Does Age Change the Distribution of Visual Attention? A Comment on McCalley, Bouwhuis, and Juola (1995)

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A paper by McCalley, Bouwhuis, and Juola (1995) suggested differences between younger and older adults in the use of visual cues. Furthermore, they reported these differences could largely be attributed to diminished (peripheral) visual processing capacities of elderly adults. Here, we reanalyze the data of McCalley and colleagues emphasizing relative rather than absolute differences. We find that when doing so, the data do not reveal differences in the way older and younger adults transiently allocate attention during visual search. Contrary to the conclusions of McCalley and colleagues, the similarity between the younger and older observers is therefore independent of the characteristics of the visual information. Furthermore, in our view the data suggest that older adults have foveal rather than peripheral visual processing difficulties. The results reemphasize the importance of the analytical approach taken in aging research. We discuss the difficulties and relevance of controlling and separating visual and attentional factors in age-related studies.

McCALLEY, Bouwhuis, and Juola (1995) examined whether younger and older adults differentially allocated selective attention in a visual search task. In two experiments, participants had to search for a target (a C) among 23 distractors (Os). Reaction times and errors for gap direction discrimination were recorded for a group of healthy young and old participants. The experiments compared the effects on target discrimination of cues presented at various locations and at various stimulus onset asynchronies (SOAs). In particular, a four-way interaction between age, target location, cue location, and SOA led to the conclusion that older and younger adults distribute attention differently, apparent from differential costs and benefits for valid and invalid cues. In a second experiment, in which target and distractor size were scaled with eccentricity, these age-related interaction effects disappeared. McCalley and colleagues therefore drew the conclusion that the differences between older and younger participants were due to differences in (peripheral) visual processing capacities.

These findings could have important implications for our understanding of how age affects the use of attention as well as older people's visual task performance in general. Although it was a well-designed study, we believe some of its conclusions may depend strongly on the particular approach taken in the data analysis. Here, we propose a different method of analysis and reach different and sometimes opposite conclusions. Our main point of critique is that McCalley and colleagues used absolute reaction time (also referred to as linear reaction time) to assess age differences. In many "real-world, real-time" conditions, such as traffic or vocation, absolute time differences are highly relevant. Therefore, an analysis of absolute reaction time data, such as carried out by McCalley and colleagues, is valuable for pointing out the extent to which an older person's performance may deviate from that of a younger person's in such circumstances.

However, when the goal is to examine possible age-related differences in the mechanisms underlying performance, analysis of absolute reaction-time data may not suffice. On nearly all tasks, older adults tend to be slower than younger adults are. As has been pointed out before (e.g., Cerella, 1985; Myerson, Hale, Wagstaff, Poon, & Smith, 1990; Salthouse, 1985), the principal effects of age on reaction time in sensory-motor tasks and mental functioning can be well understood on the basis of a simple, multiplicative "slowing" model. (Myerson and colleagues, 1990, proposed a nonlinear model, based on the assumption of information loss over multiple discrete processing steps, to also account for the positively accelerated relation between latencies for older and younger participants.) Because of the multiplicative nature of the slowing phenomenon, task manipulations that result in changes in performance in younger adults, such as cueing, can be expected to result in proportionally larger effects in older adults. Hence, before postulating specific deficits based on age by task interactions, general slowing should be ruled out as an explanation of the results. Salthouse (1988) presented an analogous line of reasoning with respect to the age by complexity phenomenon.

In this comment, we will examine the extent to which the results of McCalley and colleagues can be understood on the basis of general slowing. Whether general slowing can account for the pattern of results can easily be examined by using log-transformed, rather than absolute reaction-time, data (as has been suggested previously; Cerella, 1985; Salthouse, 1988). The log transformation treats equal ratios as equal intervals so that only influences exceeding the prediction made by general slowing will show significant age-

related interactions. Alternatively, reaction-time data can be normalized relative to a neutral condition.

There is also a statistical reason for using log-transformed rather than absolute reaction-time data. A statistical test like analysis of variance (ANOVA) requires that the measurement is normally distributed and that the variance in the data is the same for all groups or treatments tested. In the experiments of McCalley and colleagues, as in many other age-related studies, this requirement is not met because the variances in the data become larger as the absolute reaction time increases. A solution is to analyze mathematically transformed observations rather than the original observations. Clarke (1969) advises the use of a logarithmic transformation if the standard deviation increases at the same rate as the size of the response. This is clearly the case with the absolute reaction time data of McCalley and colleagues (young participants: mean = 619 ms, SD = 310; older participants: mean = 1132 ms, SD = 668; McCalley et al., 1995).

