

Research Article

PAYING ATTENTION TO TIME AS ONE GETS OLDER

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Abstract—Age-related changes in attention and interval timing as a function of time of day were examined using a temporal bisection task with single and compound auditory and visual stimuli. Half of the participants in each age group were tested in the morning, and half were tested in the afternoon. Duration judgments were found to be shorter for visual signals than for auditory signals. This discrepancy was greater in the morning than in the afternoon and larger for the older than for the younger adults. Young adults showed equal sensitivity to signal duration for single and compound trials and higher sensitivity in the afternoon than in the morning for both signal modalities. In contrast, older adults showed impaired sensitivity on compound trials and the greatest sensitivity overall to single visual trials in the morning. These results suggest that age-related reductions in attentional resources may cause older adults to focus on signals that require controlled attention during specific phases of the circadian cycle.

Interval-timing paradigms have recently attracted interest as a method of studying age-related differences in cognition (e.g., Craik & Hay, 1999; McCormack, Brown, Maylor, Darby, & Green, 1999; Vanneste & Pouthas, 1999; Wearden, Wearden, & Rabbitt, 1997; for a review, see Block, Zakay, & Hancock, 1998). Models of timing and time perception often include components of interest to many cognitive aging researchers, such as attention, memory, and decision processes (e.g., Gibbon, Church, & Meck, 1984; Thomas & Weaver, 1975). Furthermore, temporal cognition is sensitive to a wide range of behavioral (e.g., Lejeune, 1998; Macar, Grondin, & Casini, 1994) and neurobiological (Gibbon, Malapani, Dale, & Gallistel, 1997; Meck, 1996) manipulations of attention and memory.

For example, valid and invalid cues to the modality of an upcoming to-be-timed stimulus affect the latency to begin timing (Meck, 1984), and the efficiency of these cues is influenced by drug-induced changes in attention (e.g., Penney, Holder, & Meck, 1996). Internal clock and memory processes involved in time perception are also affected by manipulations of brain dopamine levels in both normal adults (Rammesayer, 1997) and patients with Parkinson's disease (Malapani et al., 1998). Other clinical disorders, such as Alzheimer's disease and amnesia, also affect time perception in a manner consistent with the cognitive disruptions accompanying these conditions (e.g., Nichelli, Venneri, Molinari, Tavani, & Grafman, 1993). The sensitivity of interval-timing procedures to variables affecting attention and memory makes these paradigms useful for studying age-related changes at both behavioral and physiological levels (e.g., Meck & Benson, in press).

The temporal bisection task (Allan & Gibbon, 1991) has been used in conjunction with an information processing model of timing (Gib-

bon et al., 1984) to investigate the roles of attention and memory in time perception. In this model, time is marked by pacemaker pulses being gated to an accumulator when attention to a stimulus closes a switch. During training for the bisection task, participants learn to call one duration (e.g., 3 s) "short" and another duration (e.g., 6 s) "long." The accumulated pacemaker pulses associated with each label are then passed into reference memory. Each label is associated with a distribution of values, rather than a single value, because of variability in current accumulated time and in the encoding and decoding of durations (Gibbon et al., 1984).

At test, participants are presented with stimuli that last for durations corresponding to the short anchor, the long anchor, and an intermediate value and are asked to indicate whether each presented duration is closer to the "short" or "long" anchor. The dependent variable is the proportion of trials in which the participant classifies each test duration as long. The decision whether to call a particular stimulus item short or long is made by comparing the number of pacemaker pulses accumulated during the presented stimulus with the number of pulses sampled from the short and long distributions in reference memory.

Recently, the bisection task has been used in combination with the classic finding that sounds are judged longer than lights to examine how attention and reference memory act together in temporal discrimination. When both modalities are used within an experimental session, an auditory stimulus is typically judged as longer than a visual stimulus of the same physical duration (e.g., Goldstone & Goldfarb, 1964; Walker & Scott, 1981; Wearden, Edwards, Fakhri, & Percival, 1998). Penney, Allan, Meck, and Gibbon (1998) suggested this difference may occur because auditory signals capture and hold attention relatively easily, whereas attending to visual stimuli requires more attentional control (Meck, 1984). Because auditory stimuli are better able to capture and hold attention, they are more efficient than visual stimuli in closing the attentional switch that allows pacemaker pulses to accumulate. As a result, more pacemaker pulses accumulate for an auditory stimulus than for a visual stimulus of the same physical duration. If a test stimulus from either modality is compared with short and long distributions in reference memory that comprise values from both modalities, then an auditory test stimulus will be more likely judged long than a visual stimulus of the same physical duration.

