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Vision for Motor Performance in Virtual Environments Across the Lifespan

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1. Introduction

Current trends in neuroscience research are heavily focused on new technologies to study and interact with the human brain. Specifically, three-dimensional (3D) virtual environment (VE) systems have been identified as technology with good potential to serve in both research and applied settings. For the purpose of this chapter, a virtual environment is defined as a computer with displays and controls configured to immerse the operator in a predominantly graphical environment containing 3D objects in 3D space. The operator can manipulate virtually displayed objects in real time using a variety of motor output channels or input devices. The use of VEs has almost exclusively been limited to experimental processes, utilizing cumbersome equipment well suited for the laboratory, but unrealistic for use in everyday applications. As the evolution of computer technology continues, the possibility of creating an affordable system capable of producing a high-quality 3D virtual experience for home or office applications comes nearer to fruition. However, in order to improve the success and the cost-to-benefit ratio of such a system, more precise information regarding the use of VEs by a broad population of users is needed. The goal of this chapter is to review knowledge relating to the use of visual feedback for human performance in virtual environments, and how this changes across the lifespan. Further, we will discuss future experiments we believe will contribute to this area of research by examining the role of luminance contrast for upper extremity performance in a virtual environment.

2. Background

The following sections identify the well-known physiologic changes that occur in the sensorimotor system as part of the natural human aging process. Further, we discuss some of the limited work that has been done to understand the implications of these changes for the design of VEs.

2.1 Changes to the human sensorimotor system across the lifespan

The human body is a constantly changing entity 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 (Schut, 1998). There is a general indication from the research that both the processing of afferent information and the production of efferent

signals steadily change as a function of age. Multiple authors demonstrate physical changes in brain tissues (Andersen, Gundersen, & Pakkenberg, 2003; Kuo & Lipsitz, 2004; Raz & Rodrigue, 2006), changes in excitability of the corticospinal tract and anterior horn cells (Rossini, Desiato, & Caramia, 1992), and changes in neurotransmitter systems. There is a general loss of neural substrate, including grey and white matter. This has been demonstrated in both the cerebral cortex (Raz & Rodrigue, 2006) and the cerebellum (Andersen et al., 2003). These tissue changes then result in a myriad of functional changes within the central nervous system (CNS). There is a general deterioration of motor planning capabilities (Sterr & Dean, 2008;Yan, Thomas, & Stelmach, 1998) and feed-forward anticipatory control (Hwang et al., 2008) with aging. Along with this decrease in planning ability, there also appears to be slowing of central processing (Chaput & Proteau, 1996; Inui, 1997; Light, 1990; Shields et al., 2005). This change in processing is partially due to neurophysiologic changes within the CNS resulting in a decrease in the available resources of the processing pool (Craik & McDowd, 1987; Schut, 1998). Loss of attentional resources also contributes to this slowing of central processing (Goble et al., 2008; Kluger et al., 1997; Sparrow, Begg, & Parker, 2006). This in itself results from a multifactorial process relating to neurophysiologic changes in the CNS and degradation of afferent information arriving from compromised peripheral receptors (Chaput & Proteau, 1996; Goble et al., 2008). 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 use of vision (Adamo, Martin, & Brown, 2007; Chaput & Proteau, 1996; Goble et al., 2008; Lemay, Bertram, & Stelmach, 2004). This shift to the use of visual resources is due to the tendency of the CNS to re-weight sensory information when one source of feedback is compromised (Horak & Hlavacka, 2001), as well as a general systems neuroplasticity effect (Heuninckx, Wenderoth, & Swinnen, 2008; Romero et al., 2003). These compensatory neuroplastic changes are the end manifestation of the normal aging process within the CNS.

The peripheral nervous system (PNS) undergoes concordant neurophysiologic changes as well (Chaput & Proteau, 1996; Goble et al., 2008; Roos, Rice, & Vandervoort, 1997). These changes occur in both the afferent and efferent pathways. Studies have shown both a decrease in number and density of proprioceptors (Goble et al., 2008), as well as a slowing of sensory receptors in general (Light, 1990). In the efferent systems, research demonstrates a loss of motor units and a decrease in firing rate and increased discharge variability of intact motor units (Roos et al., 1997). The available literature also demonstrates a loss of larger motor neurons resulting in a net decrease of alpha motor neurons, a slowing in the conduction velocity of remaining motor neurons, and changes in the excitability of alpha motor neurons (Leonard et al., 1997; Roos et al., 1997).

The changes in the CNS and PNS with age are accompanied by changes in the muscular system as well. In the aging adult, research shows a loss of muscle fibers and a decrease in size of remaining fibers resulting in a net loss of muscle mass (Roos et al., 1997). Changes in motor units in the PNS result in fiber type changes, causing a loss of fast-twitch fibers and a proportional increase of slow-twitch fibers.

Transformations in the sensorimotor system have a resultant detrimental effect on motor performance in daily life. This decrease has a physiologic basis in aging and is amplified by disuse and dysfunction. In general, aging adults demonstrate decreases in movement speed (Light, 1990; Mankovsky, Mints, & Lisenyuk, 1982; Poston et al., 2008; Yan et al., 1998),

accuracy of movement (Chaput & Proteau, 1996), reaction time (Light, 1990; Sparrow et al., 2006; Yan et al., 1998), strength (Roos et al., 1997; Vandervoort, 2002), hand dexterity (Contreras-Vidal, Teulings, & Stelmach, 1998; Seidler, Alberts, & Stelmach, 2002), and postural control (Jonsson, Henriksson, & Hirschfeld, 2007; Koceja, Allway, & Earles, 1999; Mourey et al., 1998; Romero & Stelmach, 2003). En masse, these changes have the potential to contribute to a spiral of disuse and loss of function that often characterizes the process of aging. Due to the tendency for visual dominance in aged humans (Lemay et al., 2004), and the task specificity of human movement (Proteau, 1992), the fact that visual sensory feedback is much less rich in a virtual than natural environment makes it imperative to study human performance in such surroundings. Research is needed to improve our understanding of sensorimotor changes, and their consequences for performance, for an aging population interacting in three-dimensional environments.

