First online: 21 December 2016

Effect of Viewing Angle and Object Position on Accuracy of Arm Reaching in a 3D Virtual Environment

Justin M. Bobick[1], Amanda Fabera[2], Jan Perkins[*3], Ksenia I Ustinova[3]

[1]MidMichigan Medical System, Midland, MI, 48670, USA

[2]McLaren Bay Region, Bay City, MI, 48708, USA

[3]Central Michigan University, Mt Pleasant, MI, 48859, USA

[1]justin.bobick@midmichigan.org; [2]Amanda.Fabera@mclaren.org; [*3]perki1jm@cmich.edu; [4]ustin1k@cmich.edu

***Abstract*-Virtual environments permit the creation of rehabilitation settings that help prepare clients for subsequent real world functional activities. Many questions remain regarding the optimal presentation of the environment, one being how manipulation of target position and viewing angle or perspective can affect functional reaching performance. Using twenty healthy young adults (24.7+3.0), this study examined the effect on functional arm reaching by manipulating these factors in a first person 3D virtual hallway. Their goal was to touch a blue pyramidal target without stepping or overbalancing. The target was randomly positioned either directly in front of the participant or offset 10^0 to either side with randomly assigned viewing angles of 10^0, 45^0, and 90^0. Movement was recorded using an Xbox Kinect Motion Sensor. Outcome measures of endpoint error, peak velocity, and index of curvature were calculated. Manipulating the viewing angles had no significant impact on peak velocity, endpoint error, or directness of path to the target. Target positions that required contralateral reaching across the midline of the body increased peak velocities and had a less direct path to the target. Results suggest that for healthy adults, the viewing angle is not a limiting factor in reaching to a target. However, more research is needed to test this in participants with sensorimotor deficits. In our healthy population, reaching across the midline of the body in a 3D environment affects reaching pathway and peak velocity, and knowing this will be helpful in further developing virtual rehabilitation activities.**

Keywords*- *Game Platforms; Game Therapy; Rehabilitation; Reaching in Virtual Environments

I. INTRODUCTION

Virtual reality (VR) environments are computerized simulations that offer opportunities to experience a multitude of sensory rich environments via controllers, gloves, motion sensors, head-mounted displays, accelerometers, and video capture technology. There is considerable interest in their use for many aspects of health and wellness care, including activity promotion, evaluation, and rehabilitation [1-3]. One particularly appealing aspect is the possibility of offering safe rehabilitation gaming for individuals with multiple sensorimotor and cognitive deficits.

Virtual environment (VE) platforms have been used with a variety of populations, including those with a range of pathologies, phobias, and increased risk of fall [4]. It is suggested that VR can provide an environment for task practice that facilitates motor learning and neuroplastic changes in sensorimotor areas of the brain [5]. One review [4] documented the success and safety of VR treatments for patients with medical histories of stroke, traumatic brain injury, spinal cord injury, and cerebral palsy. VR has the ability to offer a protected and engaging environment for motor re-education. For example, a person with limitations in reaching may report difficulties with multiple daily activities such as gardening, shopping, self-care, or using a computer [6-8]. Studies of using VR for upper extremity rehabilitation have concluded that the virtual activities were comparable to conventional physical therapy for addressing some upper extremity dysfunctions [9].

Because VR is becoming an acceptable part of activity and therapy programs, it becomes important to examine affordable off-the-shelf options designed by companies such as Nintendo, Sony, and Microsoft as being suitable for therapeutic purposes. Dutta [10] focused attention on the Microsoft Xbox Kinect sensor, a portable 3D system that captures and responds to movement gestures and voice commands, for the reason that it can be integrated with VR systems outside of its associated gaming console. To accomplish this, the system uses an infrared laser projector and infrared camera to measure depth, which allows the Kinect to create 3D maps of viewed objects by measuring deformity in a speckle pattern on surfaces. Some [10, 11] have concluded that because of its operating accuracy, the Kinect would be a viable, inexpensive device to use in clinics or research settings. However, there are potential concerns due to its inability to fully sense dark colors, reflective surfaces, or assess rotation movements of joints. Instead it focuses more on flexion/extension and abduction/adduction extremity motions.