In an extensive series of experiments, Penney and associates (e.g., Penney et al., 1998; Penney, Gibbon, & Meck, 2000) tested college students with the temporal bisection procedure using both auditory and visual signals. The results of these studies indicated that when the same anchor durations were used for both modalities, the auditory and visual test stimuli were compared with a reference memory distribution comprising both signal modalities. Under these memory-mixing conditions, the classic finding occurred: Auditory stimuli were more likely to be judged long than were visual stimuli of the same physical duration. However, this was not the case when each modality had its own reference memory distribution (e.g., if the modalities were used in separate experimental sessions rather than within one session or if different anchor points were used for each modality). See Wearden et

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al. (1998) for additional data relating modality differences to the attention and memory components of the internal clock model.

Another area of timing research that has recently attracted interest in the cognitive aging literature is the impact that circadian arousal patterns have on age differences in attention and memory (for a review of the internal clocks that mediate circadian and interval timing, see Hinton & Meck, 1997). Scores on measures such as Horne and Ostberg's (1976) Morningness-Eveningness Questionnaire (MEQ) generally classify older adults as "morning" types and young adults as "neutral" or "evening" types, and these classifications are consistent with circadian rhythmicities on a variety of physiological, psychological, and cognitive measures (e.g., Hoch et al., 1992; May, Hasher, & Stolfus, 1993; Mecacci, Zani, Rocchetti, & Luciola, 1986; see Yoon, May, & Hasher, 1999, for a review).

For example, May et al. (1993) found that when participants were tested in the afternoon (young adults' optimal and older adults' non-optimal time of day), young adults showed better recognition memory performance than did older adults, replicating standard findings. However, there were no age differences in recognition memory for participants tested in the morning (young adults' nonoptimal and older adults' optimal time of day). Particularly for older adults, performance on measures of controlled attention, such as the Stroop (1935) interference effect or performance in the interference condition of the Trail-Making Test (Reitan, 1958), changes as a function of time of day, but performance of well-learned, relatively automatic tasks (such as vocabulary performance or Stroop color naming) does not (e.g., May & Hasher, 1998; for a review, see Yoon et al., 1999).

The current experiment built on these findings and on a previous experiment examining circadian influences on interval timing in animals (Meck, 1991) to determine how the interaction of subject and task variables thought to affect attention and memory influences performance on a time perception task. Young and older adults participated in a temporal bisection experiment using auditory and visual signals and both single and compound (divided-attention) trials during either the morning or the afternoon. We hypothesized that older adults' performance would be worse than that of young adults under task conditions requiring more controlled attention, particularly when older adults were tested at their nonoptimal time of day.

METHOD

Participants

Thirty-four young adults (mean age = 20.1 years, $SD = 1.2$) and 36 older adults (mean age = 69.3 years, $SD = 4.3$) participated in the experiment. Young adults participated to satisfy a course requirement; older adults were recruited from the community through the Duke University Center for the Study of Aging and Human Development. Participants in each age group were randomly assigned to the morning or afternoon testing times. Data from 3 older adults were discarded because these participants failed to follow task instructions or pass a dementia screen. For the remaining participants, older adults had higher scores (35.0 vs. 23.7) on the Extended Range Vocabulary Test (Educational Testing Service, 1976) and more years of formal education (17.1 vs. 13.9) than did young adults. Older adults' mean score on the MEQ (Horne & Ostberg, 1976) was 66.7 ($SD = 6.4$), putting them into the "Moderately Morning" category. Young adults' mean MEQ score was 40.2 ($SD = 9.1$), putting them in the "Moderately Evening" category.