2.2 Three-dimensional virtual environments and human computer interaction (HCI) across the lifespan

Today, the users of computers include people from all age groups. Very little information is available on how the performance of individuals in a VE changes throughout the lifespan as a function of the natural aging process. Prior to designing programs for individuals in special subgroups, such as rehabilitation programs designed for patients with neurological lesions, it will be important to understand what age-specific requirements will be beneficial to the user. For instance, because there is a paucity of information on how healthy adults in the older age groups commonly affected by stroke interact in VEs, it is likely that a system designed as an adjunct to standard rehabilitation will struggle to gain success without a foundation of baseline knowledge. This level of information regarding subjects of various age groups will greatly assist in producing successful, cost-effective VEs. Unfortunately, although computers have been commonplace in homes and work-environments for decades, the literature on interface design as it relates to age is only very recent, and is limited in scope. Early computer interface design relied primarily on the intuition of the designer (Hawthorn, 2001; Hawthorn, 2007). There was a distinct disparity between what designers recognized as necessary interface components and what was truly usable by the lay population. As access to computer technology improved and allowed the spread of computers into the hands of consumers, a necessary change to user-centered design followed. Typically, however, in order to be a feasible process, the representative users must have a basic level of proficiency with computer skills and language. This resulted in a general exclusion of both young and old age groups from the design process. In the late 1990's, interest in age-specific design increased, and there is now a reasonable body of knowledge on the design of standard computer interface systems for various age groups.

While the bulk of age-specific computer design information relates to ways to improve cognitive performance through specific training or tutorial methods (Hawthorn, 2007), there is some scientific literature which explores the areas of human motor control (Laursen, Jensen, & Ratkevicius, 2001; Smith, Sharit, & Czaja, 1999). Most of this information centers on the input device, specifically mouse usage in older adults. Smith et al. (1999) reported that there are many age-related changes in performance, and in general, it is quite difficult for older individuals to use a mouse. The act of double-clicking seems to consistently be the

most problematic. Difficulty with cursor control is also named as a top complaint among older individuals (Hawthorn, 2001; Hawthorn, 2007). It has also been shown that performance within a standard computer interface is slower and results in a greater number of errors with increased age of the operator. These specific limitations point to the need to develop new interfaces that capitalize on natural manipulation, thereby eliminating difficulties with the functional abstraction of input devices.

Contrary to standard computer interface systems, little is known about the age-related variance of HCI within three-dimensional virtual environments. The literature in this subject area is nearly non-existent. There is some evidence of age-related differences in performance between children and adults, as well as young adults and older participants. This research indicates relevant disparities in reactions to environmental immersion, usage of various input devices, size estimation ability, navigational skills and completion time for gross motor tasks (Allen et al., 2000). According to these authors, "these results highlight the importance of considering age differences when designing for the population at large." Currently, the International Encyclopedia of Ergonomics and Human Factors (Karwowski, 2006) leaves the explanation of age-related differences in virtual environments to a short, 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. Other than these works, very little specific knowledge regarding age and motor control in virtual environments has been elicited through research, especially as it relates to precision movements with the upper extremities. This fact has led us to begin a series of experiments investigating the use of vision for precise sensorimotor control of the upper extremity in virtual environments, and how that usage changes as a function of age.

3. Research methods, design, and results

In the next sections, we describe the specific methodology used in our lab, followed by a brief review of the most recent findings.

3.1 Physical apparatus

For our research, we utilize a tabletop virtual environment located in the Human Motor Behavior laboratory at the University of Wisconsin-Madison (Figure 1). This system has been used in a number of studies investigating the role of visual feedback for upper extremity movement in young adults, as well as the first phase of data collection on subjects across the lifespan. This single-user VE is specifically designed to permit detailed and highly accurate kinematic measurements of human performance. Paradigms from the Human Motor Control and Biomechanics disciplines are used to provide detailed descriptions of human movement and to make inferences about the cognitive processes controlling those movements. More recently, our research has focused on how these processes change throughout the lifespan. Our virtual environment has been designed to focus on natural manipulation, allowing users to employ their hands to manipulate and explore augmented objects located within the desktop environment (i.e. Tangible user interface or TUI) (MacLean, 1996; Mason & MacKenzie, 2002; Mason et al., 2001; Sturman & Zeltzer, 1993; Y. Wang & MacKenzie, 2000).
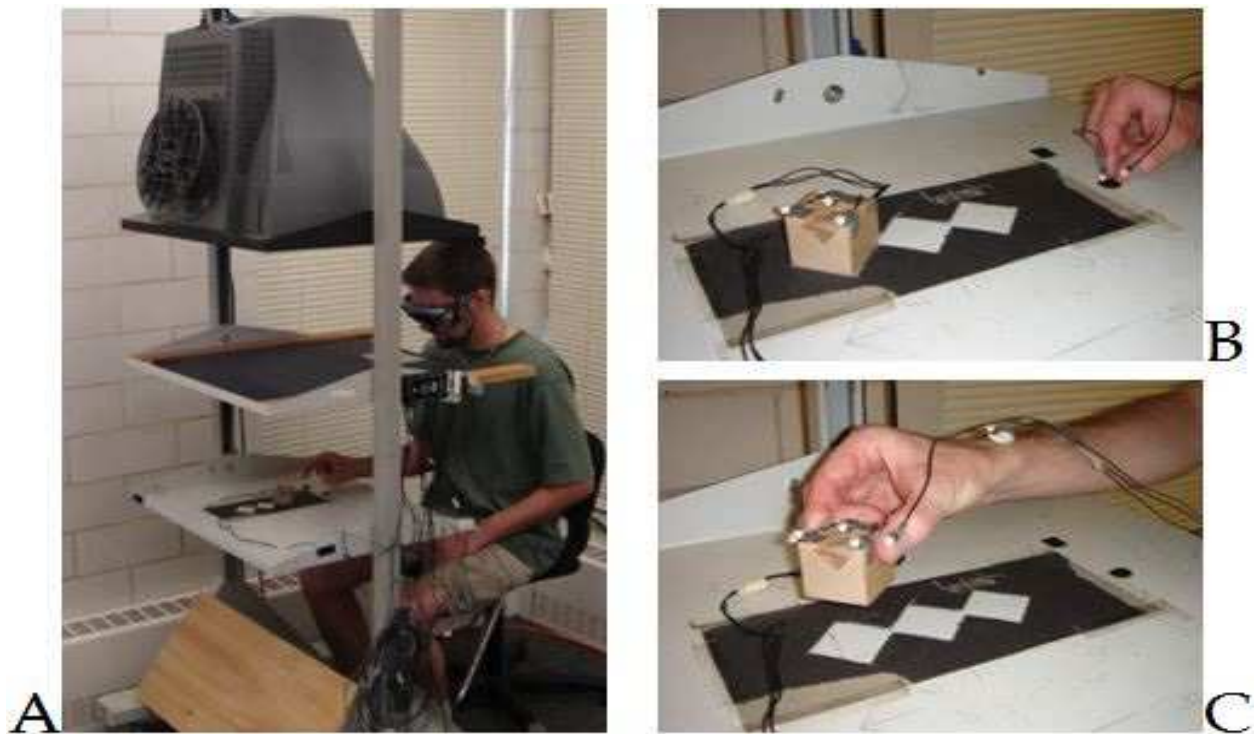
Fig. 1. Wisconsin virtual environment (WiscVE). Panel A shows the apparatus with downward facing monitor projecting to the mirror. Images are then reflected up to the user wearing stereoscopic LCD shutter goggles, and thus the images appear at the level of the actual work surface below. Panels B and C demonstrate a reach to grasp task commonly utilized in this environment. The hand and physical cube are instrumented with light emitting diodes (LEDs) that are tracked by the VisualEyez (PTI Phoenix, Inc) system, not shown.

