet was (120, 100, 100), green was (100, 120, 100), and blue was (100, 100, 120). Informal observation indicated that this was a much more difficult discrimination task than that in Experiment 1.

## RESULTS AND DISCUSSION

As was also found in Experiment 1, error rates were less than 2.5% overall and were not analyzed further. Correct RTs were first compared between match and mismatch trials (Table 4). There was a main effect of matching, $F(1, 34) = 677.21$, $p < .001$, and a main effect of age group, $F(1, 34) = 51.98$, $p < .001$. These main effects were qualified by an Age Group x Match interaction, $F(1, 34) = 491.82$, $p < .001$, which was not removed by a log transformation on RT. For younger adults, *same* responses were 12 ms slower than *different* responses, $F(1, 17) = 8.56$, $p < .01$. For older adults, *same* responses were 145 ms slower than *different* responses, $F(1, 17) = 1006.76$, $p < .01$.

Next, mismatch trials only were analyzed, with factors of difference type (*color*, *shape*, or *redundant*) and age group (Table 5). There were main effects of difference type, $F(2, 68) = 603.72$, $p < .001$ and age group, $F(1, 34) = 24.92$, $p < .001$, as well as an Age Group x Difference Type interaction, $F(2, 68) = 27.76$, $p < .001$, which was not removed by a log transformation. Within each age group, all pairwise comparisons between difference types were significant, $p < .001$. For each age group, *redundant* trials were fastest, followed by *color* and then *shape* trials. Redundancy gain on raw RT, computed as for Experiment 1, was 87 ms and 126 ms for younger and older adults respectively.

As for Experiment 1, the distributions of correct RT for the mismatch conditions were subjected to the integrated hazard function analysis of Townsend and Nozawa (1995). Mean parameter values are reported in Table 6. Similarly to the results of Experiment 1, mean capacity for older adults ($M = 0.94$) was greater than that for the younger adults ($M = 0.81$); for older adults, mean capacity coefficient did not differ from 1, $t(17) = -1.78$, $p > .05$, but for younger adults, the mean capacity coefficient was significantly below 1, $t(17) = -6.77$, $p < .01$. Also consistent with Experiment 1, the peak capacity coefficient was > 1 for a portion of the RT distribution for both age groups, indicating super-capacity for at least some of the observed RTs. [TABLE 4] [TABLE 5] [TABLE 6]

The findings from Experiment 2 indicated that increasing the discrimination difficulty effected an increase in mean RT across both groups, but the capacity coefficients remained approximately the same as in Experiment 1. Older adults' mean capacity coefficient was still approximately 1, and the young adults' capacity coefficient was still less than 1. Thus, it appeared that the older adults again benefited more from redundancy than younger adults, even when the task was increased in difficulty.

**GENERAL DISCUSSION**

In both experiments, observers viewed pairs of items and performed a same-different judgment. Experiment 1 used pairs of items that were easy to discriminate, and Experiment 2 used pairs of items that were more difficult to discriminate. For both experiments, capacity coefficients [C(t)] were computed that compared the behaviors of the system when a single dimension differed across the items, and when two dimensions differed (*redundant*). The mean of C(t) over the observed range was the index that indicated whether the system was slower in the redundant condition than the single-dimension conditions. Overall, the capacity coefficients were similar across both experiments, indicating that this coefficient is stable with respect to the sensory demands of the task. However, the cognitive aging application was rather surprising: older adults were not slowed in the redundant condition compared to the single-difference condition [mean $C(t) \sim 1$], whereas younger adults were slowed [mean $C(t) < 1$].

This result appears paradoxical: Older adults' RT was higher than younger adults', indicating age-related speed decrements, but older adults' capacity coefficients were higher than younger adults', indicating an age-related preservation. Are we to believe the story that the capacity coefficient seems to tell us, that older adults are actually more efficient in their processing of the redundant targets, compared to the single-dimension targets, than the younger adults? Or is there some other way of conceptualizing the results to accommodate both overall age-related performance decrements and age-related increases in capacity? One possibility is that the older adults had greater amounts of crosstalk or coactivation between the *shape* and *color* channels, which would result in a stronger "different" signal for highly dissimilar (redundant) targets, compared to the younger adults. The younger adults, in contrast, were able to respond quickly enough on the single-dimension condition that there was no great advantage for them (in fact even a slight decrement when expressed in terms of capacity) in the redundant condition.