We used the original data of McCalley and colleagues' first experiment and analyzed it using a repeated measures ANOVA and a 2 (age group) by 3 (target location) by 4 (cue type) by 4 (SOA) mixed model design. Target and cue location and SOA were treated as within-subject variables, and age as a between-subject variable. The only difference in approach with respect to McCalley and colleagues is that we log transformed the reaction time data prior to the statistical analysis.

As for the analysis of the absolute reaction time data by McCalley and colleagues, our current analysis supports the existence of a highly significant age effect, $F(1,21)$ = 56.0, p < .0001, as well as significant target location, $F(2,2)$ = 26.2, p < .0001, and cue, $F(3,63)$ = 12.7, p < .0001, effects. The results start to differentiate from those reported by McCalley and colleagues when we look at age-related interactions. In particular, McCalley and colleagues reported the existence of a significant interaction between all four experimental variables. A four-way interaction would indicate that the two age groups show significantly different cue effects for the different target interactions with increasing SOA.

To further substantiate this, McCalley and colleagues calculated cueing effects (shown in Figure 3 and tabulated in Table 2 of McCalley and colleagues, 1995). (This approach can enhance the statistical power in a way that is similar to using a paired t test.) However, no statistical analysis was performed on these data.

In our current log-based analysis, the four-way interaction is not significant, $F(18,378)$ = 1.33, p = .17. (Note that after log transformation the reaction-time data now behave similarly to the error data for which this four-way interaction was not reported as significant in McCalley and colleagues' original analysis [p. 320]).

Using the log-transformed reaction-time data, we further calculated for each participant the cueing effect, that is, the costs inflicted by invalid cues plus the benefits caused by valid cues. We analyzed these cueing effects using a repeated measures ANOVA with target location and SOA as within-subject variables, and age as a between-subjects variable.

Except for an overall trend in the effect of SOA, $F(3,63)$ = 2.69, p = .05, none of the parameters significantly affects

the cue effects or shows a significant interaction with age (age: $F(1,21)$ = 0.135, p = .72; age by SOA: $F(3,63)$ = 1.94, p = .13; age by target: $F(2,42)$ = 0.223, p = .80; age by target by SOA: $F(6,126)$ = 0.422, p = .86). We performed the same analysis for the error data. Although there is a significant effect of target position, $F(2,42)$ = 5.695, p = .007, the results further mimic those for reaction time in that there are no significant age-related interactions (age by SOA: $F(3,63)$ = 2.164, p = .10; age by target: $F(2,42)$ = 1.052, p = .36; age by target by SOA: $F(6,126)$ = 1.165, p = .33). Figure 1 plots these cue effects for older and younger adults for reaction time as a function of SOA (this is essentially Figure 3 of McCalley et al., 1995, plotted logarithmically and split for the different target positions).

Therefore, when relative rather than absolute differences in performance are emphasized, the reaction time results of this experiment reject the notion that there are spatial or temporal differences in the way older and younger adults used the cue information (this result is confirmed by the error data). Hence, there is no evidence that older and younger adults make different trade-offs between selection and inhibition, as is clear from the comparable cue effects.

According to McCalley and colleagues, the (in our view nonexistent) age-related differences in attentional processing of Experiment I might have been caused by differential visual processing capacities. They attempted to control for such effects in their second experiment. This experiment was nearly identical to the first one except that target and distractor sizes were scaled with eccentricity to compensate for the reduced resolving power of peripheral vision. In this
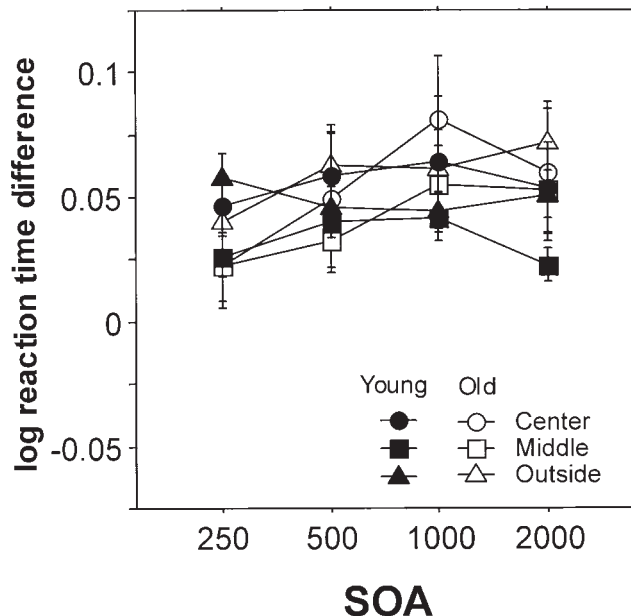