This type of interface gives investigators complete control over the three-dimensional visual scene (important in generalizeability to natural environments), and makes for maximal use of the naturalness, dexterity and adaptability of the human hand for the control of computer mediated tasks (Sturman & Zeltzer, 1993). The use of such a tangible user interface removes many of the implicit difficulties encountered with standard computer input devices due to natural aging processes (Smith et al., 1999). The exploitation of these abilities in computer-generated environments is believed to lead to better overall performance and increased richness of interaction for a variety of applications (Hendrix & Barfield, 1996; Ishii & Ullmer, 1997; Slater, Usoh, & Steed, 1995). Furthermore, this type of direct-manipulation environment capitalizes on the user's pre-existing abilities and expectations, as the human hand provides the most familiar means of interacting with one's environment (Schmidt & Lee, 1999; Schneiderman, 1983). Such an environment is suitable for applications in simulation, gaming/entertainment, training, visualization of complex data structures, rehabilitation and learning (measurement and presentation of data regarding movement disorders). This allows for ease of translation of our data to marketable applications.

The VE provides a head-coupled, stereoscopic experience to a single user, allowing the user to grasp and manipulate augmented objects. The system is configured as follows (Figure 1):

- 3-D motion information (e.g. movement of the subject's hand, head and physical objects within the environment) is monitored by a VisualEyez (PTI Phoenix, Inc.) motion

analysis system connected to a Windows PC workstation. The VisualEyez system monitors the 3-D positions of small infrared light emitting diodes (LEDs) located on landmarks of interest. We typically utilize 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.

• Once the motion information is obtained by the VisualEyez system, it is broadcast on a subnetwork to a scene rendering Linux-based PC.

• Using the motion capture information the scene is calculated and then rendered on a downward facing CRT monitor, placed parallel to a work surface. A half-silvered mirror is placed parallel to the computer monitor, midway between the screen and the workspace. The image on the computer monitor is reflected in the mirror and is perceived by subjects, wearing stereoscopic goggles, as if it were a three-dimensional object located in the workspace below the mirror.

3.2 Human performance measurement

Human motor control, biomechanics and neuroscience research has provided a comprehensive description of how humans reach to grasp and manipulate objects in natural environments under a variety of sensory and environmental conditions (MacKenzie & Iberall, 1994). By using the same measurement techniques as those employed to monitor human performance in natural environments we can compare movement in virtual environments to decades of existing human performance literature. The comparisons allow the development of comprehensive cognitive models of human performance under various sensory feedback conditions. Simple timing measures such as reaction time and movement time provide a general description of upper limb movements. However, in motor control studies, more complex three-dimensional kinematic measures such as displacement profiles, movement velocity, deceleration time, and the formation of the grasp aperture (distance between the index finger and thumb for a precision pinch grip) have also been used to characterize object acquisition movements (MacKenzie & Iberall, 1994). By observing regularities in the 3D kinematic information, inferences can be made regarding how movements are planned and performed by the neuromotor control system. This detailed movement information essentially provides a window into the motor control system and allows the determination of what sensory feedback characteristics are important for movement planning and production.

3.3 Preliminary experiments: Understanding vision for motor performance in virtual environments across the lifespan

In a study investigating the role of visual feedback about the hand for the control of reach to grasp movements, Mason and Bernardin (2009) demonstrated that young healthy adults could utilize very simple visual feedback of their fingertips to improve motor performance when compared to a condition in which no visual feedback of self was present. The crude visual representation consisted of two 10 mm yellow spheres representing the thumb and index finger tips (see Figure 2B for example). The visual representation of the hand was always provided with moderate contrast. Mason and Bernardin (2009) also noted that vision of the hand was not necessary throughout the movement, but only up to movement onset. If vision of the hand was completely

removed, performance deteriorated. The results of this work shed light on ways to minimize the amount of visual feedback necessary for successful control of precision upper extremity movements in virtual environments. While the rendering of complex images capable of simulating the full human hand is now possible in VEs, it remains problematic in two ways. First, the motion capture and computing technology can result in significant increases in equipment costs to render a realistic hand. More importantly, the complexity of the rendering process generally results in significant latency problems, with time lags on the scale of 150+ ms from the movement of the real hand to its represented movement within the virtual environment (Wang & Popović, 2009). Latencies of this magnitude can have a significant negative impact on human performance (Ellis et al., 1997). Further, time delays in the range of 16-33 ms become noticeable to subjects when performing simple visual tasks in virtual reality (Mania et al., 2004). As a result of these problems, a key area of research in the development of successful, cost-effective VEs must relate to simulator validity. That is, the degree of realism the environment provides in approximating a real situation. Simulator validity has been identified as a key parameter for the effectiveness of learning in training simulations (Issenberg et al., 2005). This is extremely important in applications such as neurologic rehabilitation, where the ultimate goal is to ensure that practice in the virtual environment will carry over to function in activities of daily living. We must identify the minimal features of sensory feedback required for valid simulations so that humans can interact in ways sufficiently similar to movements in natural environments. In their initial study, Mason and Bernardin (2009) identified some sufficient visual feedback parameters for young adults. We conducted a follow up study using a similar paradigm to see if these results generalize to older and younger user groups.[1]

In our follow-up study, participants were asked to reach from a designated start position to grasp and lift a target cube. We manipulated three variables. The first was age group membership: children (7-12 years), young adults (18-30 years), middle age adults (40-50 years) and senior adults (60+ years). Each of these groups included 12 participants. Second, we manipulated target distance by placing the target object at either 7.5cm or 15cm from the start mark. Finally we varied visual feedback of the hand by providing the subject with one of five visual feedback conditions (Figure 2). In the no vision (NV) condition, the subject was not given any graphical feedback about the position of the hand. In the full vision crude (FVC) condition, graphical feedback about hand position (10mm spheres at the fingertips) was provided throughout the entire reach-to-grasp movement. For the vision up to peak velocity (VPV) condition, graphical feedback about hand position was extinguished once peak velocity of the wrist was reached. In the vision until movement onset (VMO) condition, graphical feedback of the hand was extinguished at the start of movement. For these conditions, subjects were prevented from seeing the real workspace below the mirror so that vision of the actual limb and surrounding environment was absent. For the final condition (full vision or FV), subjects were given full vision of the real hand as in a natural environment. Computer rendered graphical information about the target size and location was always available. All visual feedback was presented with visual stimuli of moderate contrast in relation to the background.