Materials and Procedure

All testing occurred in the early morning (before 9 a.m.) or late afternoon (after 4 p.m.). Participants judged whether the duration of a computer-generated stimulus was closer to a short or long anchor duration. The short anchor duration was 3 s; the long anchor duration was 6 s. Stimuli consisted of a 5.5- × 5.5-in. black square or an 880-Hz tone presented on an Apple Macintosh Quadra 700 computer with a 14-in. Apple color monitor.

The 76 test trials were presented after an 8-trial training period (2 single trials per modality, 4 compound trials) that familiarized participants with the anchor durations. Durations of 3, 3.57, 4.24, 5.27, and 6 s were used during test trials. Upon termination of a stimulus, the participant classified its duration as closer to the short or long anchor duration. Each participant completed 40 trials in which a single stimulus modality (the square or the tone) was presented and 36 compound trials that required simultaneous judgment of two stimuli of different modalities, durations, and onset latencies. Discrepancies in onset latency for compound trials ranged from 0.5 to 2 s. Trials were presented in a random mixed order. After the test trials, participants completed the MEQ and a vocabulary test (Extended Range Vocabulary Test, Version III; Educational Testing Service, 1976). Older adults also completed a dementia screen.

RESULTS AND DISCUSSION

Psychophysical functions relating the probability of a "long" response to signal duration for each group were sigmoidal in form and closely matched those previously reported for this testing paradigm (e.g., Penney et al., 2000). The psychophysical functions for the visual stimuli were shifted to the right of those for the auditory stimuli, replicating the classic finding that auditory stimuli are reliably judged longer than visual stimuli of the same duration. These effects can be explained by the different clock speeds for the two modalities (i.e., the internal clock accumulates pulses at a slower rate for visual than for auditory signals, because visual signals are less efficient in closing the attentional gate to allow the accumulation of pacemaker pulses that mark the passage of time). This difference in clock speeds for the two modalities, combined with mixed-modality memory distributions for both the short and the long anchor durations, results in the maintained displacements of the auditory and visual functions (Penney et al., 1998, 2000). Figure 1 shows the mean temporal bisection functions plotting the probability of a "long" response as a function of signal duration for each of the four combinations of modality and trial type (single tone, single light, compound tone, and compound light), separately for the two age groups.

We fit the psychophysical functions from individual participants with a modified version of scalar timing theory that fits the auditory and visual functions simultaneously (Penney et al., 1998, 2000). The model accounted for a relatively large proportion of the variance (overall $M = .89 \pm .01$). For the young adults, the proportion of variation accounted for was $.88 \pm .02$ for single trials in the morning, $.93 \pm .01$ for compound trials in the morning, $.90 \pm .02$ for single trials in the afternoon, and $.93 \pm .01$ for compound trials in the afternoon; for the older adults, the corresponding proportions were $.92 \pm .02$, $.82 \pm .03$, $.91 \pm .03$, and $.85 \pm .03$.

We allowed four parameters in the model to vary: (a) response bias, (b) auditory dominance of memory, (c) relative rate of the auditory and visual clocks, and (d) gamma (γ), the coefficient of variation of remembered time. The bias parameter measures the participant's