Aside from the potential of the Kinect or other such systems, the creation and integration of customizable virtual environments can be complicated and expensive. Research in this area has consistently noted that more studies need to be conducted to demonstrate functional improvement and show how manipulation of sensory, auditory, and haptic feedback may affect these functional gains. Other considerations for developers and users to study are costs, accuracy of outcome measurements, interface limitations, and prevention of adverse effects such as motion sickness [4, 5].

While studies document possible health benefits from VR, questions remain as to how manipulating VE variables can affect performance [6, 12-15]. One study examined reaching accuracy by comparing depth judgment in the real world (RW) and VE. It found that some aspects of VE perception could negatively affect reaching distance estimations [12]. Perception can be altered by manipulating the viewing angle in a variety of methods. Gardner and Mon-Williams [16] used prism glasses to manipulate the perception of viewing angles and object distance. They found that participants tended to underestimate distances when reaching for objects presented with simulated lower viewing angles, and overestimated distances when reaching for objects viewed with higher viewing angles. Participants in another prism glasses study [17] underestimated object distances as well. After removing the prisms, they consistently overestimated throwing and walking distances.

Other studies in VR have examined characteristics of reaching. In one, a 2D VE resulted in slower, shorter, and less accurate upper extremity movements with reduced shoulder and elbow joint range of motion [18]. Another 3D presentation found decreased accuracy and range of motion [13].

Another study [6] found that manipulation of viewing angle in a 3D third person point of view (POV) could affect reaching distance during performance of open-ended pointing. Greater reaches were achieved with a viewing angle of 45.00-77.50 than with larger or smaller angles. This emphasizes the importance of examining the effect of manipulation of VR attributes in order to optimize therapeutic results. When compared to ipsilateral reaching tasks in both VR and RW situations, others [19] found that reaching across midline for contralateral targets resulted in lower values of movement time, peak velocity, and peak accelerations. It has also been found that improved reaction time, peak velocity, accuracy, and more direct movement trajectories are seen with ipsilateral target reaching than with contralateral reaching [20-23]. These differences were believed to result from participants preferring their dominant hand for ipsilateral and midline reaching, as well as for small, simple reaches across the midline. The non-dominant hand was preferred only when a large reach across midline would be demanded from the dominant hand [20-23].

In order to maximize benefits when using VR for health related gaming, there are many research requirements [6, 12-15]. Many VE considerations should be better understood to optimize beneficial effects and to determine whether practice in VR can generalize to RW functioning. Research has led to suggestions for further exploration on the manipulation of angles, personal viewpoint, visual dimensions, visual delivery equipment, and graphics resolution [4-6, 14, 15].

This study examines whether the manipulation of viewing angle while reaching for a target in a first person 3D VE affects dominant hand reaching accuracy and speed. It is measured by endpoint accuracy, peak velocity, and index of curvature. We also examined the effect on these parameters of target position of the participant, either directly in front of or offset to the ipsilateral or contralateral side.

II. METHODS

A. Participants

A volunteer sample of convenience consisting of twenty healthy young adults (14 females, 6 males) with a mean age of 24.7 ± 3.0 years was recruited for the study. Each of the individuals signed an informed consent form that was prepared in compliance with the Helsinki Declaration and approved by a university Institutional Review Board. Initially, individuals completed a Berg Balance Scale (BBS) [23] to screen out any participants at high risk of falls. All were interviewed to ensure that none had any cognitive or physical health complications that would limit participation or suggest they might experience adverse side-effects from the use of a 3D VE.

