Research Forum

# Age-Related Changes in Cognitive and Sensory Processing: Focus on Middle-Aged Adults

Larry E. Humes[a]

**Purpose:** The purpose of this article was to examine the effects of age on (a) various psychophysical measures of threshold sensitivity and temporal processing in hearing, vision, and touch and (b) measures of cognitive processing as assessed by the Wechsler Adult Intelligence Scale–Third Edition (Wechsler, 1997).
**Method:** Age group differences and correlations with age were examined, as were associations among age, sensory processing, and cognition.
**Results:** The group analyses showed significant differences on most sensory and cognitive measures such that middle-aged adults performed significantly worse than young adults and significantly better than older adults. Correlations of performance with age were also significant when analyses were restricted to just the young and middle-aged adults. Last, sensory processing, but not age, was significantly correlated with cognitive processing when analyses were restricted to just the young and middle-aged adults.
**Conclusion:** Middle-aged adults experienced declines in both sensory and cognitive processing. The declines in both the cognitive and sensory domains were such that, for most measures in each domain, the performance of middle-aged adults fell somewhere between that of young and older adults.

Humes, Busey, Craig, and Kewley-Port (2013) measured threshold sensitivity and temporal processing in hearing, vision, and touch for 50 young adults (18–30 years, $M$ = 22.6), 60 middle-aged adults (40–55 years, $M$ = 48.1), and 135 older adults (60–87 years, $M$ = 70.8). Cognitive processing was also measured in these same subjects using the Wechsler Adult Intelligence Scale–Third Edition (WAIS-III; Wechsler, 1997). The results for all 245 study participants were pooled, and correlational analyses were employed to examine the effects of age on performance across the adult life span. Given the volume of data—both the large number of measures and the relatively large sample size—the prior report focused almost exclusively on the effects across the entire life span for the entire sample of 245 adults.

Here, these same extensive data are used to refocus the analyses on the middle-aged adults in particular. The article begins with an analysis of the effects of age group, considering the group data for young, middle-aged, and older adults. There are at least three possible patterns of results across the three age groups: (a) Young and middle-aged adults do not differ, but both perform better than the older adults, confining the effects of age to only older adults (≥60 years); (b) each age group differs significantly from the other two, suggesting that significant changes emerge in middle age but continue to progress with advancing age; or (c) middle-aged and older adults do not differ from one another in performance, but both perform significantly poorer than young adults, indicating that deficits in performance emerge in middle-aged adults but do not worsen appreciably with advancing age.

Examination of individual data via correlations could also provide insight into the nature of the life-span changes, and these are examined next. This was accomplished here by including either all of the individual data ($N$ = 245) or only the data for young and middle-aged adults ($n$ = 110). With this approach, one could determine whether the previously observed correlations of performance with age across the adult life span were primarily driven by changes in old age or emerged in middle age. This approach was used to examine associations between age and either sensory or cognitive performance.

Last, Humes et al. (2013) found that associations between age and cognition across the adult life span disappeared when controlling for individual differences in sensory-processing performance, whereas sensory processing and

[a]Indiana University, Bloomington
Correspondence to Larry E. Humes: humes@indiana.edu
Editor and Associate Editor: Robert Burkard
Received October 22, 2014
Revision received November 25, 2014
Accepted November 26, 2014
DOI: 10.1044/2015_AJA-14-0063

*Disclosure:* *The author has declared that no competing interests existed at the time of publication.*

cognitive processing remained moderately and significantly correlated with cognition even when controlling for age. These analyses were repeated here for the middle-aged adults alone to examine the changes in performance across the adult life span in greater detail. That is, among middle-aged adults ranging in age from 40 to 55 years, the question was whether sensory and cognitive processing are correlated when controlling for age. If significant correlations are again observed over this restricted range of ages in the adult life span, then this would further support the contention of Humes et al. that individual differences in cognitive function may be determined by individual differences in sensory processing abilities regardless of age.

Full details of the method used in the study by Humes et al. (2013) can be found in that publication or earlier articles from that project (Busey, Craig, Clark, & Humes, 2010; Craig, Rhodes, Busey, Kewley-Port, & Humes, 2010). In brief, a total of 40 psychophysical measures were obtained in hearing, vision, and touch with an emphasis on threshold sensitivity and temporal processing. Temporal processing measures included gap-detection thresholds, temporal-order thresholds for various stimulus sequences (two or four items in the sequences), and temporal masking (forward and backward masking). In addition, as noted, the full 13-scale WAIS-III, plus two optional incidental learning tests, were completed. The full battery of cognitive and psychophysical sensory measures required about 40 sessions of 90 min for a total of approximately 60 hr of data collection from each of the 245 subjects. The reliability of the measures and the learning effects from repeated exposure to the auditory stimuli have been reported previously (e.g., Fogerty, Humes, & Kewley-Port, 2010). In brief, the measures are reliable, and small systematic learning effects take place during testing for all age groups.

