Virtual reality therapy as adjunct to traditional physical therapy for a TBI patient who suffered a gunshot wound to the head: Case report.

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Abstract—Traumatic brain injury by gunshot creates a variety of unique sequelae that can be very challenging for clinicians to develop rehabilitation interventions. This case report presents an example of supplementing traditional physical therapy with virtual reality training for a patient who suffered a penetrating traumatic brain injury to the back of the head. By personalizing and modulating the virtual scenes to the patient's deficits and tolerance for virtual reality exposure, the patient was able to progress in his rehabilitation, which had plateaued after traditional therapy alone. At the conclusion of his rehabilitation, the patient showed clinically meaningful improvements in functional mobility assessments and subjective self-reports.

Keywords—balance, physical therapy, gunshot wound, traumatic brain injury, virtual reality, head-mounted device

I. INTRODUCTION

Gunshot wounds (GSW) to the head, leading to penetrating traumatic brain injury (TBI), are estimated to account for about 10% of all GSW. Less than a third of the victims of GSW to the head survive to be taken to the hospital and only half of them survive after hospital intervention, making it one of most lethal forms of injury [1], [2]. Those who survive a penetrating TBI can experience significant physical and psychological impairment, requiring extensive rehabilitation to maximize independent mobility and reduce the burden of care on family members and caregivers [3], [4]. Long term impairment is common and motor function in moderate-to-severe TBI survivors does not change considerably in the period of 1-5 years post injury, as identified by the Functional Independence Measure scores [5].

A number of factors contribute to the complexity of treating individuals with TBI from GSW. The location and severity of the brain injury creates a variety of unique sequelae requiring a rehabilitation program to be individually tailored for each patient [6]–[8]. TBI patients will often present with altered behaviors such as deceased self-awareness and decreased motivation, thus limiting them from taking full advantage of rehabilitation interventions and delaying return to community functions [9], [10]. Current physical rehabilitation research for TBI recovery supports early intervention to maximize the neuro-restoration process, characterized by angiogenesis, neurogenesis, and changes in synaptic connectivity [11], [12], by using motivating, intensive, repetitive, salient, and task-specific interventions [13]. Heterogeneous patient presentations and recalcitrant symptoms call for creative and flexible clinical solutions.

Virtual reality (VR) has been gaining popularity in rehabilitation in recent years, as it facilitates multi-sensory integration and relies on a wide range of cognitive functions [12], [14]–[16] while allowing the physical therapist to tailor treatment to a patient’s specific deficits and complaints [13], [17], [18]. Moreover, VR has been shown to improve self-awareness and social behavior [15] and cause changes in cortical activation to promote neuroplasticity [19].

The current case report presents an example of a therapeutic application of VR for an individual with a penetrating brain injury from a GSW to the back of the head, which injured the occipital and suboccipital regions of the head and neck. The individual underwent standard physical therapy (PT) at an inner-city pro bono center to treat balance difficulties, but persistent complaints of visual difficulties and fear of walking in the community, led us to design and employ a tailored VR therapy. We designed VR tasks viewed via head-mounted device (HMD) that was worn by the patient to visually immerse him in a variety of virtual street crossing environments. The goal of the VR intervention was to maximize the recovery of higher level of functions, increase tolerance of busy environments while multi-tasking, as well as improve balance and visual processing deficits, in order to facilitate community reintegration.

II. CASE DESCRIPTION

CC is a 26-year-old male, who sustained a gunshot wound from an assault, during which a bullet traversed through the posterior fossa of the skull from the left occipital region, injuring the transverse sinus. He underwent a suboccipital craniectomy for decompression of his wound and ligation of the transverse sinus. Post-operative recovery and in-patient rehabilitation was complicated by pseudomeningoecele of the occipital and suboccipital regions of the brain and pneumocephalus at the craniectomy site, requiring debridement and secondary closure of the superficial cranial wound. Prior to starting treatment with us at the pro bono PT clinic, CC reported spending a total of two weeks at inpatient rehab and then three months (2-3x week) at outpatient rehab immediately after the
initial surgery. When insurance denied further outpatient rehab, CC stopped attending PT. CC was 9-month post-injury when treatment began at the pro bono PT clinic run by Doctor of Physical Therapy (DPT) students with faculty oversight located in the inner city of Philadelphia. All appointments lasted one hour and he was treated by two volunteering DPT students and supervised by a licensed physical therapist.