B. Instrumentation

The VE consisted of a rectangular room with patterned walls and floor. It was created using WorldViz software (WorldViz LLC, Santa Barbara, CA, USA), on a Dell Alienware M18 laptop (quad-core 2.2GHz Intel Core i7-2670QM processor), with computer graphics performed by the Alias' Maya package for 3D animation (Maya®, Version 7.0.1; Autodesk, Inc., San Rafael, USA) and a graphics accelerator (NVIDIA GeForce GTX 560M) integrated with the Kinect Motion sensor (Microsoft, Inc). This system presented a virtual hallway on an 82-inch screen (1080p Mitsubishi DLP® TV bundle, RealD), which was viewed through Real 3D CE5 glasses. The virtual target consisted of a blue pyramid. The participant's hand was represented in the VE by a virtual hand, which had a visual circle placed on the distal phalange of the middle finger (Fig. 1).

Participants stood in front of the screen at a distance of 262cm with their dominant hand outstretched at shoulder height in front of them. In the virtual world, the target was created at the point where the circle on their middle finger was positioned. The participant performed five practice reaches to familiarize their movements in the first person 3D VE. Each reach started with their dominant arm resting on their xiphoid process and ended when the sphere on their virtual hand touched the target, causing it to disappear. The sagittal plane distance from their xiphoid process to the tip of their middle finger was measured in the physical world. The participant was then repositioned to stand an additional 30% away from the previous target distance. This distance was selected as being enough to make it a challenging reach, but not far enough to cause overbalancing which meant that the reaches required trunk movement but allowed them to stay within their limits of stability [24]. Fig. 1 shows a participant reaching for the target after repositioning. The target could be located at the midline, which was a direct extension of the participant's arm, or shifted to the left or right side of the midline.