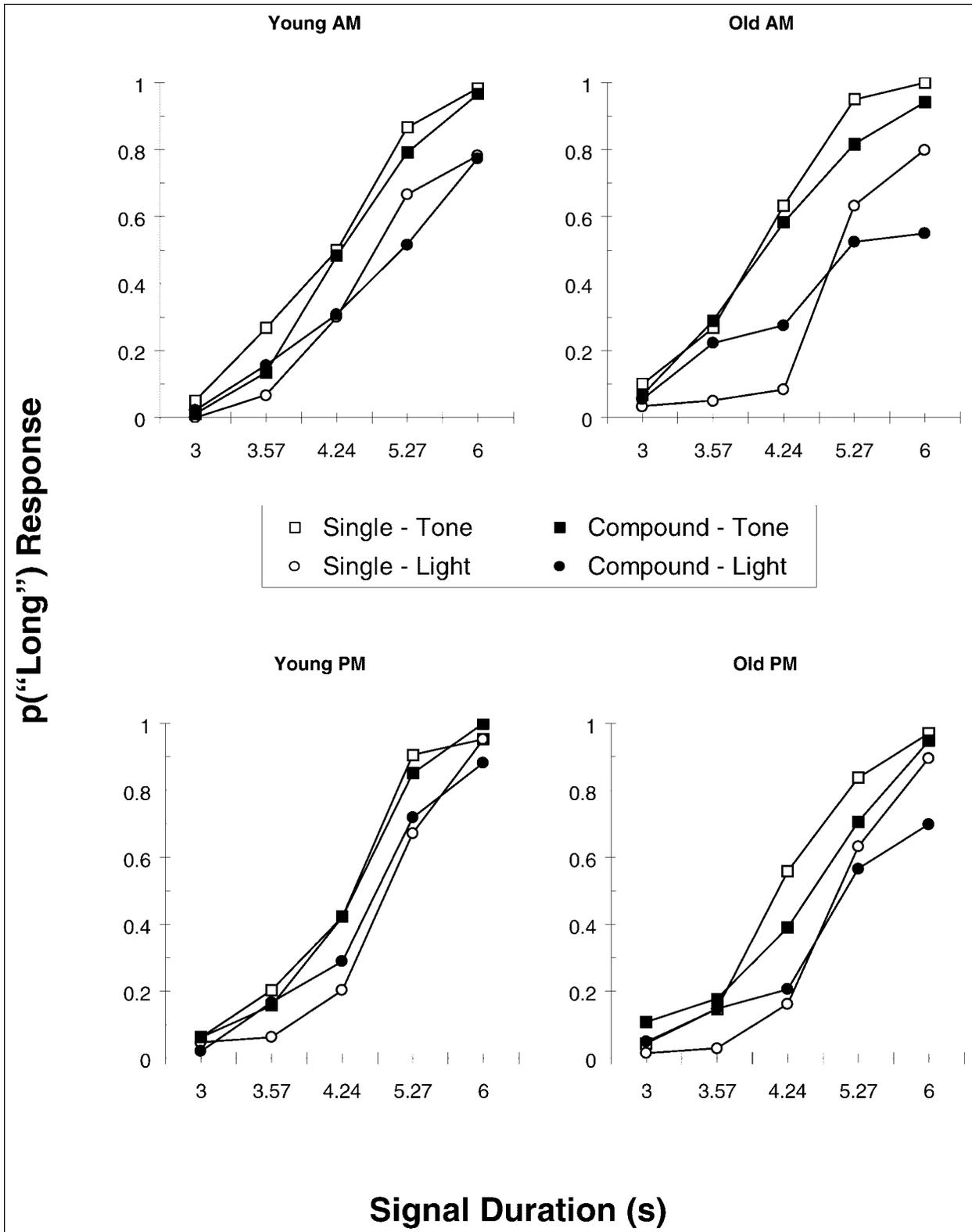


Fig. 1. Temporal bisection functions (probability of a "long" response) for the young and older adults as a function of modality (light vs. tone), trial type (single vs. compound), and circadian phase (morning vs. afternoon).

tendency to be biased in favor of a “long” response. Auditory dominance indicates the degree to which the distributions in reference memory corresponding to the anchor values are dominated by auditory rather than visual values. Relative rate is the ratio of clock speed for visual signals to clock speed for auditory signals. Relative rate equals 1.0 when clock speed is the same for both modalities, is greater than 1.0 when visual clock speed is faster, and is less than 1.0 when auditory clock speed is faster. The sources of variability represented by gamma include encoding and decoding variability in the representation of the anchor durations, as well as variability in the representation of the current accumulated time. Lower values indicate less variability and thus greater sensitivity to signal duration.

