Luminance Contrast Influences Reaction Time in Young and Older Adults

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***Abstract*—Age-specific design principles for three dimensional virtual environment systems are sparse. Given that sensorimotor control systems change across the lifespan, understanding age differences in motor performance within virtual environments is crucial to designing effective, usable interfaces. This paper investigates the effect of luminance contrast level on reaction time to a visual stimulus in both young and senior adults. Results indicate that young adults have faster reaction times than seniors, but both groups improved reaction times with increasing luminance contrast of the target. Young adults improved at lower levels of contrast than seniors. Implications for age-specific design of virtual environments are discussed.**

Keywords- virtual environment; aging; motor control; reach to grasp; luminance contrast

I. INTRODUCTION

The aging of our population presents a number of challenges for the coming decades. In particular, aging brings about potential loss of an individual's function due to disease, injury, or the degenerative nature of aging itself. This results in significant burden on caregivers, healthcare systems, and economies. For example, the aging of the United States' population is the driving factor behind a predicted 300% increase in medical spending on cardiovascular diseases (i.e., coronary heart disease and stroke, among others) by the year 2030 [1]. One potential intervention for performance enhancement and rehabilitation of elderly individuals involves the development of computer-based technologies designed as adjuncts to traditional intervention methods. Specifically, three-dimensional (3D) virtual environments (VE) have been identified as systems with good potential to serve in these types of applications [2, 3].

The ultimate purpose of VEs is to provide the user with a computer-based tool in which a variety of common and novel manipulative, cognitive, and exploratory activities can be performed easily and efficiently. Applications of such technology often target younger users, such as surgical training and flight simulation [4, 5]. A much smaller number of applications address special populations of elderly. For example, VEs designed in various formats assist individuals in rehabilitation after stroke, including training of obstacle avoidance during walking, and enhancement of driving skills [6-8].

While the application of this technology broadens, authors continue to point out distinct weaknesses of virtual environments [2, 3, 9]. First, cost-effectiveness remains problematic, as many systems employ extensive computing resources and require technical expertise to run. VEs also typically utilize complex visual graphics, a trait inherent in the design of programs targeting young users. This increases the overall cost of production, and these visually rich displays also have the potential to be overly distracting, hampering motor performance in older individuals and producing discomfort or even nausea (i.e., cybersickness) [3]. While cost and comfort remain problematic, the foremost underlying barrier to implementation of VEs into real-world applications for the general population continues to be an incomplete understanding of the human sensorimotor system [10, 11]. When one considers that this system changes across the lifespan, this barrier becomes further complicated. Indeed, the sensorimotor performance of older individuals is not equivalent to that of the younger users targeted in most 3D computer applications**.** Therefore, the purpose of this paper is to provide information about the age-associated use of specific visual information in virtual environments. Background information will be presented, followed by a description of the experimental methodology. Results will then be reviewed followed by a discussion of their significance and relevance to future work.

A. Human computer interaction across the lifespan in 3D environments

Evidence of age-related differences in performance between young and older adults indicates disparities in reactions to environmental immersion, usage of input devices, size estimation ability, and navigational skills (for review see [12]). While these studies indicate a need for age-specific design principles, very little knowledge regarding sensorimotor control in VEs exists. Currently, the International Encyclopedia of Ergonomics and Human Factors leaves the explanation of age-related differences in virtual environments to a two sentence description recommending that equipment be tailored to physically fit the smaller frames of children, and for designers to take into consideration the changes in sensory and motor functions of the elderly [13]. These vague recommendations clearly show that evidence on which to base age-specific design is lacking, and this lack of guidance leaves a significant gap in scientific knowledge. Because the human sensorimotor system changes naturally across the lifespan, such information is particularly crucial to the age-specific design of VEs.

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B. *Sensorimotor changes across the lifespan*

The human body constantly changes throughout the lifespan. Most physiologic processes begin to decline at a rate of 1% per year beginning around age 30, and the sensorimotor system is no exception [14]. Both the processing of afferent information and the production of efferent signals steadily change as a function of age. Multiple studies demonstrate physical changes in brain tissues, in the excitability of the corticospinal tract and anterior horn cells, and in neurotransmitter systems [15-18]. A loss of neural substrate, including grey and white matter, occurs in both the cerebral cortex and the cerebellum [16, 17]. Tissue changes result in myriad functional changes within the central nervous system (CNS). A general deterioration of motor planning capabilities and feed-forward anticipatory control arises with aging [19-21]. Along with a decrease in planning ability, there also appears to be degradation of timing ability and general slowing of central processing [22, 23]. Loss of attentional resources also contributes to this slowing of central processing [24, 25]. The CNS re-weights sensory information when one source of feedback is compromised and compensates with alternative senses through a general systems neuroplasticity effect [26]. The implication here is important; the result of these attentional and processing changes is a decline in the ability to integrate multiple sensory modalities causing a relative decrease in the use of proprioceptive feedback and an increased reliance on vision for motor performance [25, 27, 28].

