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Age differences in spatial memory in a virtual environment navigation task

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Abstract

The use of virtual environment (VE) technology to assess spatial navigation in humans has become increasingly common and provides an opportunity to quantify age-related deficits in human spatial navigation and promote a comparative approach to the neuroscience of cognitive aging. The purpose of the present study was to assess age differences in navigational behavior in a VE and to examine the relationship between this navigational measure and other more traditional measures of cognitive aging. Following pre-training, participants were confronted with a VE spatial learning task and completed a battery of cognitive tests. The VE consisted of a richly textured series of interconnected hallways, some leading to dead ends and others leading to a designated goal location in the environment. Compared to younger participants, older volunteers took longer to solve each trial, traversed a longer distance, and made significantly more spatial memory errors. After 5 learning trials, 86% of young and 24% of elderly volunteers were able to locate the goal without error. Performance on the VE navigation task was positively correlated with measures of mental rotation and verbal and visual memory.

Keywords: Navigation; Hippocampus; Age; Spatial memory; Route learning; Virtual reality; Maze; Human

1. Introduction

Age-related deficits in spatial maze-learning are evident in both place and route learning tasks in a number of mammalian species [5,23,35]. In the rodent hippocampus, "place cells" which respond to particular locations in space [29] change their response characteristics with age. It is thought that these and other cellular alterations in the hippocampus and other cerebral structures may underlie the age-related behavioral deficits observed in spatial learning tasks in non-human species [6,7,51,56].

There have been few studies that have systematically examined age-related vulnerability in route-learning or topographical memory in humans. Survey research indicates that elderly individuals have self-perceived deficits in navigation and develop behavioral patterns to avoid unfamiliar routes and places [10]. Direct assessments of navigational/route finding skills in non-demented elderly adults provide evidence of age-related differences in these skills [26,27, 41,61]. Furthermore, clinically relevant impairments in navigational skills are often apparent in the early stages of dementia [28,46], in many cases contributing to the diagnosis [3,37]. These results suggest that elderly adults encounter more difficulty than younger adults in learning and remembering routes through novel environments.

The ecological evaluation of route-learning in humans is complicated by the fact that human navigation takes place over relatively large-scale space. It is difficult to gain sufficient control over the external environment to allow the systematic evaluation of human navigation in a controlled setting. The development of virtual environment (VE) technology has made possible a systematic and laboratory-based investigation of navigation in humans [31,58]. These computer-based programs allow simulated exploration of 3D environments from a viewer-centered perspective and allow the experimenter to gain control over environmental stimuli and complexity of the learning environment. Moreover, detailed records of the behavior of individuals within the environment may be recorded and subjected to objective scoring criteria. VE technology has been used successfully in younger participants to assess acquisition of spatial knowledge [20], sex differences in both overall perfor-

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mance [4,36] and strategic use of environmental cues [50], theta oscillations in electroencephalography [25] and regional brain activation patterns in neuroimaging studies [1,21,30,32].

Despite the fact that navigating successfully through the world is clearly an ecologically important aspect of human behavior, the vast majority of studies of human cognitive aging have assessed memory using tests that require the encoding and retrieval of words or geometric figures. In contrast, spatial memory in non-human species is typically assessed using maze learning tasks that require the animal to navigate and remember routes or specific locations in novel environments. Researchers examining behavior in non-human species, particularly rodents, theorize that the hippocampus and related structures may generate representations of the position of an animal in space and continually update this position via the firing of networks of cells responsive to spatial location [15,45], head direction [11], optic flow [63] and other spatial and movement sensitive parameters. These data have led to models which are navigational in nature, or which focus primarily on spatial memory, and emphasize the role of the hippocampus, subiculum and parahippocampal regions. Models of human cognitive aging have been derived primarily from the perspective of episodic memory in which an explicit memory system may be involved in the encoding and explicit recall of events or episodes [12,43]. Although there appears to be considerable divergence between spatial navigation and episodic memory approaches, it seems likely that there is considerable functional, anatomic and evolutionary continuity between these systems [15,38,40,52,54].

The tendency to emphasize different components of cognitive aging and of hippocampal and parahippocampal memory function in particular can be seen to arise primarily from the different behavioral tasks used across species. To investigate cognitive aging from a comparative approach, it is desirable to assess the behavior of human and non-human species under similar behavioral conditions and to develop an understanding of the degree of behavioral and ultimately the neurological overlap between navigational measures of human learning and memory and more traditional cognitive measures.

The purpose of this study was two-fold. Firstly, we quantified the magnitude of age-related decline in VE navigation in a variety of aspects of performance. Secondly, we sought to examine the intercorrelation between our VE navigation task and more traditional psychometric measures of cognitive aging. Because researchers draw similar inferences for cognitive aging from spatial navigational tasks in non-human species and from psychometric measures in humans, it is important to understand the behavioral overlap between these apparently divergent cognitive tasks.

Table 1
Sex and age distribution of sample

	Young (<45 Years)	Middle (45–65 Years)	Old (>65 Years)
Male	14	21	33
Female	14	22	13
Total	28	43	46

2. Methods

2.1. Participants

The sample included 133 individuals—123 participants from the Baltimore Longitudinal Study of Aging (BLSA) and 10 volunteers recruited from Johns Hopkins Bayview Medical Campus. BLSA participants are generally healthy, community dwelling, volunteers who return regularly to the National Institute on Aging for comprehensive medical, physiological and neuropsychological evaluations [53]. Participants meeting NINCDS-ADRDA diagnostic criteria for dementia [34] were excluded from participation. Mean age of the BLSA participants was 57.8 ($\pm$18.5) years (range 22–91 years). BLSA participants are generally well-educated, and our sample had a mean education of 16.89 ($\pm$2.58) years. Because the age distribution in the BLSA is skewed toward older participants, additional young participants were recruited from the Johns Hopkins Bayview Medical Campus ($N = 10$). These volunteers ranged in age from 20–36 years and were matched to BLSA participants in years of education (16.00 $\pm$ 1.70 years). Thirteen participants withdrew from the study due to nausea or dizziness induced by VE exposure (10 women, 3 men, mean age = 76.3 years). The sex and age distribution of the final sample is presented in Table 1. All participants provided informed consent for participation in this study, which was approved by the local institutional review board.

2.2. Procedures

2.2.1. Assessment of level of computer experience

Because elderly participants may have less experience using computers than younger volunteers, all participants completed a computer experience questionnaire prior to VE testing. This questionnaire asked participants to rate the amount of experience they had using a computer, playing computer games, and playing computer games that involve VE technology (e.g. flight or driving simulators). The total score of these 3 items (each rated from 0 to 7) was calculated to obtain an overall computer experience rating for each participant (maximum score = 21).

2.2.2. Pre-test training and assessment of joystick visuomotor control

Prior to maze testing, extensive pre-training was provided to familiarize participants with the VE and with the