We analyzed the best-fitting parameters obtained from the scalar timing theory fits using an Age (young, older) \times Time of Day (morning, afternoon) \times Trial Type (single, compound) design. Age and time of day were between-subjects variables; trial type was a within-subjects variable. No significant differences were found for measures of auditory dominance or response bias. (Mean best-fitting values for auditory dominance were as follows: $.49 \pm .03$ for the young group in the morning, $.55 \pm .04$ for the young group in the afternoon, $.47 \pm .05$ for the older group in the morning, $.51 \pm .03$ for the older group in the afternoon. Mean best-fitting values for response bias were as follows: $.89 \pm .04$ for the young group in the morning, $.92 \pm .02$ for the young group in the afternoon, $.90 \pm .03$ for the older group in the morning, $.83 \pm .03$ for the older group in the afternoon.) We next examined the relative clock speed for visual versus auditory signals. As expected, these values were less than 1.0 for all groups, indicating a faster auditory clock. Young adults showed less disparity between visual and auditory clock speeds than did older adults, $F(1, 63) = 7.83, p < .01$, and both age groups showed less disparity in clock speeds in the afternoon than in the morning, $F(1, 63) = 4.01, p < .05$. Relative clock speed is plotted as a function of age and time of day in Figure 2.

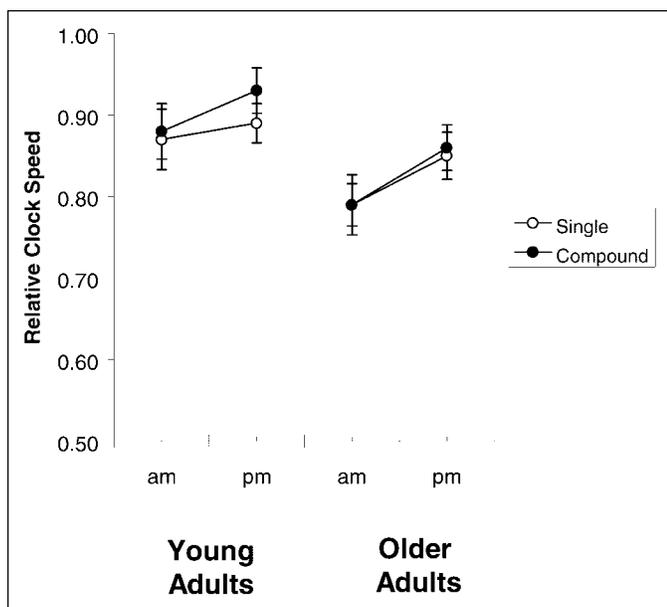


Fig. 2. Relative clock speed as a function of age (young vs. old), trial type (single vs. compound), and circadian phase (morning vs. afternoon). Values less than 1.0 indicate a slower visual clock speed relative to the auditory clock speed.

Analyses of the sensitivity measure, gamma, showed that overall, participants tested in the afternoon were less variable in their judgments (i.e., more sensitive to duration) than were participants tested in the morning, $F(1, 63) = 4.88, p < .05$. Examination of the significant Age \times Trial Type interaction, $F(1, 63) = 17.96, p < .0001$, revealed that whereas young adults did not display an effect of trial type, $t(33) = 1.04, p > .05$, replicating the results of Penney et al. (2000), older adults performed similarly to young adults on single trials, $t(32) = 1.80, p > .05$, but were much less sensitive to time on compound (divided-attention) trials, $t(32) = 4.03, p < .0005$. Data showing sensitivity to duration as a function of age and time of day are plotted in Figure 3.

These analyses confirm earlier reports that task variables such as stimulus modality can affect the functioning of the internal clock, and indicate the impact of other attention-related variables. All groups produced the classic “sounds are judged longer than lights” finding, indicating faster clock speeds for auditory than for visual trials. These results also show that interval timing is affected by circadian cycle, with greater sensitivity to time and smaller modality differences in clock speed in the afternoon than in the morning (see also Meck, 1991). Finally, these results demonstrate that age differences in controlled attention can affect the functioning of the internal clock. Like other populations thought to have difficulty controlling attention (e.g., frontal lobe patients and individuals at risk for schizophrenia; Meck & Benson, in press), older adults showed larger disparities than did young adults in their duration judgments of visual versus auditory signals. As is the case in many domains (e.g., memory; see Anderson, Craik, & Naveh-Benjamin, 1998; Grady & Craik, 2000), age differences were greater under divided-attention conditions than on single-stimulus trials. Young and older adults were equally sensitive to time on single trials, a result that replicates previous findings (Wearden et al., 1997, Experiment 2). However, although young adults’ sensitivity to time was not affected by the divided-attention manipulation (see Penney et al., 2000), older adults were much less sensitive to time on the compound trials than on the single trials.