Comprehending the wide variety of physiologic changes occurring across the lifespan is important, but the concept of visual dominance for motor control in senior adults is especially imperative to the design of virtual environments. While VEs can recruit multiple senses for interaction, vision is the most common by far. Hence, provision of useful visual information for senior adults is extremely important to their success as a user group. While numerous studies characterize age-associated changes in visuomotor control, human movement is task specific. Thus, it is necessary to study human performance in VE surroundings [29, 30].

C. *Aging and luminance contrast*

Contrast sensitivity is one important aspect of visual function that declines significantly across the lifespan [31]. Additionally, it has been shown that reaction times to visual stimuli, a measure of general processing speed, vary based on the luminance contrast of those stimuli for both young and senior adults [32]. As reviewed in Section B, the decline of motor performance with aging results from the slowing of central sensorimotor processing. Since speed of processing varies with contrast level of the visual stimulus, it follows that motor performance will as well. Prior studies of the effects of luminance contrast on motor performance of young adults in natural environments support this concept [33, 34]. The current experiment seeks to extend these results by including a senior adult cohort, and by performing the experimental task within a virtual environment.

II. METHODS

A. *Participants*

This research received approval from the University of Wisconsin-Madison Social and Behavioral Sciences Institutional Review Board under protocol number SE-2009-0112. Individuals participated in single experimental sessions totaling approximately 30 minutes each. We recruited the young cohort on the UW-Madison campus and the senior cohort on campus, throughout the general community, and from a local independent living apartment complex. Prior to participating in the study, individuals confirmed by self-report that they were healthy, living independently, without history of neurologic disease or injury, and right-handed. When a participant met all pre-screening criteria, s/he signed the informed consent form and filled out the General Practice Physical Activity Questionnaire, which provides an overall measure of functional level [35]. Participants also performed a standard visual acuity test using a Snellen chart [36]. Participants were required to demonstrate visual acuity (with glasses or contact lenses as needed) at a level of 20/40 or better. This represents the legal limit for driving in the State of Wisconsin. Participants then completed a modified version of the Simulator Sickness Questionnaire (SSQ) and the Mini-Cog [37, 38]. Participants were excluded if they experienced dizziness on a daily basis or showed evidence of dementia. Finally, we assessed computer via a seven point Likert scale ranging from “1-no prior experience” to “7-considerable experience.” Thirteen participants met the criteria for the young adult group, and 13 for the senior adult group (Table I).

TABLE I. PARTICIPANT CHARACTERISTICS

Group	Mean age (yrs)	Age range	Male: Female	GPPAQ Activity Level
Young	21.2	19-24	5:8	Active
Senior	70.7	60-85	6:7	Moderately Active

Of the 13 senior participants sampled, three resided in the independent living apartment complex. No potential participants failed to meet the inclusion/exclusion criteria. Participants received an honorarium of $10 for completing the protocol.

B. *Experimental apparatus*

The Wisconsin Virtual Environment (WiscVE) was used to complete the experimental protocol (Fig. 1). The VE provides a head-coupled, stereoscopic experience to a single individual, allowing the user to grasp and manipulate augmented objects. A VisualEyez (PTI Phoenix, Inc.) motion analysis system, connected to a Windows PC workstation, captures three-dimensional motion information (e.g., movement of the subject’s hand, head and physical objects within the environment) for real-time scene