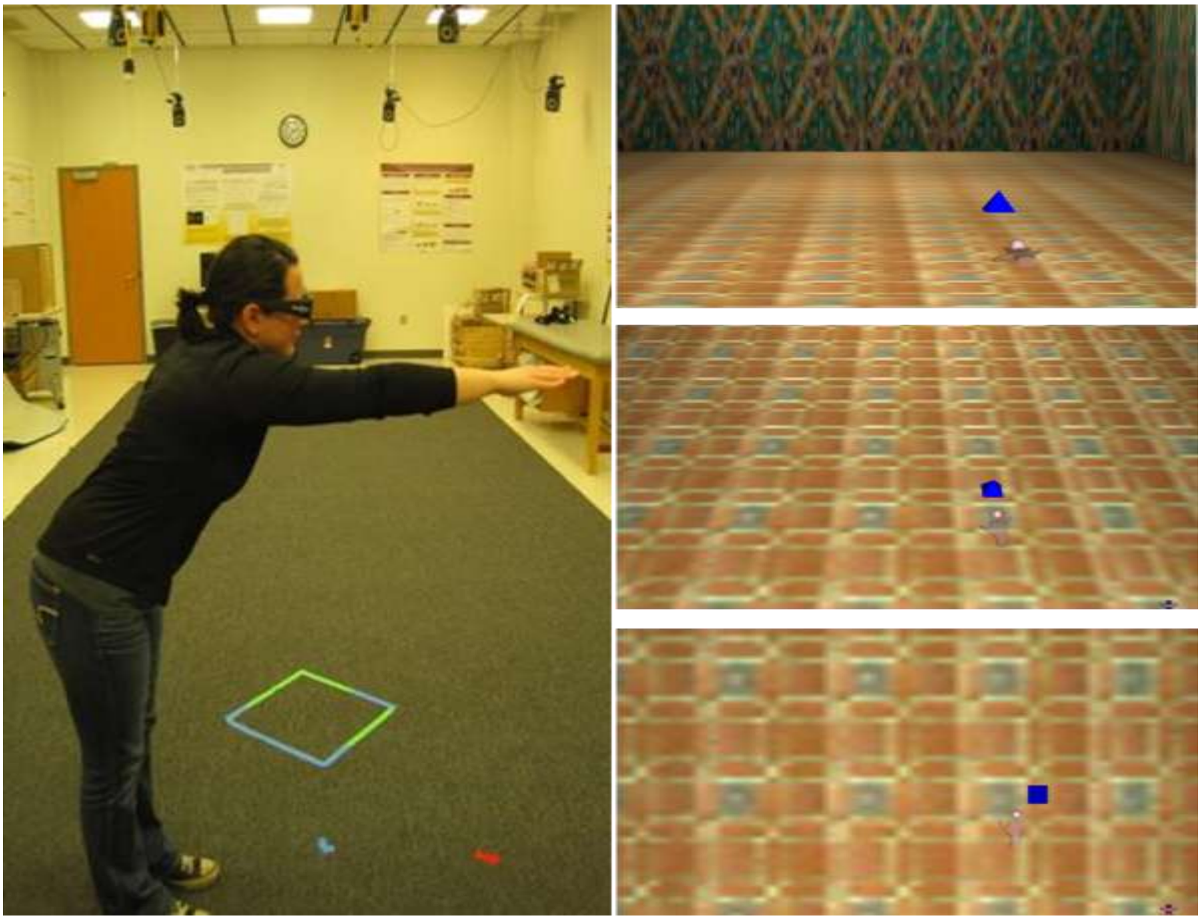

Fig. 1 Participant wearing 3D goggles and to guide the avatar hand to the target, alongside three views of the VE room and target with different viewing angles and offsets

Each participant performed nine sets of five reaches, including all combinations of midline offset (ipsilateral, contralateral, none) and viewing angles (10°, 45°, 90°), with set order randomized. When the target was reached it disappeared with an audible "pop", then reappeared five seconds later.

C. Data Collection and Analysis

Linear displacement of the participant's reaching arm (hand segment) in three different planes were recorded by the Xbox Kinect Motion Sensor, each at a sample rate of 30 Hz. Displacements endpoint error, peak velocity, and index of curvature were calculated from the linear. Statistical analysis was performed with IBM SPSS version 21. Repeated measures factorial design ANOVA was used. Mauchly's test was used to assess for the sphericity assumption, and where indicated degrees of freedom were corrected using Greenhouse-Geisser estimates. Post hoc comparisons were adjusted using Bonferroni corrections.

III. RESULTS

Findings are summarized in Table 1. There was a significant main effect of offset on peak velocity, measured in meters per second, $F(1.49, 28.34) = 20.19$; $p < .001$. There was no significant interaction between angle and offset: $F(4, 76) =.82$; $p=.51$, and there was not a significant effect of angle of view on peak velocity: $F(2, 38) = 0.88$; $p = .42$. Pairwise comparisons for offset showed a significant difference between no offset and contralateral (across body midline) offset ($p = .001$). There was also a significant difference between contralateral offset and ipsilateral (outward from the dominant side) offset ($p < 0.001$), but not between no offset and ipsilateral offset ($p = .45$). Peak velocity increased for all contralateral reaches regardless of angle of view. When compared to either no offset or contralateral offset, offset at each viewing angle showed the same pattern with peak velocity being significantly higher for contralateral offset. There was no significant difference between no offset and ipsilateral offset.

TABLE 1 DESCRIPTIVE STATISTICS FOR OUTCOME VARIABLES

VE Parameter	Peak Velocity Mean (SD)	Index of Curvature Mean (SD)	Endpoint Error Mean (SD)
10 °No Offset	1.37 (0.85)	1.46 (0.36)	0.09 (0.04)
10 °Ipsilateral Offset	1.28 (0.67)	1.83 (0.86)	0.09 (0.01)
10 °Contralateral Offset	1.92 (0.84) [b,c]	3.92 (3.01) [b,c]	0.09 (0.01)
45 °No Offset	1.42 (0.70)	1.48 (0.34)	0.09 (0.01)
45 °Ipsilateral Offset	1.24 (0.44)	1.91 (1.08)	0.09 (0.01)
45 °Contralateral Offset	2.10 (0.93)[b,c]	3.34 (2.39) [b,c]	0.09 (0.01)
90 °No Offset	1.40 (0.69)	1.46 (0.34)	0.09 (0.01)
90 °Ipsilateral Offset	1.29 (0.64)	1.92 (0.87)	0.09 (0.01)
90 °Contralateral Offset	2.26 (1.15) [b,c]	4.10 (2.82) [b,c]	0.09 (0.03)

