AGE, SEX AND REGIONAL BRAIN VOLUMES PREDICT PERCEPTUAL-MOTOR SKILL ACQUISITION

Kristen M. Kennedy and Naftali Raz

(Institute of Gerontology and Department of Psychology, Wayne State University, Detroit, MI, USA)

Abstract

Neural mechanisms of skill acquisition across the lifespan are largely unknown. Neuroimaging in younger adults and research on neurodegenerative disorders suggests that perceptual-motor learning relies on the striatum, cerebellum, and prefrontal cortex. Our objective in this study was to explore whether individual differences in regional brain volumes modify the effects of age and sex on the acquisition of a perceptual-motor skill in healthy adults. The participants (N = 85, age 22-80) performed five 5-trial blocks of a mirror-drawing task on three separate days (for a total of 25 trials). Index of performance was time to completion and number of errors committed. All participants improved with practice, but younger adults performed better than their older counterparts, and women performed better than men. Four brain regions – lateral prefrontal cortex (LPFC), hippocampus (HC), cerebellar hemispheres (Cb) and the caudate nucleus (Cd) – were selected on the basis of the relevant literature and measured on MRI scans. All regional volumes were negatively associated with age, although the magnitude of association differed from LPFC (the strongest) to Cd (the weakest). Larger lateral PFC was associated with better performance on the mirror drawing task, and this link was stronger in the older participants and was strengthened at the later stages of learning. Larger caudate was related to better performance, especially at later learning, among men, but among women the link was evident only during early learning. Thus, mirror-drawing represents a task that, despite its visual-spatial nature, favors women, and may exhibit sexually dimorphic brain substrates.

Key words: MRI, volume, prefrontal cortex, basal ganglia, perceptual-motor, skill acquisition

Introduction

Extensive research of the past several decades yielded converging evidence of significant age-related declines in speed of information processing (Salthouse, 1979), executive functions (West, 1996), declarative memory (Verhaeghen et al., 1993) and motor control (Spirduso and MacRae, 1990). By comparison, the investigations of motor and perceptual-motor learning in healthy adults are rather scarce and their results are inconclusive. Some studies of age differences in pursuit rotor (PR) performance revealed age-related slowing of acquisition and reduced levels of proficiency (Gutman, 1965; Raz et al., 2000; Thumin, 1962; Wright and Payne, 1985). Others confirmed the age-related difference in level of performance but not in the rate of acquisition (Durkin et al., 1995; Surburg, 1976). Research on aging and acquisition of other skills reveals a pattern of age-related declines in speed or accuracy of performance but not of the acquisition rate (Cerella et al., 1987; Parasuraman and Giambra, 1991; Thomas-Anterion et al., 1995; Wishart and Lee, 1997).

Study of age differences in perceptual-motor skill learning is complicated by apparent sex differences observed across the life span. Boys outperform girls in pursuit rotor (Langhorne, 1933), peg-moving and dot-filling tasks (Singh et al., 2001). In some samples, men performed PR tasks more accurately and less variably than women, regardless of age (Noble, 1970; Raz et al., 2000). Women perform slower than men in graphic design learning (Thomas-Anterion et al., 1995) and coordination task acquisition (Kauranen and Vanharanta, 1996). However, in the latter study, women were more accurate than men. Notably, in mirror peg-turning task, girls outperformed boys (Sifft, 1980). Women outperformed men in mirror-reversed variants of star-tracing, rotary pursuit, and tapping tasks but there were no sex differences in canonical, non-mirror conditions of these tasks (Darden and Shappell, 1972; O'Boyle and Hoff, 1987; O'Boyle et al., 1995). To complicate the matter even further, individual differences in mental imagery use (Borresen and Klingsporn, 1992; Koslow, 1987), anxiety levels (Kumari, 1970), declarative awareness (Willingham et al., 2001), and prior expertise and abilities (Helode, 1983) may significantly modify acquisition of mirror-tracing skills.

Understanding the mechanisms of skill acquisition was long ago recognized as an important and challenging aspect of general cognitive theory (McGeoch, 1931). Several models proposed to meet that challenge (Anderson, 1983; Karni and Bertini, 1997; Willingham, 1998), share at least one common feature. They all contain a provision for distinct stages of a skill acquisition process. Specifically, early attempts to acquire a novel skill are characterized by effortful, explicit information processing which proceeds under conscious executive control. As the practice progresses, the skill becomes less effortful, more proceduralized and implicit, with almost complete automaticity attained at the expert levels of performance. Surprisingly, those theoretical accounts have been rarely applied to understanding age differences in skill learning.