Upon initial interview, CC spoke slowly and showed some difficulty with comprehending the PT’s questions. In addition to previous PT, he reported that he had received speech therapy for his speech difficulties. In general, he was alert and oriented and able to follow all commands. He scored a 29/30 in the Mini-Mental State Examination. He complained of poor balance, neck pain, memory issues, and fatigue. While he did not use or require assistive devices for gait, he reported being unable to turn his head when walking, unable to cross streets, and spent most of his time at home because populated areas like malls or grocery stores brought on dizziness and headaches. CC focused his gaze toward the ground when seated and in standing, was unable to maintain head-neck posture in a neutral position due to complaints of neck pain. During the entire interview, CC exhibited a slight left spatial neglect; he looked to the left only when cued, and he bumped into a table on his left side during navigation of the clinic. CC showed a mild decrease in left peripheral visual field, as compared to right side, during cranial nerve testing. Aside from the complaints of dizziness, eye-strain, and headaches from visual overload in crowded settings, CC did not have other visual deficits. He wore glasses, and he was able to perform object search and object tracking in his entire visual field. He did not show signs of benign paroxysmal positional vertigo or vestibular hypofunction upon initial testing. Gross upper and lower extremity strength was within functional limits and he reported being able to perform resistance training in a local gym on a weekly basis. Current medications included: Elavil, Benzac AC, Cefalex, Flexeril, Neurontin, Prilosec, Retin-A, and Vimpat. Prior to the GSW incident, CC was independent with all activities of daily living, with no other significant past medical history.

III. INTERVENTION

A. Pre-VR Intervention

CC’s initial five treatment visits focused on stretching and traction of the neck to alleviate neck pain [8] as well as balance activities (see Figure 1). He was educated on and provided with a home exercise program (HEP) focusing on stretching of his neck extensors along with static and dynamic balance exercises. Neck exercises included variations of self-assisted stretching of levator scapulae and upper trapezius muscles. Static balance exercises included a range of standing balance with feet together to standing in tandem with eyes closed. Dynamic exercises included ambulation with vertical and horizontal head turns. On his sixth visit evaluation, CC exhibited a 3-point increase in dynamic gait index (DGI) and reported reduction of neck discomfort, however, he continued to experience fear and discomfort regarding walking outside in the community, especially crossing busy intersections with car traffic. More specifically, CC reported increased eye-strain and dizziness in public environments. We hypothesized that this was caused by increases in the number of static (i.e. spatial clutter and spatial density) and moving (i.e. optic flow) objects in his visual field. Challenging environments for CC included shopping malls and busy streets. In order to address these ongoing functional problems, we decided to implement VR therapy into the patient’s plan of care. Additional functional outcome measures were incorporated to establish a baseline in CC’s physical and perceived abilities in ambulation and community activities, directly prior to beginning VR treatment. (See Figure 1).

B. VR Intervention

Two virtual environments (VE) with street crossings and traffic were created (Unity 3D Engine, San Francisco, California) for the treatment regimen. The VE scenes involved: 1) standing at a pedestrian crossing in front of a two-way, single lane street with stop(red) and go(green) signals to tell the pedestrian when to walk, and 2) standing on a traffic island between a two-way, double-lane street with traffic passing on both sides of the pedestrian. Both scenes included a night and day version, with moving cars and static buildings (see Figure 2). The cars all moved at the same speed, however the number of cars was set at three different levels simulating low, medium, and high traffic (see Table 1). The scenes were uploaded to a Samsung Galaxy S7 Edge smartphone and mounted onto a Gear VR headset for use. This system utilizes internal inertial sensors in the smartphone to update the VE in synchrony with the wearer’s head rotations creating an immersive experience. See Table 1 for technical specification for current VR set up. To
standardize the VR training, a protocol with a checklist of VR scene settings and secondary balance tasks was used.