In short, the results replicate standard findings regarding the influence of modality, age, and divided attention on duration judgments. They also provide evidence that the duration judgments of older adults are more affected by modality differences and divided-attention manipulations than are those of younger adults.

The most notable findings, however, suggest that older adults tested in the morning may have focused their efforts on the single visual trials, largely ignoring the other trial types. To investigate this possibility, we reanalyzed the sensitivity measure and compared performance on the single auditory and single visual trials using sequential rather than simultaneous fits, thus allowing for a separate sensitivity measure to be calculated for each function. In this set of analyses, older adults tested in the morning were found to be extremely sensitive to the single visual trials and relatively insensitive to the single auditory trials, $F(1, 63) = 5.96, p < .05$. This suggests that in the morning older adults successfully concentrated their attentional resources on the single visual trials, largely ignoring the others. Data showing sensitivity to duration (γ) for single trials are plotted as a function of age, time of day, and modality in Figure 4.

Our interpretation of this age-by-time-of-day interaction for temporal stimuli that require controlled attention receives indirect support from a number of sources. Previous observations (Meck, 1991) show that rats tested at nonoptimal portions of their circadian cycles also demonstrate an increase in sensitivity to signal durations presented in one modality (e.g., visual) and a decrease in sensitivity to signal dura-

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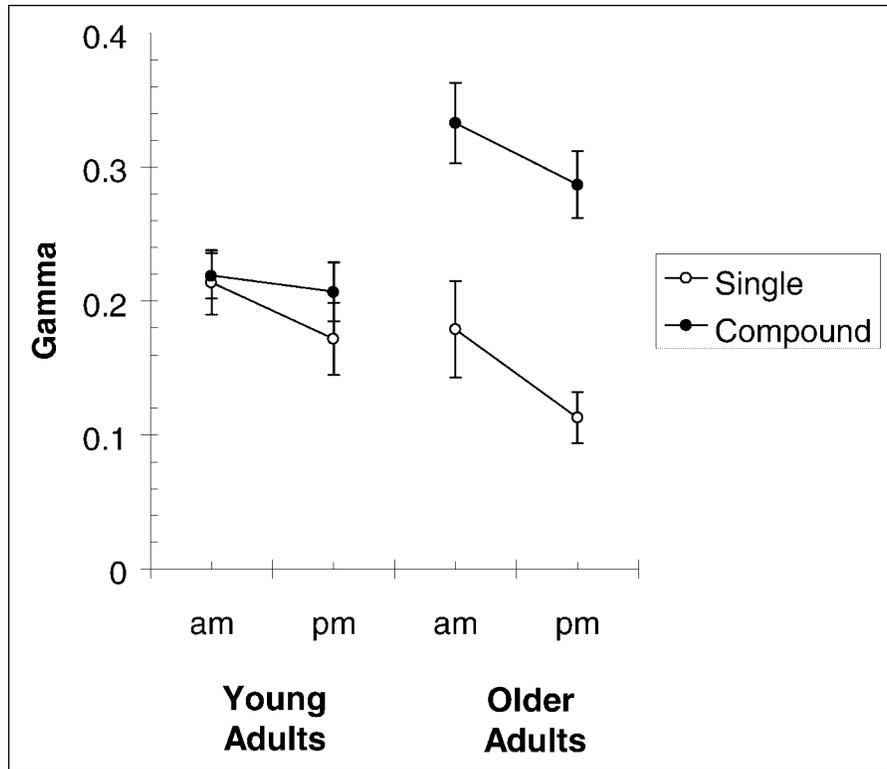


Fig. 3. Sensitivity to signal duration (gamma) as a function of age (young vs. old), trial type (single vs. compound), and circadian phase (morning vs. afternoon).

tions presented in the other modality (e.g., auditory). Such concurrent increases and decreases in temporal sensitivity deviate from the expected form of the circadian modulation that would occur if only one modality were used. The divergence in sensitivity to signals of different modalities previously shown by animals tested at nonoptimal times of day suggests that when attentional resources are limited, participants may apply a selection process that determines the allocation of those resources to different sensory channels.

