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Age differences in fluid intelligence: Contributions of general slowing and frontal decline

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Abstract

The current study examined the contributions of general slowing and frontal decline to age differences in fluid intelligence. Participants aged 20–89 years completed Block Design, Matrix Reasoning, simple reaction time, choice reaction time, Wisconsin Card Sorting, and Tower of London tasks. Age-related declines in fluid intelligence, speed of processing, and frontal function were observed. Hierarchical regression analyses showed that the processing speed and frontal function measures accounted for significant variance in fluid intelligence performance, but there was also a residual effect of age after controlling for each variable individually as well as both variables. An additional analysis showed that the variance in fluid intelligence that was attributable to processing speed was not fully shared with the variance attributable to frontal function. These findings suggest that the age-related decline in fluid intelligence is due to general slowing and frontal decline, as well as other unidentified factors.

Keywords: Aging; Fluid intelligence; Frontal function; Processing speed

1. Introduction

In a recent article, Salthouse (2004) makes several observations regarding the "what" and "when" of age-related changes in cognition. He notes that a number of aspects of cognition are detrimentally affected by aging, including processing speed, memory, and reasoning; the negative age trends are often large; and the decline often begins before age 50. At the same time, Salthouse points out that some aspects of cognition (e.g., vocabulary) remain fairly stable from the mid 50s onward. In comparison to what is known about the what and when of cognitive aging, much less is known about what Salthouse calls the "how" of cognitive aging, the mechanisms underlying the cognitive decline. The current study examines the mechanisms that may be responsible for the decline in one aspect of cognition, fluid intelligence.

Fluid intelligence generally refers to reasoning and novel problem-solving ability and is thought to be related to metacognition (Cattell, 1971; Gray, Chabris, & Braver, 2003; Sternberg, 1985). A number of studies, going back to early work by Horn and Cattell (1967), report an age-related decline in performance on fluid intelligence tasks. The existing literature offers several possible mechanisms for the age-related decline in fluid intelligence. Salthouse (1996, 2001a) contends that the age-related decline in a variety of cognitive abilities, including reasoning, can be accounted for by a single mechanism, generalized slowing. By this view, generalized slowing has a detrimental effect on cognitive function in two ways. The first is an inability to effectively execute the component operations involved in a task due to time limitations and the second is the inability to hold information on-line that is necessary for task completion.

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Past aging research on the relationship between fluid intelligence and speed of processing supports the generalized slowing explanation (Hertzog, 1989; Schaie, 1989). In a four-year longitudinal study involving older adults, changes in processing speed strongly correlated with changes in fluid intelligence ($r = .53$; Zimprich & Martin, 2002). About 28% of the age-related variance in processing speed and fluid intelligence was shared variance. In a cross-sectional study, Salthouse (1991) reported that age differences in reasoning ability were significantly attenuated after controlling for processing speed: Across three studies, just 9–29% of the age-related variance in the reasoning measures remained unaccounted for after controlling for variance in perceptual comparison speed. In addition, Bors and Forrin (1995) found that the correlation between age and performance on a fluid intelligence task, Raven's Advanced Progressive Matrices, was non-significant after controlling for mental speed.

A second explanation for age-related cognitive decline relates to the functioning of the frontal lobes. Prefrontal cortex theory (cf. West, 1996) states that goal-oriented functions of the prefrontal cortex (e.g., integrating information, executing complex, sequential behaviors, handling novelty, and inhibiting distracting or interfering information) are most susceptible to age effects because of the neurophysiological changes occurring in this area of the brain. Recent evidence suggests that the frontal lobes are one of the first areas of the brain to be negatively affected by aging. Research has identified decreases in frontal lobe volume (DeCarli et al., 2005; Raz, Torres, Spencer, & Acker, 1993) as well as alterations in frontal cell morphology (Buckner, 2004; Flood & Coleman, 1988; Masliah, Mallory, Hansen, DeTeresa, & Terry, 1993) with age. In addition, the largest age-related reductions in cerebral blood flow have been localized to the frontal and prefrontal areas (Gur, Gur, Obrist, Skolnick, & Reivich, 1987; Mathew, Wilson, & Tant, 1986; Schroeter, Zysset, Kruggel, & von Cramon, 2003; Shaw et al., 1984).

A variety of studies suggest that the frontal lobes are recruited when performing fluid intelligence tasks. Isingrini and Vazou (1997) found, for example, that performance on traditional frontal tasks correlated with measures of fluid intelligence but not crystallized intelligence in a group of older adults. Parkin and Java (1999) showed that fluid intelligence performance accounted for 15–24% of the variance in performance on three tasks of frontal function. Moreover, in a recent functional magnetic resonance imaging study, Gray et al. (2003) found that participants who scored high on a standard measure of fluid intelligence also showed a significantly stronger blood flow response in regions of the frontal cortex (including the lateral prefrontal cortex and anterior cingulate) during a working memory task. This pattern was especially apparent on working memory trials in which interference was high and attentional control was presumably needed to focus on goal-relevant information.

Some existing research supports a frontal explanation for the decline in fluid intelligence with age. Schretlen et al. (2000) hypothesized that "age-related atrophic changes in frontal brain structures undermine the functioning of executive abilities, and that this results in the gradual decline of fluid intelligence" (p. 53). Consistent with this view, they found that executive ability and frontal-lobe volume, but not non-frontal volume, significantly reduced the age-related variance in fluid intelligence. Note, however, that processing speed also reduced the age-related variance in fluid intelligence. Moreover, the contribution of executive ability and frontal volume to the decline in fluid intelligence was largely unrelated to the contribution of processing speed. The Schretlen et al. study therefore suggests that reduced frontal functioning and reduced processing speed both contribute to the decline in fluid intelligence with age.

Schretlen et al.'s (2000) study, as described above, is rather uncommon in that it examined both the generalized slowing and frontal explanations of cognitive aging in the same study. Parkin and Java (2000) note that studies of frontal function often do not include tests of speed or fluid intelligence, fluid intelligence studies often do not include tests of speed or frontal function, and speed of processing studies often do not include tests of frontal function or fluid intelligence. As such, most existing studies operate on a confirmatory bias rather than pitting two theories against one another. Here we follow Schretlen et al.'s lead and examine the role of both generalized slowing and frontal function in the age-related decline of fluid intelligence.

2. Overview of the study

The primary goal of the present study was to examine the contribution of age and processing speed to performance on two fluid intelligence tasks, Block Design and Matrix Reasoning. Following Salthouse (2001b; also see Salthouse, 1996), we examined the residual age-related variance in fluid intelligence after statistically controlling for variance on the processing speed measures (simple reaction time, choice reaction time, and processing speed composite). Specifically, we were interested in contrasting the initial age-related variance with the residual age-related variance following the statistical control procedure. If general slowing contributes to the age-related decline in fluid intelligence performance, one would expect a significant reduction in the age-related variance in fluid intelligence after controlling for measures of processing speed. If general slowing fully accounts for the age difference in fluid intelligence, the increment in variance associated with age after control of the processing speed measure should no longer be significant. If, on the other hand, other factors specific to fluid intelligence performance contribute to the age differences in fluid intelligence, one should observe a significant residual effect of age after controlling for processing speed. Such a result would suggest that competing accounts of the age-related decline in fluid intelligence, such as the frontal function account, may be viable. A second