### TABLE 1. SPECIFICATION FOR VR SET UP

<table>
<thead>
<tr>
<th>Gear VR weight</th>
<th>0.7 pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samsung S7 Edge weight</td>
<td>0.34 pounds</td>
</tr>
<tr>
<td>Field of Vision</td>
<td>101 degrees</td>
</tr>
<tr>
<td>Frame Per Second</td>
<td></td>
</tr>
<tr>
<td>Car Spawn Rate on Single Lane (Low/Medium/High Traffic)</td>
<td>Every 2-3 / 3-5 / 5-7 seconds</td>
</tr>
<tr>
<td>Car Spawn Rate on Double Lane (Low/Medium/High Traffic)</td>
<td>Every 3-5 / 5-7 / 7-9 seconds</td>
</tr>
</tbody>
</table>

The checklist allowed for the therapists to exercise clinical judgment when incorporating different types of secondary tasks into the VR training, in order to progress and challenge the patient. An example of low-level task composition was as follows: in the real world the patient was standing on a flat level surface in the clinic, while viewing a VE in a daytime scene with normal lighting from the perspective of a sidewalk at a stoplight, as medium traffic passed on a 2-way street, without traffic sounds, with normal lighting (day), and was instructed to self-initiate marching-in-place whenever the pedestrian signal turned green. An example of a high-level task composition was as follows: in the real world the patient was standing with feet together on a foam pad in the clinic, while viewing a VE from the perspective of being on a traffic island with a high rate of 2-way traffic passing in both lanes, with no traffic sound, but low lighting (night), and was instructed to perform head turns at a self-selected, comfortable speed.

Figure 2. Figure 2A and 2B shows exemplar scenes of the single lane street with stop and go signals in daytime and nighttime, respectively. Figure 2C and 2D shows exemplar scenes of the two-way, double-lane street with traffic passing on both sides in daytime and nighttime, respectively.

CC performed five treatment sessions with VR training. VR training involved 12 trials of standing balance exercises while wearing the VR HMD, with each trial lasting one minute and a break in-between each trial. The duration of breaks was decided by CC, and the actual duration of the breaks was not recorded but each break was typically between 1-2 minutes. The difficulty of the secondary tasks and the setting of the VR scene were gradually increased as tolerated by the patient. Furthermore, the patient continued traditional balance and dynamic walking training as previously described per the HEP. At the clinic, CC also performed ambulation tasks such as object avoidance with walking over and around objects, ambulation with visual search requiring head turns to identify sticky notes planted in narrow hallway, and ambulation while passing and catching objects. Ambulation tasks were always performed after VR training, with the time available. Each PT session was one hour long. A standard PT treatment session was delivered by PT students and clinical instructors. During all VR treatments, one of the authors (FT or LM) was present.

### IV. RESULTS

#### A. Outcome Measures

Outcome measurements included: DGI, Mini Balance Evaluation System Test (Mini-BEST), Dizziness Handicap Index (DHI), and the Activities Balance Confidence Scale (ABC). The DGI was used to assess CC’s walking balance abilities (Marchetti et al. 2014). At initial evaluation and 1st re-evaluation, only the DGI was assessed. Prior to beginning VR training (i.e. 2nd re-evaluation), the other three measurements were added to get baseline measurements (see Table 2). The Mini-BEST was used to assess a wider range of balance components and has a lower ceiling effect than DGI [20], [21]. The DHI and ABC Scale provided subjective measures of perceived balance difficulties [22]. On the 3rd re-evaluation, post-VR therapy assessments were taken using all four outcome measurements. Baseline and post measurements were both assessed by the same individuals (student PTs: PM and LM, supervised by clinical instructor BE). For each of the re-evaluations, CC filled out the Global Rating of Change (GROC), an ordinal scale from -7 to +7 for self-assessment of his progress during PT sessions [23].