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[1] A preliminary version of these results were published elsewhere (Grabowski & Mason, 2011).
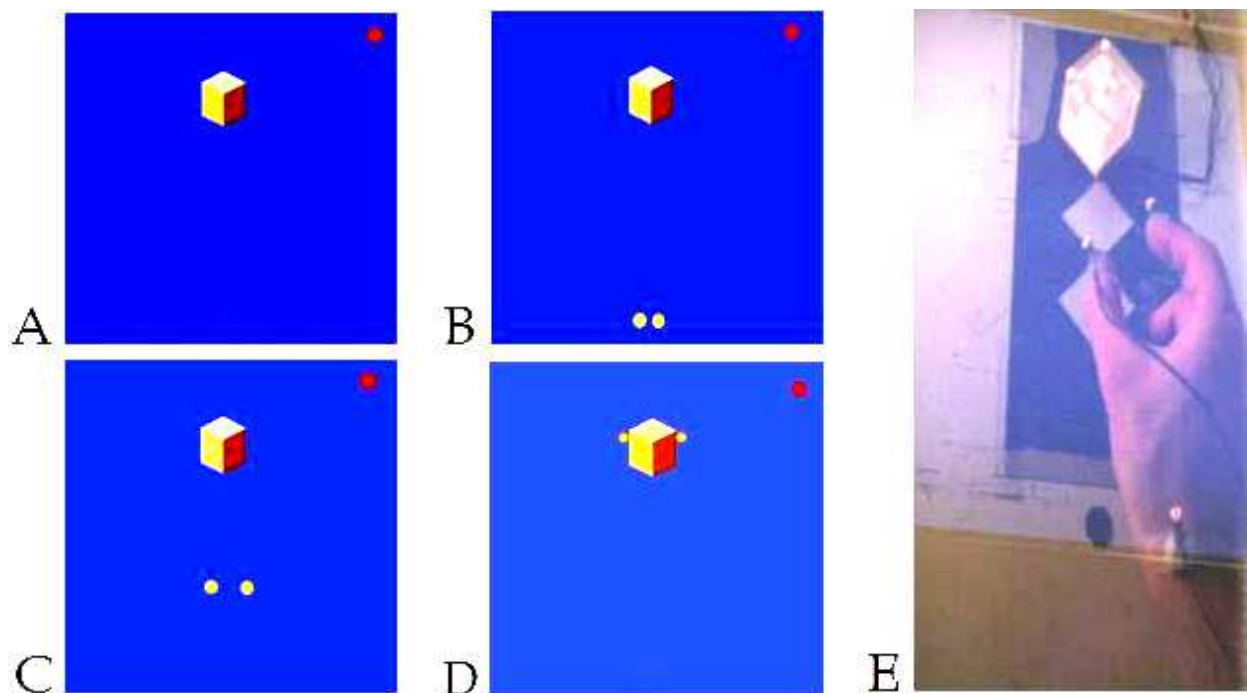
Fig. 2. Visual conditions. A) No vision-NV B) Vision to movement onset-VMO C) Vision to peak velocity – VPV D) Full vision crude-FVC E) Full vision-FV.

Results - Transport Component: Movement time results for young adults showed that crude feedback of the hand (both FVC and VPV) resulted in performance that was not different from performance under natural viewing conditions (FV) (Figure 3B). Conditions where this feedback was provided only to movement onset or not at all (VMO and NV) showed distinct performance deterioration. This pattern of results has been replicated several times in our lab (Mason, 2007; Mason & Bernardin, 2008; Mason & Bernardin, 2009). Older adults did not show any differences between visual conditions, indicating that they used a transport strategy that was independent of visual feedback of self (Figure 3D). While this strategy was effective for performance of the current experimental task, it could result in significant limitations with more complex and continuous tasks. For middle age adults and children (Figure 3C and 3A respectively), results indicated that they make use of full visual feedback of their moving limb to improve performance, but use of any crude feedback failed to provide significant performance enhancements.

The peak velocity of the transport varied with visual condition for all age groups, but children showed the most distinct effect (Figure 4). All conditions with altered feedback (FVC, VPV, VMO, and NV) had significantly lower peak velocities when compared to the natural viewing conditions (FV). Peak-velocity is determined by feed-forward motor planning mechanisms. Therefore, since slower movements are more accurate, it appears that children used a pre-planned strategy of slowing their reach to enhance the accuracy of their transport when they were only provided with crude visual feedback or no visual feedback.