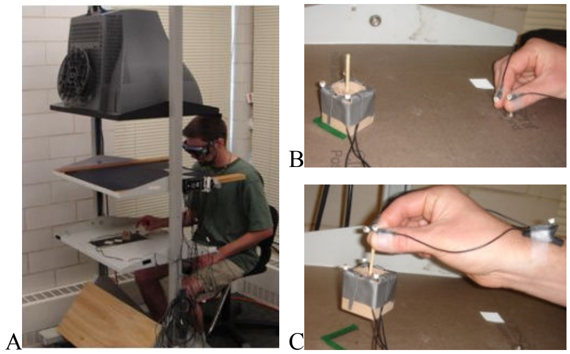

Figure 1. Panel A shows the WiscVE apparatus with downward facing monitor projecting to the mirror. Images are reflected up to the user wearing stereoscopic LCD shutter goggles, and thus the images appear at the level of the actual work surface below. Panels B and C demonstrate a reach to grasp task commonly utilized in this environment. The hand and physical cube are instrumented with light emitting diodes that are tracked by the VisualEyez (PTI Phoenix, Inc) system, not shown.

rendering and off-line kinematic analysis. The VisualEyez system monitors the 3D positions of small infrared light emitting diodes (LEDs) located on landmarks of interest. These landmarks include the tips of the thumb and index finger along with the radial styloid at the wrist to demarcate the hand. Objects in the environment are also equipped with three LEDs for motion tracking. Motion information from the VisualEyez system transmits on a subnetwork to a scene rendering Linux-based PC. Using the motion capture information, the scene is calculated and then rendered (10 ms lag time) on a downward facing CRT monitor placed parallel to a work surface. Also parallel to the computer monitor, a half-silvered mirror sits midway between the screen and the workspace to reflect images upward to the user. By wearing stereoscopic goggles, participants perceive the reflected image as if it were a three-dimensional object located in the workspace below the mirror**.** The environment is located in a dedicated room with blackout shades that provide the experimenter with good control of ambient room lighting.

C. Procedure and design

Participants completed a reach to grasp task, using a small wooden cylinder as the target object (3 mm diameter, 72 mm total height, Fig. 1B and1C). The visual scene varied from a low contrast condition equivalent to the individual's just noticeable difference contrast threshold, to the maximum contrast available in the WiscVE. Additionally, a moderate (50%) contrast condition added a third level to this factor (Fig. 2). To determine these settings, participants completed a JND contrast threshold test prior to the start of the experiment, as per the methods of Tamura, Satoh, Uchida, and Furuhata [39]. Briefly, participants sat for five minutes at the environment console to allow for dark adaptation. At this point, we instructed participants to begin increasing the luminance of the target object and finger representation gradually by tapping their index finger on a virtual button. Individuals performed this task in a self-paced manner until they just perceived the presence of the object and their fingertips in the environment. Each participant performed three JND trials, and the average luminance value at which they perceived the target and finger spheres determined their individual threshold. Luminance was controlled using the standard 255-point Red-Green-Blue (RGB) scale, maintaining equal values for each of the three color values, thereby maintaining white (achromatic) visual stimuli. The moderate contrast level was calculated by taking the difference between the maximum RGB (i.e., 255) and the individual's JND threshold, dividing this by 2, and adding the result to the JND value. For example, a participant that, on average, perceived the target and fingers when they reached an RGB level of 21 would have a moderate contrast condition set at: ((255-21)/2) + 21 = 138. This normalizes the moderate level to the individual. Actual luminance values in candela per square meter (cd/m$^{2)}$ for the background and stimuli were obtained using a spot luminance photometer (Spectra Cine). JND values ranged from twelve to 26 on the RGB scale. RGB and luminance values are listed in Table II.

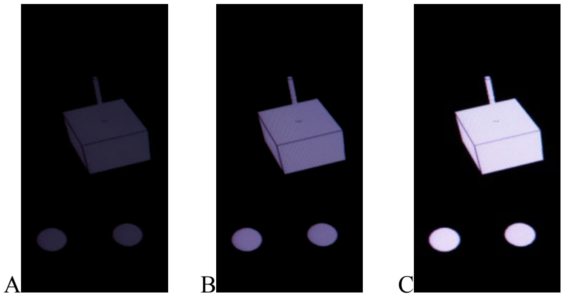

Figure 2. The visual scene varied in luminance contrast from A) the just noticeable difference threshold, to B) 50% contrast level, to C) 100% maximum luminance contrast.