Figure 1. Mean cueing effect (difference between reaction time for invalid and valid cues) as a function of stimulus onset asynchrony (SOA) and target location for older (open symbols) and younger (filled symbols) observers. Bars show standard errors. Logarithmically transformed reaction time data of Experiment I of McCalley, Bouwhuis, and Juola (1995) were used to derive this figure.

experiment, the four-way interaction of age with the other three experimental variables disappeared. McCalley and colleagues therefore concluded that the age-related attentional effects found in the first experiment could be attributed to (peripheral) visual processing difficulties. Log transforming the reaction-time data of Experiment II does not result in a different conclusion than that already drawn by McCalley and colleagues. On the basis of our current analysis of Experiment I, we can now draw the conclusion that the similarity of cue effects in younger and older participants is independent of the specific visual stimulus characteristics.

Scaling targets for eccentricity had a somewhat unexpected side effect. Whereas in Experiment I reaction times *increased* with eccentricity, in Experiment II reaction times (and error rates) *decreased* with eccentricity (see Table 8 of McCalley et al., 1995). McCalley and colleagues explain this finding as either an attentional effect, an effect of stimulus degradation, or visual interference. We would like to suggest a further possibility. Scaling factors differ widely for different visual tasks (for an overview see, e.g., Drasdo, 1991). The scaling McCalley and colleagues used was based on data published by Anstis (1974) for letter acuity thresholds. Data published on the scaling of Landolt-C acuity with eccentricity (data of Weymouth, 1958, and Virsu, Näsänen, & Osmoviita, 1987, cited in Table 19.2 of Drasdo, 1991) show that the required increase in size for Landolt-C–type stimuli is much smaller (in the order of a factor 2) than the scaling based on Anstis's letter acuity experiment. Scaling the Landolt-C target and the distractors according to Anstis's formula therefore induces an overcompensation for eccentricity. Consequently, reaction time and errors will decrease, rather than increase with eccentricity.

As indicated by McCalley and colleagues, older people profited most from (over)scaling target size with eccentricity. This can quite readily be understood on the basis of the nonlinear relationship between performance and visual stimulus characteristics such as contrast and size (performance saturates at roughly 10 times the threshold value for these factors). In the first experiment, the targets measured 0.55 deg of visual angle with 0.1 deg gaps. Older participants' visual acuity will tend to be somewhat lower than that of younger participants (in a group of seven young adults, mean age 25, we found Snellen acuity to be 1.26, whereas that of 10 healthy older adults, mean age 70, was 1.0). Gap size will therefore have been closer to older people's acuity limit ($6\times$ threshold) than to that of the younger people ($7.6\times$ threshold). Due to the nonlinear relationship, those with the lower acuity, that is, the older adults, will profit most from an increase in size.

Using relative rather than absolute comparisons may lead to further differences in interpretation of the data. McCalley and colleagues emphasize that older participants had more problems identifying *peripheral* targets. The proportional increase in reaction time of the older adults (relative to that of the young) is 81% for central and 73% for outside targets, respectively. In the second experiment, in which targets were scaled with eccentricity to control for potential stimulus visibility effects, the proportional increase for older participants is 52% for central and 40% for outside targets, respectively. Therefore, the age-related change in reaction time with ec-

centricity is such that we would conclude that older adults have relatively *more* problems identifying central and *fewer* problems identifying peripheral targets. This could potentially be due to their somewhat lower foveal visual acuity.

We agree with McCalley and colleagues that the age by target location interaction in the error data of Experiment I might indicate that older people use attention to offset visual processing difficulties (but then only the sustained component of attention; see Nakayama & Mackeben, 1989). Our interpretation, however, would be that older participants were using attention to attempt to compensate for their *foveal* rather than *peripheral* visual difficulties.