Finally the results from the limb deceleration data, which give an indication of the portion of movement allotted for closed-loop sensory feedback processing, shed light on the same phenomenon mentioned previously in older adults: this age group did not alter their movement patterns based on the visual feedback conditions provided. This finding is
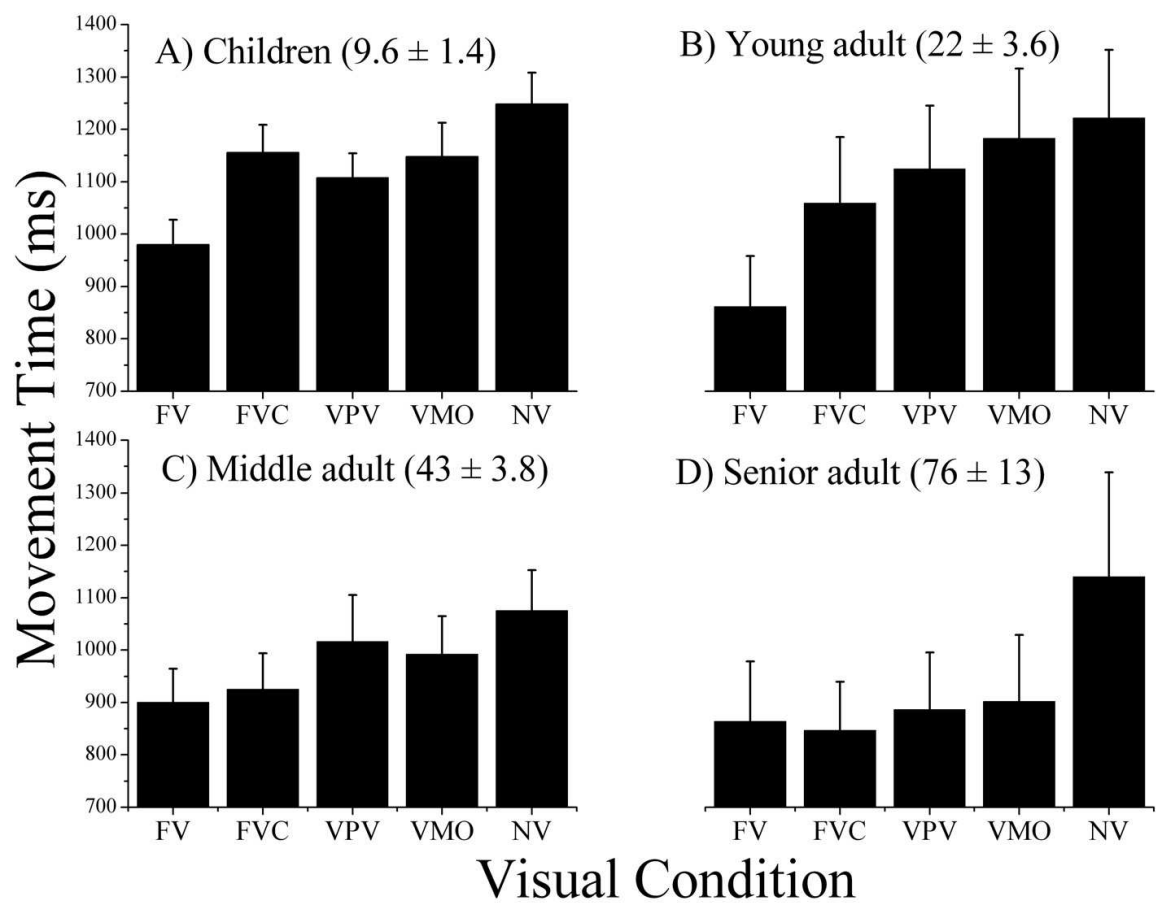
Fig. 3. Effect of visual condition manipulations on average movement times (error bars show ±SE) and mean age ±SE is shown in parentheses: A) Children $F_{4,44}$=10.09, p<0.01 B) Young adult $F_{4,44}$=7.24, p<0.01 C) Middle age adults $F_{4,44}$= 4.23, p<0.01 D) Senior adult $F_{4,44}$= 1.86, p=0.19. In young adults, FV was significantly faster than VMO and NV, but not different from the other simple feedback conditions (FVC and VPV). Also of note is the lack of any discernable condition effect in the group of older adults. Adapted from (Grabowski & Mason, 2011).
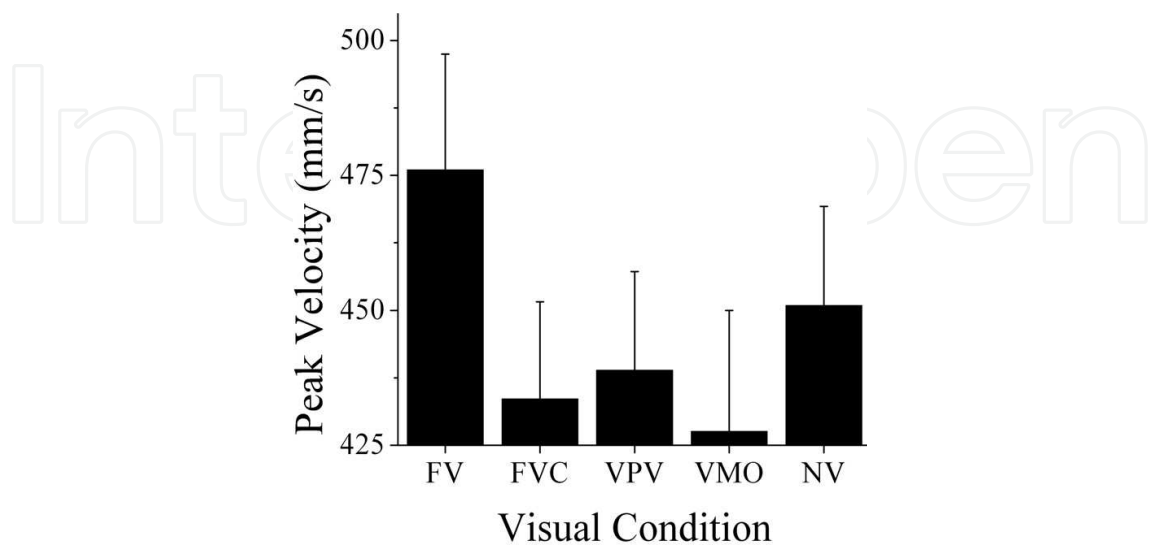

Fig. 4. Peak velocity results for children, $F_{4,44}$=5.32, p<0.01. All conditions show a slowing compared to the natural viewing in the FV condition.