[a] N for all measures was 20.
[b] Indicates significant difference from No Offset value at same angle of view.
[c] Indicates significant difference from Ipsilateral Offset value at same angle of view.

There were similar findings in regards to the effect of angle of view and offset on the index of curvature, which reflects the directness of the path taken to reach the target. There was a significant effect of offset on index of curvature, F(1.20, 22.70 = 22.70, p < .001 and no significant interaction between angle and offset, F(1.71, 32.44) = .056, p = .55 or angle of view, F(1.52, 28.90) = .46; p = .58. The index of curvature increased with any offset, indicating a less direct path to the target. Contralateral (inward) offset had the greatest deviation. The difference was significant between contralateral and ipsilateral offset (p < 0.001) and between contralateral and no offset (p = .002), but not for no offset and ipsilateral offset (p = .06). When each angle of view was analyzed individually, the pattern remained significant at each angle of view between inward and ipsilateral offsets and inward and no offsets, but not between no offset and ipsilateral offset (Table 1).

Endpoint error results did not show a similar pattern. There was not a significant effect of angle (F(2.0, 38.0) = 0.44; p = .65) or offset (F(1.17, 22.31) = 0.013; p = .94) on endpoint error. There was also not a significant interaction between angle and offset (F(2.06, 39.16) = 0.64; p = .54).

IV. DISCUSSION

The present study investigated how manipulation of viewing angles and target positions with regards to body midline would affect selected performance variables (endpoint error, peak velocity and index of curvature) while reaching for a target in a 3D first person VR environment. The three viewing angles used did not significantly affect any of the outcome variables. However, changing the offset of the target from the body midline altered both peak velocity and accuracy of the path (index of curvature) used to reach the target.

Reaching directly forward with the hand in a sagittal plane and no offset produced the most accurate path to the target, with index of curvature closest to the ideal. When participants reached to a target with their dominant hand and an ipsilateral offset, i.e. one displaced away from the body midline, the index of curvature was not significantly larger. Reaches with a contralateral offset, i.e. crossing the body midline, had significantly less accurate paths to the target than an ipsilateral or no offset reach. This effect was consistently seen across all viewing angles.

The peak velocity of the reaches also showed a consistent pattern across all angles of view. Reaches to the contralateral side demonstrated the highest peak velocity and they were significantly faster than no offset and ipsilateral offset reaches.

Endpoint error did not demonstrate a similar pattern. For with this outcome variable, there were no significant effects of angle of view or offsets.

While previous research has shown that manipulation of viewing angle can alter reach distance in a third person VR environment, these findings suggest that similar viewing angle alterations have no significant effect on speed or accuracy of reaches in a first person 3D VR environment [6]. This effect may be explained by the difference in performance of closed versus open-ended tasks. In the present study, the end point of reaching was predetermined and displayed as a single point (the peak of the pyramid) on the screen. The reach may not have been affected by changing the visual perspective as this single point did not have a 3D representation. By contrast, in the previous study there were multiple possible targets and the endpoint of the reach was selected by the participant. It is possible that in the process of target selection in that specific study, participants included the parameter of visual perspective in their motor planning and performance. At present these explanations are speculative. More work needs to be done to investigate and verify the effects in different virtual environments.