We further agree with McCalley and colleagues that such visual factors need to be controlled before definitive conclusions can be drawn on age-related effects in visual attention. In our view, one further aspect that should be controlled when investigating visual attention is the effort with which people carry out the task that serves to establish baseline performance. Ideally, effort and baseline performance should be similar for both older and younger adults. The large differences in reaction time and error rates in the neutral conditions suggest this was not the case in the experiments of McCalley and colleagues. It will be hard to obtain comparable baseline performance for older and younger participants using the same stimulus display (even when targets are scaled for eccentricity as the results of McCalley and colleagues' second experiment show). A potentially viable approach might be the use of different stimuli for older and younger adults, adapted in size and contrast to each group's or even individual's visual capacities. Cue effects could then be established relative to the baseline performance that is established using these individually scaled stimuli.

Furthermore, large differences in error rate between younger and older adults, as was the case in the experiments of McCalley and colleagues (see Tables 1 and 7, in McCalley et al., 1995), may indicate the use of different speed-accuracy trade-offs (e.g., Pachella, 1974). Such differences should be avoided because they imply younger and older participants operated at different levels of certainty when responding, thereby hampering a proper evaluation of age-related influences on processing (e.g., Myerson et al., 1990).

In conclusion, McCalley and colleagues' (1995) results on the influences of aging on the use of selective attention in visual search can be accommodated by the notion of general slowing. As such, our current interpretation of their results is in line with other recent findings on visual search, attention and peripheral target localization (e.g., Hartley & Kieley, 1995; Hartley, Kieley, & McKenzie, 1992; Kramer, Hahn, Irwin, & Theeuwes, 1999; Scialfa, Esau, & Joffe, 1998; Seiple, Szlyck, Yang, & Holopigian, 1996).

References

Anstis, S. M. (1974). A chart demonstrating variations in acuity with retinal position. *Vision Research, 14,* 589–592.

Clarke, G. M. (1969). *Statistics and experimental design* (2nd ed.). London: Edward Arnold (Publishers) Ltd.

Cerella, J. (1985). Information processing rates in the elderly. *Psychological Bulletin, 98,* 67–83.

Drasdo, N. (1991). Neural substrates and thresholds gradients of peripheral vision. In J. R. Cronly-Dillon (Series Ed.) & J. J. Kulikowsky, V. Walsh, & I. J. Murray (Vol. Eds.), *Vision and visual dysfunction: Vol. 5. Limits of vision* (pp. 251–265). London: MacMillan Press.

Hartley, A. A., Kieley, J., & McKenzie, C. R. M. (1992). Allocation of attention in younger and older adults. *Perception & Psychophysics, 52,* 175–185.

Hartley, A. A., & Kieley, J. M. (1995). Adult age differences in the inhibition of return of visual attention. *Psychology and Aging, 10,* 670–683.

Kramer, A. F., Hahn, S., Irwin, D. E., & Theeuwes, J. (1999). Attentional capture and aging: Implications for visual search performance and oculomotor control. *Psychology and Aging, 14,* 135–154.

McCalley, L. T., Bouwhuis, D. G., & Juola, J. F. (1995). Age changes in the distribution of visual attention. *Journal of Gerontology: Psychological Sciences, 50B,* P316–P331.

Myerson, J., Hale, S., Wagstaff, D., Poon, L. W., & Smith, G. A. (1990). The information-loss model: A mathematical theory of age-related cognitive slowing. *Psychological Review, 97,* 475–487.

Nakayama, K., & Mackeben, M. (1989). Sustained and transient components of visual attention. *Vision Research, 29,* 1631–1647.

Pachella, R. G. (1974). The interpretation of reaction time in information-processing research. In B. H. Kantowitz (Ed.), *Human information processing: Tutorials in performance and cognition* (pp. 41–82). Hillsdale, NJ: Erlbaum.

Salthouse, T. A. (1985). *A theory of cognitive aging.* Amsterdam: North Holland.

Salthouse, T. A. (1988). The complexity of age × complexity functions: Comment on Charness and Campbell (1988). *Journal of Experimental Psychology: General, 117,* 425–428.

Scialfa, C. T., Esau, S. P., & Joffe, K. M. (1998). Age, Target-Distractor Similarity, and Visual Search. *Experimental Aging Research, 24,* 337–358.

Seiple, W., Szlyck, J. P., Yang, S., & Holopigian, K. (1996). Age-related functional field losses are not eccentricity dependent. *Vision Research, 36,* 1859–1866.

Virsu, V., Näsänen, R., & Osmoviita, K. (1987). Cortical magnification and peripheral vision. *Journal of the Optical Society of America, 4,* 1568–1578.

Weymouth, F. W. (1958). Visual sensory units and the minimal angle of resolution. *American Journal of Ophthalmology, 46,* 102–112.