TABLE II. VISUAL STIMULUS PARAMETERS

RGB (JND-Low)	c/m^2	RGB (Mod)	cd/m^2
12	0.02	133.5	23.24
13	0.03	134	23.49
14	0.04	134.5	23.74
15	0.05	135	24.00
16	0.05	135.5	24.25
17	0.06	136	24.51
18	0.08	136.5	24.77
19	0.09	137	25.03
20	0.10	137.5	25.29
21	0.12	138	25.55
22	0.14	138.5	25.81
23	0.15	139	26.08
24	0.17	139.5	26.35
25	0.20	140	26.62
26	0.22	140.5	26.89
RGB (High)	cd/m^2		
255	147.34		

The task instructions for this movement were for participants to reach to grasp the target object with a precision grasp (i.e., thumb and index finger), initiating the movement as quickly as possible after appearance of the target. The reach to grasp progressed in a mid-sagittal plane, in line with the middle of the right shoulder. Subjects started from a designated start mark, identified with a tactile cue (a small metal cap nut, 8 mm in diameter, 7 mm in height). The target object rested 180 mm away from the start mark, resulting in a visual eccentricity of approximately 10 degrees from midline. Each trial began with the participant resting their hand away from the start mark. A visual cue, in the form of a green circle in the far right corner of the desktop, indicated when to move to the start position. When the participant placed their hand in the correct position over the start mark, with their thumb and index finger resting together in a light pinch grip, the visual cue disappeared. The system requires participants to maintain this position for one second prior to the start of a trial, to ensure individuals start from complete rest. Once the one-second rest period had elapsed, the system initiated the trial. To prevent anticipation, the presentation of the target object and fingers varied between 400-800 ms after trial initiation. Participants then reached out to grasp the cylinder, lifting it vertically about 50 mm before replacing it on the desktop. After replacing the object, participants moved their hand near the start mark, awaiting the visual cue for initiation of the next trial.

Participants completed three practice trials in each condition prior to the start of the experiment. There were ten trials per contrast condition, with a 2 (age group) x 3 (contrast level) design, for a total of 30 experimental trials presented in random order. These reaction time trials were embedded in a series of other experiments reported elsewhere.

D. Dependent measures

The primary dependent variable of interest was simple reaction time (RT). Subtracting the time point of stimulus presentation from the time point of movement onset provided the RT results. Movement onset was defined as the point where the fingers had departed from their starting position by 5 mm. This corresponds to the amount of displacement needed to depress a key on a standard computer keyboard, which is commonly employed in studies of RT.

E. Hypotheses

Based on prior studies of luminance contrast and reaction times, as well as contrast sensitivity and age, the following was hypothesized:

Hypothesis 1: Young adults will have faster reaction times than senior adults.

Hypothesis 2: Both young and senior adults will improve their reaction times as luminance contrast increases.

Hypothesis 3: Young adults will improve their reaction time at the moderate and high contrast levels, seniors only at the highest contrast.

F. Data analysis

SPSS (IBM) was used for statistical analysis. We performed a Mann-Whitney U test to analyze group difference in computer experience. Next, an ANOVA with post-hoc blocking was used to assess group difference in RT controlling for group difference in computer experience. Computer experience (3 levels based on Likert responses: 7, 6, and ≤ 5) was used as the blocking factor. This allowed evaluation of hypothesis 1. Planned comparisons of contrast level within each age group evaluated hypothesis 2 and 3. For all results, the a priori alpha level was set at $p \leq 0.05$.

III. RESULTS

Computer experience level was significantly different between groups (Young Median = 7, Mode = 7, Senior Median = 6, Mode = 6, p = 0.04). There was a significant main effect of age ($F_{1,\,20} = 4.55$, p = 0.05) controlling for computer experience, with young adults having faster reaction times (M = 441 ms, SD = 90.92) than senior adults (M = 498 ms, SD = 90.45). The simple effect of contrast within each age group appears in Fig. 3. This shows that for young adults, the low contrast reaction time was significantly slower than both the moderate and high contrast conditions, which did not differ. For senior adults, the low and moderate contrast conditions did not significantly differ, while both the low to high and moderate to high mean differences did reach statistical significance.

IV. DISCUSSION

The first important finding is that young adults have faster reaction times than senior adults, replicating numerous previous studies and confirming hypothesis 1 [22, 32]. Further, level of computer experience differed between groups, but age group differences remained apparent in the analysis. This lends support to the idea that group differences are truly related to sensorimotor differences between groups, rather than familiarity with technology.

The data clearly show that reaction times improve for both groups with increasing luminance contrast (Fig. 3). While young adults improve from low to moderate contrast, they do not get further benefit going from moderate to high contrast. Senior adults, on the contrary, improve significantly in the high contrast condition, but do not improve going from low to moderate. This confirms hypothesis 2 and 3.