consistent with previous work on age and motor control showing that for faster movements, older adults rely on modes of control that are minimally dependent on sensory feedback (Chaput & Proteau, 1996). These results can be interpreted as a manifestation of slowed central processing of sensory information.
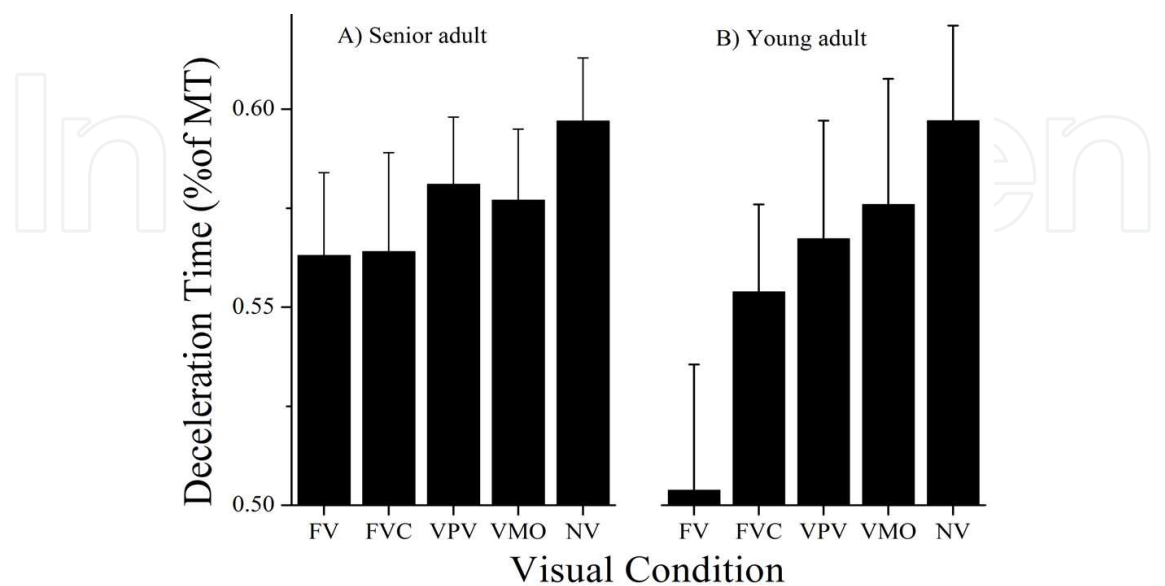

Fig. 5. Time spent in deceleration as a percentage of total movement time. A) Senior adult, $F_{4,44}=1.84$, p=0.15 and B) Young adult , $F_{4,44}=13.70$, p<0.01.

Results – Grasp component: To quantify formation of the grasp component we analyzed peak grasp apertures. Grasp aperture gives an indication of the precision requirements of a task, with larger apertures considered a compensatory strategy present in more demanding tasks with higher levels of uncertainty. In young adults apertures were significantly smaller in the FV, FVC, and VPV when compared to the condition where no visual feedback of the hand was provided (NV). This replicates the results found for movement time and indicates that young adults were able to use some limited visual feedback to reduce uncertainty in planning their grasp. In contrast, older adults used a markedly larger grasp aperture than the rest of the cohorts, and showed a minimal condition effect. Middle age adults did show an effect on grasp measures when provided with crude visual feedback of the hand throughout the movement (FVC). This condition resulted in apertures that were significantly smaller than in the no feedback condition (NV). No other condition resulted in smaller apertures than NV (Figure 5). Therefore, it appears that for middle age adults, the condition with crude feedback available throughout the movement simplified the sensorimotor requirements even more than when participants were provided with natural viewing conditions (FV).

Further inspection of the grasp aperture results shows that, although not statistically significant, the FVC condition resulted in the smallest average grasp apertures for all four age groups. These results provide preliminary evidence that luminance contrast may be an important variable for reducing movement complexity when grasping objects in a virtual environment. In our experiment, due to room lighting, the luminance contrast between the real limb and the background was low in the FV condition. Therefore, aperture planning in this condition may have been more difficult than in the FVC condition where the graphical

representation of the fingertips provided greater luminance contrast. All other conditions either had a low contrast representation (FV) or no representation at all (VPV, VMO, NV). Therefore, the quality of the visual representation, specifically the luminance contrast, may serve as a means to further reduce task demands and uncertainty.
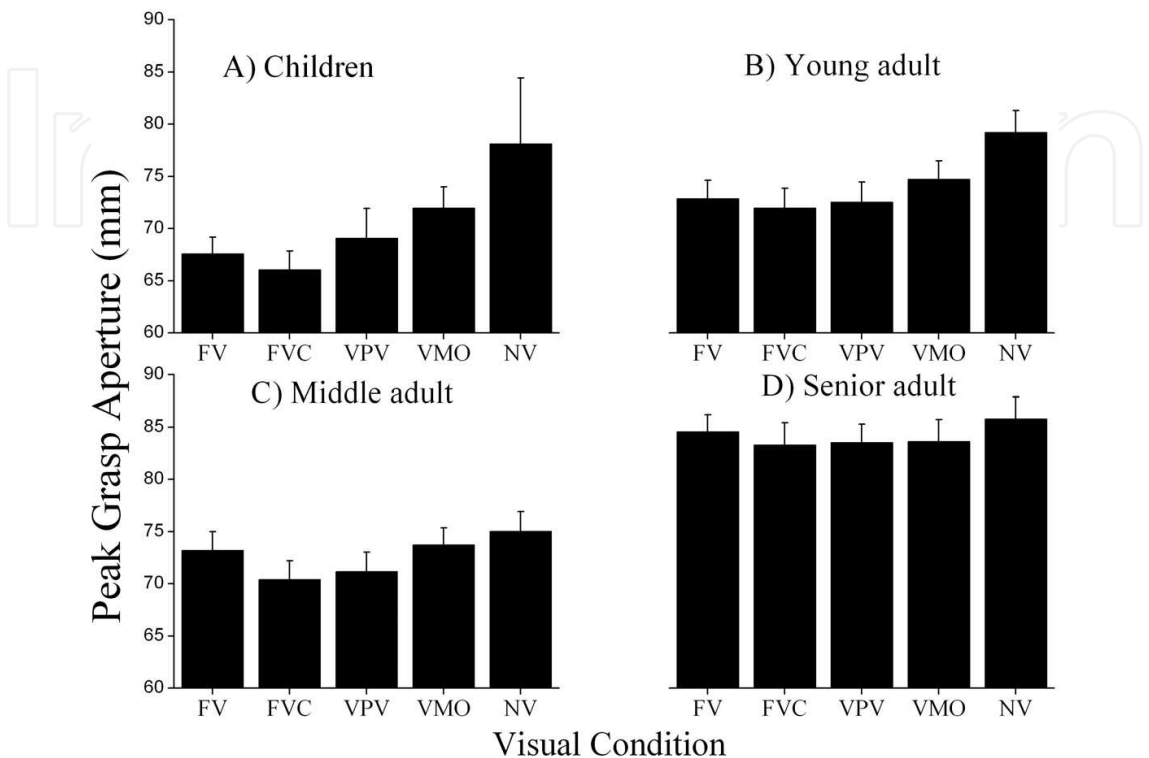

Fig. 6. Effect of visual condition on average peak grasp apertures (error bars show ±SE): A) Children $F_{4,44}=3.061$,p=0.102 B) Young adults $F_{4,44}=10.011$,p<0.001 C) Middle age adults $F_{4,44}=4.144$ p=0.022 D) Senior adults $F_{4,44}=1.207$,p= 0.320. For young and middle age adults, aperture in FVC was significantly smaller than in NV. For children and seniors FVC also had the smallest mean aperture, although this did not reach significance at the p<0.05 level. Also of note is that in young adults, FV and VPV also had significantly smaller apertures than NV. Note the general lack of visual condition effect among seniors. Adapted from (Grabowski & Mason, 2011).