While no difference was found regarding accuracy between no offset and ipsilateral offset, our data showed that when reaching toward the contralateral offset, participants tended to demonstrate less accuracy as compared to the other two offsets, represented by greater index of curvature. As some research has shown, one theory that could explain this difference is that when reaching 20 ° or more across the midline, those with a strong hand dominance tend to use the arm with the closest proximity to the object regardless of dominance, while for smaller angle reaches they tended to prefer to use the dominant hand [19, 25, 26]. Therefore, when asked to reach to the left, participants preferred to reach with the left hand even if their dominant hand was right. Our participants were required to reach with their dominant hand rather than their preferred, and as our offset was smaller than 20 °, the requirement of using the dominant hand may explain reaching differences for those crossing the midline. This is also consistent with a general pattern of research which has found that visually controlled ipsilateral reaches are more accurate in their path to the target than contralateral, and that people strive for accurate movements whenever possible in the interests of efficiency [27, 28].

Complexity of the action required also influences hand preference and kinematics. Individuals are more likely to use the dominant arm, even for contralateral tasks, when task complexity increases [21]. When forced to make reaches contralaterally, accuracy is then diminished [25]. In comparison, we provided a simple task of reaching to touch a target, but they could only use their dominant arm. These studies suggest that in both real and virtual worlds, if our participants were able to choose their preferred arm they might have shown better accuracy.

Our results showed that when participants reached across midline, peak velocity increased. This result is contrary to other research [18, 29] which indicated contralateral reaching has slower peak velocity, suggesting that peak velocity decreases with across midline reaching. One of these studies [18] compared this in both real and virtual environments, both with similar findings. However, in that study researchers noted that there were considerable individual differences. Other possibilities for differences between our findings and others' may relate to participant positioning and the size of the offset. Our participants reached from a standing position rather than sitting, and we used a small offset of approximately 10 degrees. Again, these are speculative explanations and more investigation is needed. Similar observations have been reported earlier by Gillette and Abbas [30]. Participants in their study performed standing reaches either to the left, right, or center. Although participants reported reaching to the contralateral side to be their least preferred, the reaches made to the left by the right-handed participants (across the body midline) were able to cover greater distances than reaches to the right or center. The author explained this phenomenon by trunk and shoulder rotation and other joint segment movements, which turned the shoulder closer to the target. In our study, trunk rotation while reaching across the midline could have added momentum and increased velocity of the simple reach to touch the target we used. This may not have been required for the ipsilateral targets. There are also differences in movement strategies between reaching to manipulate or grasp and reaching for maximal distance or to touch a target [28], but more investigation is needed to determine the explanation.

V. LIMITATIONS

Some limitations are present in this study. First, limited research has been done using the Xbox Kinect, therefore there is a question of system accuracy. While participating in the research, individuals consistently showed more difficulty finding the target when reaching across the midline. It is unclear if some of this inaccuracy may be attributed to the system's ability to track the arm movement across the body. It has also been suggested that certain clothing items may not be as recognizable by the Kinect system, which may have attributed to inaccuracy of the system [10, 11]. Kinect measurement error may also have limited results.

Another limitation of our study is that the difference between those left hand vs right hand dominant were not analyzed separately. Eighteen of our participants were right-handed and two were left-handed. Although we oriented reaches so that they were ipsilateral and contralateral to the participant's dominant hand, we did not address extent of handedness, and our sample size did not permit analysis of right and left hand dominant participants separately. This could be an area for further exploration.

VI. CONCLUSION

Our study evaluated how manipulation of visual angles and target offset in a first person 3D VE can affect kinematics of dominant hand reaching, with endpoint accuracy, peak velocity, and index of curvature as dependent variables. We found that manipulating viewing angles did not alter these factors. However, contralateral reaching resulted in less accurate paths to the target, as well as increased peak velocities. Some of our findings support those found by other researchers and some do not. We then suggest additional work and experimentation to clarify and expand findings. We also recommend comparing future off-the-shelf interactive gaming systems with current options to help confirm or refute the findings, determine optimal manipulation of factors in different VE, and identify other systems that can be adapted for safe, engaging, and effective virtual rehabilitation.