Another answer may lie in the concept of *capacity* as used in the present experiments. In this task, the performance envelope mapped out by the two conditions (single-dimension and redundant) may be considered as a subset of all the performance space mapped out by all of the possible manipulations. In this conceptualization, older adults "prefer" to operate in the part of the performance space with redundant inputs; i.e. their capacity is unlimited with respect to processing two inputs instead of one. In other words, older adults enjoy a performance advantage (lower RT) and no costs with respect to system slowdown when going from one input to two. On the other hand, young observers also have a performance advantage (lower RT) when going from one input to two, but it comes at the price of system slowdown [$C(t) < 1$]. All other factors being equal, younger adults should still prefer to process redundant inputs, because it lowers overall RT, but the cost is that the system suffers some kind of redundant-input slowdown. The capacity coefficient, therefore, should not be construed as a measure of global capacity, but rather as characterizing the change in system speed over a processing range determined by the task.

These results, though, also highlight the fact that the capacity coefficient may yield more information than mean RT about system performance. Mean RT was less in the redundant condition than the single-dimension conditions for both older and younger adults, yet capacity remained approximately constant only for the older adults; it was less than one for the younger adults. Of course, these results are consistent with the fact that the redundancy gain as measured on mean RT was greater for the older adults than for the younger (as revealed in the Age Group x Difference Type interactions in both experiments), but the capacity coefficient allows for a more definitive interpretation of the data. In the current case, the capacity measures indicated that there was a qualitative difference in processing across age groups.

The logic of the capacity coefficient can be compared to that of testing the Miller Inequality using the cumulative distributions (Townsend & Nozawa,1995): (1) If there is a Miller inequality, then the parallel independent channels model is falsified. (2) If $C(t) > 1$ for some range of RTs, then the parallel independent channels model is falsified for those RTs. (3) If Miller's inequality is violated for some observed values of response time, then $C(t) > 1$ for those values. (4) If $C(t) > 1$ for all of the observed RTs, then Miller's inequality is violated for a least a portion of the RT distribution (it is not possible for Miller's inequality to be violated in the right-hand portion of the RT distribution). The above four statements lead to the conclusion that violation of Miller's inequality implies $C(t) > 1$, but $C(t) > 1$ does not necessarily imply a violation of Miller's inequality. Furthermore, C(t) allows comparisons between different groups, at least to an ordinal level. Therefore, the Townsend and Nozawa capacity measure may prove to be a valuable tool for characterizing the response of the system and for determining whether age-group differences in overall response time are also reflected in differences in capacity. These capacity differences, in turn, may lead to inferences concerning the types of stimuli that are most efficiently processed by young and older observers.

One inference from the current results relates to processing information in computer displays or point-of-purchase ATM machines. Older adults may particularly benefit when critical elements in those displays differ from other elements on two dimensions. In contrast, younger adults would not benefit as much. In general, these results indicate that processing models may uncover qualitative as well as quantitative age-group differences, and that speed and capacity may be disassociated under certain conditions.

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Table 1. Match vs. Mismatch RT (ms), by age group, for Experiment 1

| | Mismatch | Match |
|---|---|---|
| Younger adults | 592.32 (26.29) | 560.01 (26.29) |
| Older Adults | 748.72 (26.29) | 756.06 (26.29) |

**Note**: Least-square means.

Table 2. Mismatch RT (ms), by Age Group and Mismatch Type, for Experiment 1

| | Color | Shape | Redundant |
|---|---|---|---|
| Younger adults | 595.81 (25.52) | 647.45 (25.55) | 564.29 (25.20) |
| Older Adults | 784.89 (25.53) | 805.61 (25.52) | 703.85 (25.20) |

**Note**: Least-square means.

Table 3. Parameters from the Capacity Analysis, for Experiment 1

| Age Group | Mean Capacity | Peak Capacity[a] | First Obs. (ms) | Integration Range (ms) |
|---|---|---|---|---|
| Younger | 0.76 (0.06) | 1.24 (0.10) | 478.82 (20.69) | 470.36 (44.65) |
| Older | 0.92 (0.04) | 1.51 (0.14) | 618.72 (14.26) | 476.09 (32.86) |
| F (1, 20) | 4.88 * | 2.29 | 30.95** | 0.01 |

* $p < .05$. ** $p < .01$. [a]After smoothing with a 51 ms window.