To summarize, there are a few key findings from these two studies. First, young adults were quite adept at utilizing limited visual feedback for the control of precision grasp tasks in virtual environments. In contrast, senior adults could not make use of limited visual feedback and tended to rely on a feed-forward strategy. While this strategy allowed the older adults to be successful with the experimental task, it may limit the nature of their interactions in such environments when tasks become more complex. Children and senior adults both appeared to make compensatory adjustments in their motor planning for the demands of the experimental task, however they involved different components of the movement. Children altered the transport of their hand in space by using lower peak velocities. Senior adults used a very large grasp configuration to compensate for task uncertainty. Finally, aperture results indicated that there could potentially be some enhancement in performance when augmented feedback about the hand (i.e. the crude finger representation) contrasts at least moderately with the background environment. This

was most pronounced in middle age adults, but weakly present in all age groups. While there are many directions to head with future research, the finding regarding the possibility of performance enhancement through the manipulation of luminance contrast is one particular area of interest.

4. Future directions

In the final sections, we will develop a theoretical basis for the importance of understanding the role of luminance contrast for precise, visually guided movements of the upper extremities. Following this, we briefly describe our next set of experiments aimed at a deeper understanding of the role of vision for motor performance in virtual environments across the lifespan.

4.1 Contrast sensitivity and tuning of neuronal populations

The neural processing of sensory information is described by the tuning of neuronal populations to specific stimuli (Desimone & Duncan, 1995). Within areas of the visual cortex, groups of neurons fire in response to the presence of afferent information. This firing rate is tuned to specific aspects of the stimulus, thereby increasing the precision by which the system can differentiate visual information. Within neuronal populations, firing rates differ among neurons. Some neurons will fire constantly with the presence of a stimulus, known as tonic firing. Other neurons fire rapidly at the onset of the stimulus, and rapidly decrease activity thereafter; this is known as phasic activity. This phasic activity makes the general sensorimotor system particularly sensitive to changes in stimulation. The visual cortex is no exception. Phasic neurons located within the visual cortex are sensitive to areas within the visual scene that are actively changing. It is simple to understand this in the case of a moving object, however the border of a stationary object also has this effect. Specifically, when the eye is moving and a stationary image passes over the moving retina, the border of the stationary object causes the visual scene to abruptly change, and phasic neurons react accordingly.

Sensitivity to object borders is dependent on the visual contrast between the object and its background. Contrast is described by two characteristics, luminance (brightness) and chromaticity (color), which are processed differently in the dorsal and ventral visual streams. The two visual stream hypothesis put forth by Goodale and Milner has a wide breadth of experimental support in explaining multiple functions for visual processing (Goodale and Milner 1992 as cited in Milner & Goodale, 2008). Briefly, the ventral stream includes structures along the pathway from the visual cortex in the occipital lobe to the inferotemporal lobe. This circuit has been implicated in the use of vision for perception of the surrounding environment, allowing the conscious experience of seeing the world around us. The dorsal stream includes the pathway from the visual cortex to the posterior parietal lobe. This pathway is responsible for the visuomanual transformations that allow visual information to guide our motor system in interacting with the surrounding environment. The neuronal structure of the ventral stream allows for high spatial resolution and sensitivity to chromaticity (Wade et al., 2002). Processing of color information in the ventral stream plays a role in the perception of objects (Kleinholdermann et al., 2009; Morrone, Denti, & Spinelli, 2002). The role of color contrast in visual processing for motor output has not been clearly elucidated, but it appears the strict dichotomous notion of the

two visual stream hypothesis may be overly rigid. Recent investigation has shown that for simple eye movements and pointing tasks, color information can be used to guide movement (White, Kerzel, & Gegenfurtner, 2006). Pisella, Arzi, and Rossetti (1998) studied the ability of humans to utilize color information to quickly update their movements in a perturbation paradigm. While movement reorganization was possible utilizing only color information, the results showed a distinct slowing of movement reorganization. Brenner and Smeets (2004) also studied a similar paradigm, finding that color could in fact be utilized rather quickly for task reorganization; however, they still showed a minor slowing compared with movement reorganization based on luminance information. Luminance contrast, while also important in perception, may have more direct implications for motor output. Motion sensitivity is dependent on contrast sensitivity and motion sensitivity is a hallmark of the neuronal structure of the dorsal stream (Born & Bradley, 2005). Therefore luminance contrast may be an important source of visual sensory feedback for motor output.

Properties of visual feedback are used both in the planning and online control of movement. The specific role of luminance contrast for such processes has not been clearly identified, and previous study of this topic is sparse. Recently Braun et al. (2008) investigated whether initiation of eye movements differed when tracking two types of targets, one with luminance contrast compared to the background and one isoluminant with the background (i.e. defined by color only). They showed a strong and significant effect of target contrast on speed of eye movement initiation, with tracking of isoluminant targets delayed by 50 ms. They also showed lower eye accelerations to these no-contrast targets. For upper extremity control, studies have shown mixed results. White, Kerzel, and Gegenfurtner (2006) showed that there was no difference in accuracy or response latency when comparing simple rapid aiming movements to targets of high luminance contrast versus isoluminant targets. In a more complex task, Kleinholdermann et al. (2009) looked at the influence of the target object's luminance contrast as subjects performed reach to grasp movements within a desktop augmented (physical object with graphical overlay) environment. Participants were not provided with a head-coupled stereoscopic view, nor were they provided any visual representation of the hand. They were given a view of the environment that included only a virtual image overlaying the actual target disk. The independent variables controlled by the experimenters were the visual properties of chromatic and luminance contrast between the target object and the environment background. The results of this study showed only a minimal effect of luminance contrast on the formation of grasp aperture. They concluded that isoluminant targets were as suitable for the motor planning of grasp as targets defined by a luminance contrast or a luminance plus chromatic contrast. However, because current theories of motor control rest on the premise that object location can be precisely identified in relation to limb location (Wolpert, Miall, & Kawato, 1998) we contend that the lack of visual feedback about the limb likely resulted in a ceiling effect for a number of performance measures used by Kleinholdermann et al. Given that neuronal tuning properties make the visual system particularly sensitive to change, it is logical that some property involving a change in visual stimulus may be especially useful in this quick, precise identification of object and limb spatial location. Luminance contrast is such a property. Future experiments should expand upon the work of Kleinholdermann et al. by examining the role of luminance contrast of both the target object and the effector limb for upper extremity performance. Further, the Kleinholdermann et al. paper focused predominantly

on motor planning. Future studies should examine kinematic findings at a deeper level to understand the use of vision in both open and closed loop functions. Additionally, since the treatment of visual contrast information by the CNS changes with time, as discussed in the next section, new studies must focus on delineating the role of such information for populations differing by age.