Selection-optimization-compensation (SOC) models of development focus on the idea that resource limitations influence how remaining resources are allocated to prospective goals (Freund, Li, & Baltes, 1999). In particular, age-related declines in physical and cognitive function may cause older adults to show a different pattern of goal selection and resource allocation than do young adults (e.g., Li, Lindenberger, Freund, & Baltes, 2001). Age-related reductions in controlled attention are well established (e.g., Anderson et al., 1998; Grady & Craik, 2000; Lustig, Hasher, & Tonev, 2001) and have clear effects on older adults' interval timing (e.g., Craik & Hay, 1999; McCormack et al., 1999; Vanneste & Pouthas, 1999; Wearden et al., 1997). It has also been observed that reduced attentional resources can cause older adults to act as "cognitive misers" who devote their resources to one aspect of a task while neglecting others (Hess, Follett, & McGee, 1998).

In the present study, older adults tested in the morning appear to have devoted their attention to the single visual trials, ignoring the other signal modalities and trial types. This interaction between age and circadian phase is consistent not only with SOC theory, but also with previous findings that circadian influences have their largest impact on older adults' ability to ignore irrelevant information in order to

focus on relevant information in the service of current goals (as in the interference trials of the Stroop paradigm or the Trail-Making Test; Yoon et al., 1999). In conclusion, the results of the temporal bisection task reported here provide strong evidence for the influence of age and circadian phase on the reduction and allocation of attentional control in timing and time perception.

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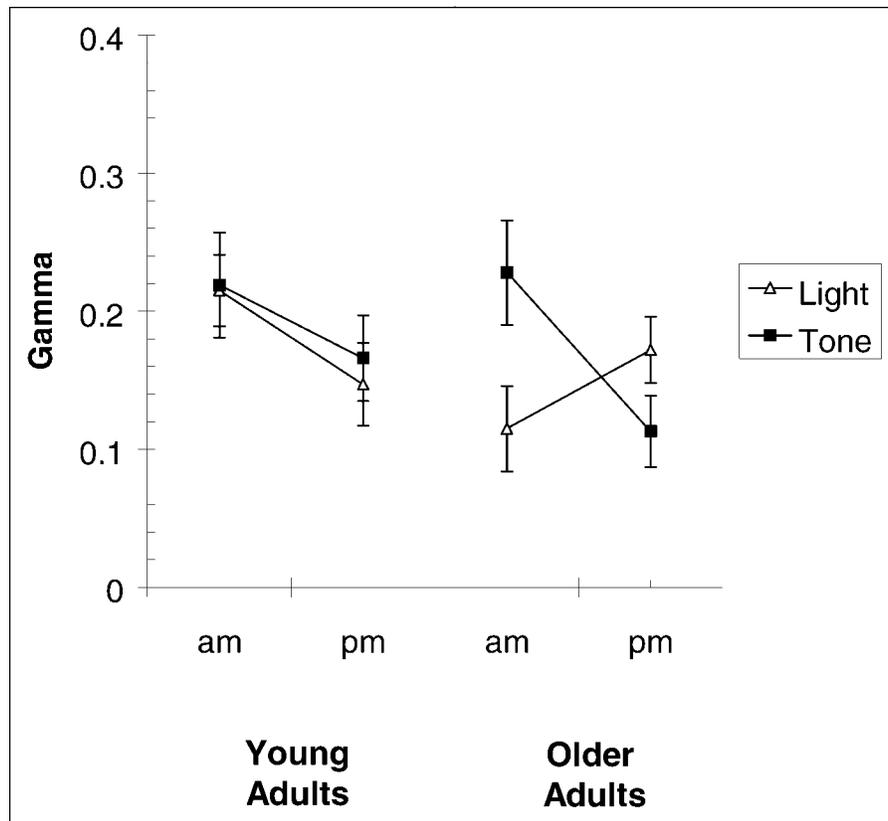


Fig. 4. Sensitivity to signal duration (gamma) for single trials as a function of age (young vs. old), stimulus modality (light vs. tone), and circadian phase (morning vs. afternoon).

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