ACKNOWLEDGEMENT

We wish to acknowledge Wesley A. Leonard for his assistance in developing the virtual room and integrating the environment with the Kinect.

REFERENCES

[1] K. J. Miller, B. S. Adair, A. J. Pearce, C. M Said, E. Ozanne, and M. M. Morris, "Effectiveness and feasibility of virtual reality and gaming system use at home by older adults for enabling physical activity to improve health-related domains: a systematic review," *Age and Ageing*, vol. 43, pp. 188-195, 2014.

[2] M. J. Taylor, D. McCormick, T. Shawis, R. Impson, and M Griffin, "Activity-promoting gaming systems in exercise and rehabilitation," *Journal of Rehabilitation Research & Development*, vol. 48, pp. 1171-1186, 2011.

[3] W. G. Wright, "Using virtual reality to augment perception, enhance sensorimotor adaptation, and change our minds," *Frontiers in Systems Neuroscience*, vol. 8(1), p. 56, 2014.

[4] P. L. Weiss, H. Sveistrup, D. Rand, and R. Kizony, "Video capture virtual reality: A decade of rehabilitation assessment and Intervention," *Physical Therapy Reviews*, vol. 14, pp. 307-321, 2009.

[5] S. V. Adamovich, G. G. Fluet, E. Tunik, and A. S. Merians, "Sensorimotor training in virtual reality: a review," *Neurorehabilitation*, vol. 25, pp. 29-44, 2009.

[6] K. I. Ustinova, J. Perkins, L. Szostahowski, L. S. Tamkei, and W. A. Leonard, "Effect of viewing angle on arm reaching while standing in a virtual environment: Potential for virtual rehabilitation," *Acta Psychologica*, vol. 133, pp. 180-190, 2010.

[7] S. Schneiberg, P. McKinley, E. Gisel, H. Sveistrup, and M. Levin, "Reliability of kinematic measures of functional reaching in children with cerebral palsy," *Developmental Medicine & Child Neurology*, vol. 52, pp. 167-173, 2010.

[8] A.K. Balitsky-Thompson and Y. P. Henriques, "Visuomotor adaptation and intermanual transfer under different viewing conditions," *Experimental Brain Research*, vol. 202, pp. 543-552, 2010.

[9] J. H. Crosbie, S. Lennon, M. C. McGoldrick, M. D. J. McNeill, and S. M. McDonough, "Virtual reality in the rehabilitation of the arm after hemiplegic stroke: a randomized controlled pilot study," *Clinical Rehabilitation*, vol. 26, pp. 798-806, 2012.

[10] T Dutta, "Evaluation of the Kinect sensor for 3D kinematic measurements in the work place," *Applied Ergonomics*, vol. 43, pp. 645-649, 2012.

[11] R. A. Clark, Y. H. Pua, K. Fortin, C. Ritchie, K. E. Webster, L. Denehy, and A. L. Bryant, "Validity of the Microsoft Kinect for assessment of postural control," *Gait & Posture*, vol. 36, pp. 372-377, 2012.

[12] G. Singh, J. E. Swan II, J. A. Jones, and S. R. Ellis, "Depth judgments by reaching and matching in near-field augmented reality," In: *Proceedings of IEEE Virtual Reality 2012*, pp. 165-166, Washington, 2012.

[13] L. A. Knaut, S. K. Subramanian, B. J. McFadyen, D. Bourbonnais, and M. F. Levin, "Kinematics of pointing movements made in virtual versus a physical 3-dimensional environment in healthy and stroke subjects," *Archives of Physical Medicine and Rehabilitation*, vol. 90, pp. 793-802, 2009.