For all of the results presented here, the factor scores generated in Humes et al. (2013) for the cognitive and sensory measures from the entire sample of 245 adults were used. Because all of the measures are factor scores (for all scores, $M = 0$, $SD = 1$), relative comparisons of age effects can make use of the same scale. As expected, for the entire sample of 245 subjects, there were three cognitive factor scores that emerged from the analysis of the WAIS-III measures: (a) Process, sometimes referred to as fluid or nonverbal intelligence; (b) Product, also known as crystallized or verbal intelligence; and (c) Incidental Learning. The latter factor represented performance on the two additional optional measures included from the WAIS-III. These three factors were moderately correlated, and an oblique rotation was most suitable for the factor analysis. Due to the presence of correlated factors, a second-order factor analysis was conducted with a single factor, interpreted as *Global Cognitive Processing* emerging. Examination of age-group differences for each of the three sets of lower-level factor scores and the lone higher-order factor score revealed significant effects of age group in three of the four cases. Only the factor scores for the Product (or crystallized intelligence) factor failed to show significant effects of age group. This was entirely expected (e.g., Salthouse, 2010).

For the three sets of factor scores yielding significant age-group effects, post hoc Bonferroni-corrected paired comparisons showed that the three age groups differed significantly from one another with performance declining with advancing age.

When similar analyses were performed for the sensory-processing measures, Humes et al. (2013) identified eight individual, but somewhat correlated, factors and one global sensory-processing factor for the entire set of 245 subjects. Significant effects of age group were observed for the factor scores for all but the Tactile Gap Detection sensory-processing factor. For seven of the eight sets of factor scores with significant age-group differences, the pattern of group differences was identical to that observed for most of the cognitive measures. To be specific, each age group differed significantly from the others with performance declining with advancing age. The lone exception was the Visual Flicker Fusion factor for which the older adults differed from both younger groups, but the two younger groups did not differ significantly from one another.

To summarize the age-group comparisons, for three of the four cognitive domains and seven of the nine sensory-processing domains that emerged from the analysis in Humes et al. (2013), performance in middle age is significantly worse than that of young adults but significantly better than that of older adults. These group analyses support the gradual worsening of sensory and cognitive processing throughout the adult life span beginning in middle age.

Turning to the correlational analyses, for the four sets of cognitive factor scores, correlations with age across the full adult life span were –.71, –.04, –.45, and –.55 for the Process, Product, Incidental Learning, and Global Cognitive Processing factors, respectively. Only the correlation between age and the Product factor score was not significant ($p < .05$), again, as expected. When the correlational analyses were confined to the younger and middle-aged adults, the resulting correlations were –.56, –.07, –.31, and –.42 for the Process, Product, Incidental Learning, and Global Cognitive Processing factors, respectively. Again, all correlations, except the correlation between age and Product factor score, were significant. The magnitudes of the correlations, however, are muted or attenuated by about 20% when the age range is reduced from 18–86 years to 18–55 years. Nonetheless, these moderate and significant correlations support the group analyses described previously and suggest a graded decline in cognitive function throughout the adult life span beginning in middle age.

When a similar evaluation of the correlations for sensory processing was performed, a pattern comparable to that observed for the cognitive measures was observed. The two sets of correlations with age are shown in Table 1. The middle column shows the correlations between age and each of the nine sets of sensory-processing factor scores for the entire sample of 245 adults spanning 18–86 years of age. The right-hand column shows the same correlations for the 110 subjects ranging from 18 to 55 years of age. Again, the correlations for the narrower range of ages are generally attenuated about 20% compared to those observed

**Table 1.** Pearson *r* correlation coefficients between age and each of the nine sensory processing factor scores for the entire sample of 245 subjects ranging in age from 18 to 86 years (middle column) and for just the young and middle-aged subjects ($n$ = 110) ranging in age from 18 to 55 years.

| Sensory processing factor | Pearson *r* ($N$ = 245; ages 18–86 years) | Pearson *r* ($n$ = 110; ages 18–55 years) |
|---|---|---|
| Auditory Temporal Order/Masking | .56 | .40 |
| Tactile Temporal Order/Masking | .70 | .47 |
| Auditory/Tactile Threshold | .83 | .60 |
| Visual Flicker Fusion | .23 | –.06 (ns) |
| Auditory/Visual/Tactile Temporal Order–Location Task | .55 | .39 |
| Visual Temporal Order/Masking | .59 | .51 |
| Auditory Gap Detection | .33 | .23 |
| Tactile Gap Detection | .06 (ns) | –.12 (ns) |
| Global Sensory Processing | .75 | .52 |

*Note.* All correlation coefficients are statistically significant ($p < .01$) unless indicated (ns = not significant).

for the full age range, but most remain moderate and statistically significant. The correlation between age and the Visual Flicker Fusion factor is the only one that went from a significant to nonsignificant correlation when the age range was narrowed to exclude the older adults.