4.2 Aging and luminance contrast

While there are changes at the ocular level with age, the predominant cause of functional decline is due to a slowing of central processing in the brain (Chaput & Proteau, 1996; Inui, 1997; Light, 1990; Shields et al., 2005). The slowing of temporal processing has been specifically implicated in the decline of luminance contrast sensitivity in adults over 60. Motion sensitivity, which is dependent on contrast sensitivity, also declines with age (Spering et al., 2005; Trick & Silverman, 1991). Motion sensitivity is also known to be directly linked to function of dopaminergic circuitry, a system known to play a major role in the aging process (Wild-Wall et al., 2008). Despite these declines, older adults become more dependent on vision over time, resulting from the relative sparing of visual resources when compared to other sources of sensory feedback (Adamo et al., 2007; Chaput & Proteau, 1996; Goble et al., 2008; Lemay et al., 2004). The important concept to note is that this sparing of neurons in the visual systems results in a greater amount of substrate available for positive neuroplastic changes relating to motor output. Indeed, such positive changes have been documented in older adults when trained via the visual system to improve speed of processing (Ball, Edwards, & Ross, 2007; Edwards et al., 2005; Long & Rourke, 1989; Zhou et al., 2006). The key question to consider is how might this potential for plastic changes be manipulated and optimized? Given that the processing of luminance contrast information is linked in multiple ways with speed of processing, and speed of processing is a central theme in aging related functional decline, this visual property may be a useful means to answer the plasticity question. We believe a number of attributes of 3D VEs make them an ideal tool to aid in investigating this question, and believe design of VEs will directly benefit from the information gained. Therefore, we intend to investigate changes in sensorimotor processing of luminance contrast in older adults compared to younger adults. The information gained from this study will be directly applicable to development of technologies to rehabilitate and enhance function in aging and neurologically compromised adults.

4.3 Future research aims

Aim 1 is to test the hypothesis that luminance contrasts of target and limb have an effect on upper extremity kinematics in a virtual environment. This will be investigated using the methodology described previously with a reach to grasp paradigm. We will test a population of adults age 18-25 without history of visual or upper extremity sensorimotor dysfunction. We intend to study five contrast levels ranging from very low to very high. Based on previous studies of visual feedback, we believe that low levels of luminance contrast will negatively affect kinematic markers of upper extremity performance, for example slowed movement time, when compared to moderate and high levels. We also believe that high levels of contrast will not have a significant effect on performance measures when compared to the moderate level for this group of participants.

Aim 2 is to test the interaction of age with visual contrast between the limb/target and background environment. We will use the same reach to grasp paradigm, but collect data on a group of healthy adults age 18-25, a middle age group 40-50, and a group of healthy adults age 60+. We believe that older adults will only effectively use visual feedback of self in the highest contrast condition. This will allow inferences about the age-related processing of luminance contrast as a visual feedback parameter for motor performance.

4.3.1 Application of results

We anticipate the results of this line of research will have implications in numerous fields. First, the information gained will have direct bearing on computer science for the user-specific design of next generation 3D virtual environments. As the world population continues to age, understanding of how to enhance performance with computer interfaces must take into account the physiologic changes that occur over time. Luminance contrast appears to be an important factor in upper extremity control, and one that is known to play a role in performance changes with age in natural environments. It stands to reason then that performance in a primarily visual environment, such as a 3D VE, will rely heavily on the neural processing of contrast. Secondly, we believe the field of rehabilitation will benefit indirectly through improvements in user-centered design. Currently, 3D VEs are regularly studied as a means to improve upon current practices in rehabilitation of patients post-stroke. Unfortunately, one barrier to success continues to be usability and provision of cost-effective, age-appropriate sensory feedback. Information on performance changes in older adults related to manipulation of luminance contrast may be of use to both program designers and rehab clinicians. For example, if older adults perform movements in VEs under certain contrast conditions in a manner equivalent to a natural environment, rehab clinicians may want to capitalize on such parameters to improve functional carryover of training to activities of daily living. Lastly, we believe results from our current and future study will contribute to the fields of gerontology and behavioural neuroscience by expanding our knowledge of visual processing and motor behaviour across the lifespan.

5. Conclusion

User-centered design of virtual environments continues to be an under-studied area with regard to both old and young users. Knowledge of human performance, and the nature of the sensory feedback that guides it, will be imperative in the successful, cost-effective design of tangible user interfaces intended for use by these populations. Recent work has shown that young adults can utilize visual information provided in virtual environments differently than both older adults and young children, and therefore more specific age-group studies are needed. Future studies will focus on specific parameters of visual feedback, such as luminance contrast, and how the provision of such properties in virtual environments impacts the performance of the user.

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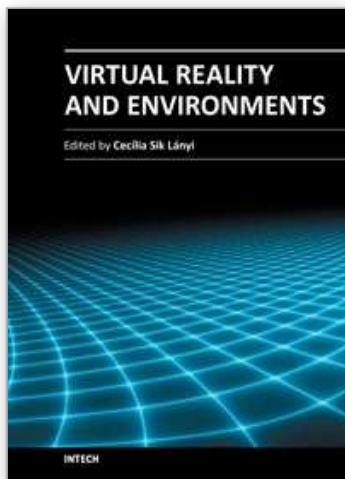
Virtual Reality and Environments
Edited by Dr. Cecília Sík Lányi

Virtual Reality is clearly interdisciplinary research. It has, not only Information Technology importance but social, educational, economical importance too. It combines multiple disciplines for the development of virtual reality systems in which the user has the immersive feeling of being in the real world. Virtual reality has several applications in almost all fields of real life. The most typical fields for the application of virtual reality are health-care, engineering and game industry. This book may be a solid basis for the novice and advanced engineers who would like to develop user friendly Virtual Environments for education, rehabilitation and other applications of Virtual Reality. Our book provides a resource for wide variety of people including academicians, designers, developers, educators, engineers, practitioners, researchers, and graduate students.

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