Table 4 Match vs. Mismatch RT (ms), by age group, for Experiment 2

| | Mismatch | Match |
|---|---|---|
| Younger adults | 717.28 (22.22) | 728.86 (22.22) |
| Older Adults | 853.28 (22.22) | 998.34 (22.25) |

**Note**: Least-square means.

Table 5. Mismatch RT (ms), by Age Group and Mismatch Type, for Experiment 2.

| | Color | Shape | Redundant |
|---|---|---|---|
| Younger adults | 717.28 (21.77) | 808.56 (21.83) | 675.54 (21.45) |
| Older Adults | 848.46 (21.76) | 1004.12 (21.99) | 800.79 (21.44) |

**Note**: Least-square means.

Table 6. Parameters from the Capacity Analysis, for Experiment 2.

| Age Group | Mean Capacity | Peak Capacity[a] | First Obs. | Integration Range (ms) |
|---|---|---|---|---|
| Younger | 0.81 (0.028) | 1.33 (0.08) | 563.39 (15.26) | 534.28 (42.34) |
| Older | 0.94 (0.036) | 1.28 (0.07) | 714.72 (22.52) | 515.83 (28.21) |
| F (1, 34) | 7.38* | 0.15 | 30.99** | 0.13 |

* $p < .05$. ** $p < .01$. [a]After smoothing with a 51 ms window.

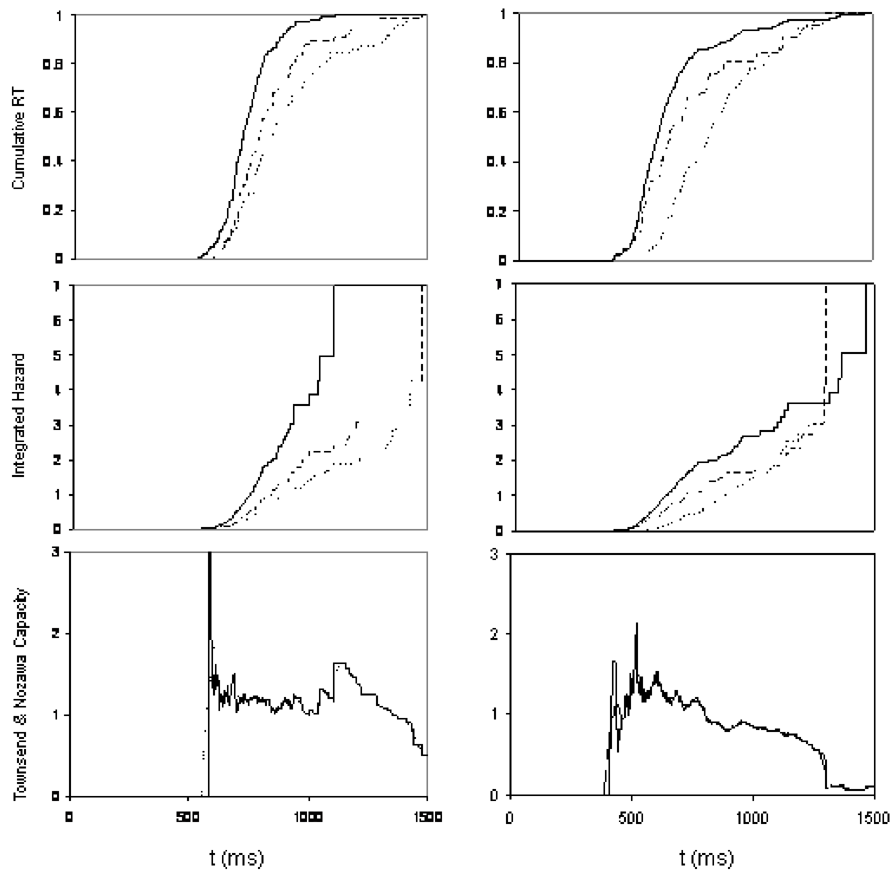


**Figure 1**. Cumulative RT distributions, integrated hazard functions, and Townsend & Nozawa capacity coefficient [C(t)] for representative older (left panel) and young (right panel) observers, as a function of RT (ms). Solid, dashed, and dotted curves represent redundant, shape, and color conditions respectively. On the bottom panel, the dotted line represents the smoothed capacity (smoothing window = 51 ms).