General and task-specific brain mechanisms of skill acquisition are poorly understood. Studies of amnesiogenic lesions suggest that the neural basis of procedural learning does not involve medial temporal structures, which are critical for declarative knowledge and episodic retrieval (Squire, 1992). Studies of focal lesions and neurodegenerative diseases suggest that perceptual-motor learning requires an intact striatum, cerebellum, and prefrontal cortex, and that the caudate nucleus is involved in the cognitive facets of skill learning while the putamen is implicated in the motor aspects (Daum et al., 1995; Gabrieli, 1998). A recent study suggests that volumes of the putamen and the cerebellum may mediate age effects in PR performance at the early stages of acquisition but only cerebellar volume appears to matter for skilled performance (Raz et al., 2000). By contrast, in acquisition of a cognitive skill, prefrontal cortex mediates the age differences at the beginning of acquisition but not after proceduralization of the skill (Head et al., 2002). Notably, in both volumetric studies, working memory proficiency (an age-sensitive ability; Salthouse, 1994) was a significant predictor of motor or cognitive performance at all stages of acquisition suggesting that age-related restriction of cognitive resources affects both acquisition and maintenance of various skills (Raz et al., 2000; Head et al., 2002).

In the study reported here, we examined age-related differences in acquisition of a novel perceptual-motor task – mirror drawing. We hypothesized that although older participants would perform slower than their younger counterparts, the former would show significant improvement over the course of practice. Because the task combines cognitive (image transformation) and perceptual-motor features, we expected that at the beginning of training, larger volume of the prefrontal cortex, striatum, and cerebellum would be associated with better performance. In contrast, we predicted that as the skill would become more proceduralized, the proportion of performance variance explained by the LPFC and striatal volumes would diminish, whereas larger cerebellar volume would continue to be associated with faster and more accurate performance. In accordance with the neuropsychological literature, we hypothesized that the volume of the hippocampus (selected as the control region) would show no significant association with performance.

Materials and Methods

Participants

Participants for this study were paid volunteers recruited as part of an ongoing investigation of neuroanatomical correlates of age-related differences in cognition. All potential participants were screened by a health questionnaire for history of cardiovascular, neurological and psychiatric conditions, head trauma with loss of consciousness, alcohol and drug abuse, thyroid problems, and diabetes. Participants were also screened for dementia and depression using a modified Blessed Information-Memory-Concentration Test (Blessed et al., 1968) and the Geriatric Depression Questionnaire (Radloff, 1977) with cut-offs of 30 and 15, respectively. All participants exhibited strong right-hand preference for basic manual activities (75% and above on the Edinburgh Handedness Questionnaire; Oldfield, 1971), were native English speakers, and had at least high-school education. Persons who indicated that they suffered from arthritis were not included in the sample. All participants underwent vision (near, far, and color) and hearing (500-4000 Hz range pure-tone audiometry) screenings. An experienced neuroradiologist examined MRI scans for space-occupying lesions and major cerebrovascular abnormalities. Informed consent was obtained according to the Helsinki Declaration and all participants were debriefed in accord with the university Human Subjects Committee guidelines.

The initial sample of this study included 103 healthy adults (45 men, 58 women) ranging in age from 19-80 years. Of those, 98 had complete cognitive data, and 85 had MRI scans. Therefore, the resulting final sample consisted of 85 healthy adults (37 men and 48 women) ranging in age from 22-80 (mean age 47.38 ± 17.03 years). The mean education was at college level (16.00 ± 2.42 years). The men and women in this study differed in neither age [t (83) = .99, ns] nor education [t (83) = 1.55, ns]. Some of the participants in this study also participated in other studies of aging, brain, and cognition (Head et al., 2002; Raz et al., 2000, 2001, 2004a).

MRI Protocol

Imaging was performed on a 1.5T Signa scanner (General Electric Co., Milwaukee, Wisconsin). The image acquisition sequences are described in detail elsewhere (Raz et al., 1997, in press). All volumetric measures were performed on the reformatted images that were acquired using T1-weighted 3-D spoiled gradient recalled acquisition sequence (SPGR, 124 contiguous axial slices, echo time, TE = 5 msec, and repetition time, TR = 24 msec, field of view, FOV = 22 × 22, acquisition matrix 256 × 192, slice thickness = 1.3 mm, one excitation, and flip angle = 30°). In addition, a double-echo proton density/T2 weighted Fast Spin Echo (FSE) axial sequence was acquired with TE = 90 msec, TR = 3300, FOV = 20, matrix 256 × 256, and slice thickness = 5 mm, gap = 2.5 mm. These images were used to screen for cerebrovascular disease.