[14] S. K. Subramanian and M. F. Levin, "Viewing medium affects motor performance in 3D virtual environments," *Journal of Neuroengineering and Rehabilitation*, vol. 8, pp. 36-44, 2011.

[15] T. Y. Grechkin, T. D. Nguyen, J. M. Plumert, J. F. Cremer, and J. K. Kearny, "How does presentation method and measurement protocol affect distance estimation in real and virtual environments?" *ACM Transactions on Applied Perception*, vol. 7(4), pp. 157-166, 2010.

[16] P. L. Gardner and M. Mon-Williams, "Vertical gaze angle: absolute height-in-scene information for the programming of prehension," *Experimental Brain Research*, vol. 136, pp. 379-385, 2001.

[17] T. L. Ooi, K. A. May, P. J. Gunther, and Z. J. He, "Prism adaptation effects on absolute distance judgment," *Journal of Vision*, vol. 1(3), p. 5, 2010.

[18] D. G. Liebermann, S. Berman, P. L. Weiss, and M. F. Levin, "Kinematics of reaching movements in a 2-D virtual environment in adults with and without stroke," *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 20, pp. 778-787, 2012.

[19] J. C. Stewart, J. Gordon, and C. J. Winstein, "Planning and adjustments for the control of reach extent in a virtual environment," *Journal of Neuroengineering and Rehabilitation*, vol. 10, pp. 27-41, 2013.

[20] C. J. Coelho, A. Przybyla, V. Yadav, and R. L. Sainburg, "Hemispheric differences in the control of limb dynamics: a link between arm performance asymmetries and arm selection patterns," *Journal of Neurophysiology*, vol. 109, pp. 825-838, 2012.

[21] P. J. Bryden, M. Mayer, and E. A. Roy, "Influences of task complexity, object location, and object type on hand selection in reaching

left and right-handed children and adults," *Developmental Psychobiology*, vol. 53, pp. 47-58, 2011.

[22] P. J. Bryden and J. Huszczynski, "Under what conditions will right-handers use their left hand? The effects of object orientation, object location, arm position, and task complexity in preferential reaching," *Laterality*, vol. 16, pp. 722-736, 2011.

[23] P. J. Bryden and E. A. Roy, "Preferential reaching across regions of hemispace in adults and children," *Developmental Psychobiology*, vol. 48, pp. 121-132, 2006.

[24] K. Berg, S. L. Wood-Dauphinée, J. I. Williams, and D. Gayton, "Measuring balance in the elderly: preliminary development of an instrument," *Physiotherapy Canada*, vol. 41, pp. 304-311, 1989.

[25] J. A. Leonard, R. H. Brown, and P. J. Stapley, "Reaching to multiple targets when standing: The spatial organization of feedforward postural adjustments," *Journal of Neurophysiology*, vol. 101, pp. 2120-2133, 2009.

[26] C. R. Helbrig and C. Gabbard, "What determines limb selection for reaching?" *Research Quarterly for Exercise and Sport*, vol. 75, pp. 47-59, 2004.

[27] J. D. Fisk and M. A. Goodale, "The organization of eye and limb movements during unrestricted reaching to targets in contralateral and ipsilateral visual space," *Experimental Brain Research*, vol. 60, pp. 159-178, 1985.

[28] A. Shumway-Cook and M. H. Woollacott, "Normal reach, grasp, and manipulation," In *Motor Control: Translating Research into Clinical Practice*, 3rd ed., pp. 443-467, Philadelphia, PA: Lippincott Williams & Wilkins, 2007.

[29] D. P. Carey, E. L. Hargreaves, and M. A. Goodale, "Reaching to ipsilateral or contralateral targets: within-hemisphere visuomotor processing cannot explain hemispatial differences in motor control," *Experimental Brain Research*, vol. 112, pp. 496-504, 1996.

[30] J. C. Gillette and J. J. Abbas, "Foot Placement Alters the Mechanisms of Postural Control While Standing and Reaching," *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 11, pp. 377-385, 2003.