To summarize these correlations between factor scores and age for cognitive and sensory processing, the decline in sensory processing across the adult life span is not driven exclusively by a rapid decline in older adults. Rather, significant declines with age are observed in three of the four sets of cognitive factor scores and seven of the nine sensory-processing factor scores even when the age range is restricted to 18–55 years. In other words, declines in both areas begin in middle age.

Last, when correlations were examined among age, Global Sensory Processing and Global Cognitive Processing for the 60 middle-aged adults alone, age was significantly correlated with the Global Sensory Processing factor score ($r$ = .33), and Global Sensory Processing and Global Cognitive Processing factor scores were correlated moderately and significantly ($r$ = –.53), but age and Global Cognitive Processing were not significantly correlated ($r$ = –.14). Moreover, this pattern of correlations among these three variables remained basically unchanged when partial correlations for each pair were computed while controlling for the third variable. For example, the partial correlation between age and Global Sensory Processing was $r$ = .31 when controlling for age among the 60 middle-aged adults, only slightly reduced from $r$ = .33. Likewise, the partial correlation between Global Sensory Processing and Global Cognitive Processing was reduced only slightly to $r$ = –.51 from $r$ = –.53 when controlling for age. Last, the nonsignificant correlation between age and Global Cognitive Processing factor scores remained weak and nonsignificant ($r$ = .05) when controlling for Global Sensory Processing.

To summarize, there appears to be an age-independent association between Global Sensory Processing and Global Cognitive Processing among the middle-aged adults that is not related to changes in age across the very narrow range from 40 to 55 years. This is consistent with the general pattern of correlations and partial correlations found in Humes et al. (2013) when focusing on the entire adult life span from 18 to 86 years.

In conclusion, these analyses of the data from Humes et al. (2013), focusing on the middle-aged group or changes during the first 55 years of life, indicate that middle-aged adults experience declines in both sensory and cognitive processing. The declines in both the cognitive and sensory domains are such that, for most measures in each domain, the performance of middle-aged adults lies somewhere between that of young and older adults. This suggests that age-related declines in both general domains are continuous rather than abruptly occurring in old age. There is also a strong link between global sensory declines and cognitive declines, but examining whether such a link supports a causal association must await further research, including longitudinal studies of sensory and cognitive declines in middle-aged and older adults. Correlations, cross-sectional or otherwise, only reveal associations among variables or over time and do not establish cause and effect.

## Acknowledgments

The preparation of the present article was supported, in part, by National Institute on Aging Grant R01 AG008293-21. The work represented in Humes et al. (2013) would not have been possible without the contributions of colleagues Tom Busey, Jim Craig, Diane Kewley-Port, Dana Kinney, and Roger Rhodes as well as the assistance of many graduate students during the course of this project. Of course, without the dedication of the many subjects who completed the long battery of tests, this article would not have been possible, and we are grateful for their participation.

## References

**Busey, T., Craig, J., Clark, C., & Humes, L. E.** (2010). Age-related changes in visual temporal order judgment performance: Relation to sensory and cognitive capacities. *Vision Research, 50,* 1628–1640.

**Craig, J. C., Rhodes, R., Busey, T. A., Kewley-Port, D., & Humes, L. E.** (2010). Aging and tactile temporal order. *Attention, Perception, and Psychophysics, 72,* 226–235.

**Fogerty, D., Humes, L. E., & Kewley-Port, D.** (2010). Auditory temporal-order processing of vowel sequences by young and elderly listeners. *The Journal of the Acoustical Society of America, 127,* 2509–2520.
**Humes, L. E., Busey, T. A., Craig, J., & Kewley-Port, D.** (2013). Are age-related changes in cognitive function driven by age-related changes in sensory processing? *Attention, Perception, and Psychophysics, 75,* 508–524.
**Salthouse, T. A.** (2010). *Major issues in cognitive aging*. New York, NY: Oxford University Press.
**Wechsler, D.** (1997). *Wechsler Adult Intelligence Scale–Third Edition*. San Antonio, TX: The Psychological Corporation.