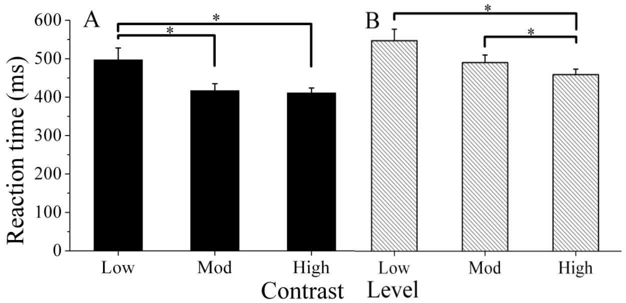

Figure 3. The simple effect of contrast level on reaction times for **(A)** Young adults and **(B)** Senior adults.

Previous study of reaction times, contrast, and age demonstrated no age group difference in the pattern of contrast-mediated reaction time improvement [32]. The results in the current study differ from that finding, and are more consistent with the concept that contrast sensitivity changes across the lifespan [31]. Accordingly, luminance contrast must be accounted for when designing interfaces for specific user groups.

Considering reaction time as a measure of general sensorimotor processing speed, and the strong link between motor performance and processing speed, these results support the idea that improvements in motor performance may be realized through the age-specific utilization of luminance contrast levels. It is important to note that while young adults achieved their entire performance enhancement with only moderate contrast, seniors required the extra increase to the high contrast condition to maximize their gains (Fig. 3). This pattern indicates that young adults can make better use of lower contrast visual stimuli, having a performance ceiling somewhere below the 50% contrast level, while senior adults may not have a distinct ceiling within the ranges of luminance contrast available in the WiscVE. This concept will require further exploration of other VE tasks under varying conditions of luminance contrast with more complex kinematic analyses.

Given the results of the current study, it may be tempting to conclude that the highest available contrast should always be used for motor tasks performed in virtual environments. While further study is needed, it must be recognized that high contrast comes at a cost. First, high luminance contrast, by definition, requires that at least one portion of the visual scene be presented at maximum luminance. This could potentially lead to eyestrain, limiting the timeframe for comfortable use of the VE. This may be especially important for users that are hypersensitive to light. Second, such contrast restrictions limit the color combinations available for use. Strictly speaking, the highest available contrast is black and white. While this may be acceptable in certain circumstances, it is not likely to be common. This is especially apparent in the design of VEs for use with young adult populations. To limit this age group to high contrast conditions would unnecessarily limit the potential richness of the visual display, adding no extra motor control benefit over a moderate contrast visual scene.

Limitations

A limitation exists with the assessment of visual acuity in this study. The chart used provides a standard measure of acuity at a distance of 20 feet, while the experimental task occurs within the personal space of the participant. A number of other sophisticated tests of vision exist, gauging such functions as depth perception and figure-ground discrimination, and may provide valuable information worth considering in future studies. Next, the method of defining each individual's just noticeable difference contrast threshold is inherently subjective. While carefully scripted instructions were used to describe the procedure, each individual had to interpret the meaning of “just able to perceive,” and this introduces a source of error in defining contrast levels. Additionally, the low and moderate contrast levels were set relative to each individual's personal contrast threshold, while the high contrast condition was set to the limit of the environment. This means that the high contrast condition was relatively different for each subject. However, given the narrow range of JND results, the relative differences are quite small. Finally, although every reasonable attempt was made to block ambient light from windows in the Human Motor Behavior lab, some minimal fluctuation did occur. This did not result in any cases of participants reporting a change in their ability to perceive the visual scene.

V. CONCLUSION AND FUTURE WORK

The virtual environment design process must account for the age of the targeted user when considering parameters of visual scene rendering. Luminance contrast is one property that is easily programmable, and has a clear age-specific effect on motor performance. Younger adults have a wider bandwidth of contrast levels that may result in optimum sensorimotor performance. Older adults, on the contrary, need higher levels of contrast to experience their maximum motor performance benefits. The exact range is yet to be determined for either group, but will be the subject of future research. General VE implications include the use of high luminance contrast to improve sensorimotor processing speed. This is an important consideration when targeting user groups known to be deficient in speed of processing, such as senior adults. Additionally, increased processing speed with high contrast stimuli is likely to improve performance when tasks are of particularly high complexity or difficulty. This will be further investigated in future research as well. Potential consequences of high contrast visual stimuli, such as eyestrain, were not assessed in this experiment. This also warrants further user-centered study, and should be carefully considered along with both the intended application and the end-user group of any high contrast virtual environment display.

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