For the initial evaluation and 1st re-evaluation, CC scored 16/28 and 19/28 on the DGI, respectively. Prior to VR-therapy scores were 70/100 on DHI, 71.3% on ABC, 20/24 on the DGI and 16/28 on mini-BEST. CC exhibited considerable difficulty in anticipatory and reactive postural control subsets of the mini-BEST. Post VR therapy, there was a 10-point improvement on the DHI (60/100), a 1-point improvement on the DGI (21/24), and a 5-point improvement on the mini-BEST (21/28). Only the ABC Scale did not show a meaningful change (69.4%). On each of the re-evaluations, GROC was scored 1, 3, and 5, respectively, suggesting the patient perceived positive progression in his plan of care. After a one-month follow up, CC scored 24/24 on DGI, 21/28 on mini-BEST, 72.5% on ABC, 58/100 on DHI, and 4 on GROC.

### TABLE 2. OUTCOMES SCORES ACROSS TIME

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Initial Evaluation</th>
<th>Re-evaluation 1</th>
<th>Re-evaluation 2 (Pre-VR)</th>
<th>Re-evaluation 3 (Post-VR)</th>
<th>One-month follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>DGI</td>
<td>16/24</td>
<td>19/24</td>
<td>20/24</td>
<td>21/24</td>
<td>24/24</td>
</tr>
<tr>
<td>miniBEST</td>
<td>-</td>
<td>-</td>
<td>16/28</td>
<td>21/28</td>
<td>21/28</td>
</tr>
<tr>
<td>ABC</td>
<td>71.3/100</td>
<td>69.4/100</td>
<td>72.5/100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DHI</td>
<td>-</td>
<td>70/100</td>
<td>60/100</td>
<td>58/100</td>
<td></td>
</tr>
<tr>
<td>GROC</td>
<td>-</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>

#### V. DISCUSSION

CC demonstrated a clinically meaningful improvement in balance and visually-related symptoms that were chronically present 9 months after a GSW to the back of the head. Although CC had previously received PT for an extended amount of time prior to the start of his treatment at the pro bono center, upon
initial evaluation he exhibited persistent balance and navigational deficits. Records of the specific interventions that CC underwent at previous rehab settings could not be obtained, however, it was evident CC had ongoing functional mobility deficits. The aims of implementing VR training into CC’s plan of care were to improve his balance [24], promote visual field attention with controlled exposure to visual simulation [25], and facilitate community reintegration, such as walking in crowded public settings, and crossing busy streets [18]. Although causal effects cannot be assumed with an uncontrolled case report, incorporating immersive VR training using an HMD may be an effective intervention to improve both balance and self-perceived abilities in an individual with postural instability and visual sensitivity resulting from a TBI.

CC’s treatment plan is an example of how adding VR treatments to standing postural tasks may enhance the effectiveness of traditional rehabilitation, as suggested by improvements founds in three of the four outcome measures, i.e. mini-BEST, DHI and DGI.

Besides cranial damage, CC’s injury led to tissue damage at the suboccipital region of the neck, which have been shown to have a high concentration of proprioceptors that contribute significantly to balance control [26], [27]. The impact of CC’s deficient head-on-body sensorimotor processing was apparent when he attempted to turn while walking: this increased unsteadiness and trunk sway. CC’s improvement in posture and gait control over the course of the VR therapy was evident from scores on a subcomponent of the mini-BEST called the Timed-up-and-go (TUG) test. CC improved in the TUG, as well as the TUG with dual cognitive task, which requires the patient to perform the TUG while doing number subtraction. Reductions of 1.97 seconds and 2.89 seconds from pre to post were measured in TUG and TUG with dual-task, respectively. Since the TUG requires the patient to stand up from a chair, walk 3 meters, turn, walk back, and sit back in the chair, performance in this task is dependent on awareness of postural orientation, efficient multi-sensory integration, and accurate head-on-body information [28]. In the current case, the integration of VR stimulation while performing different standing tasks, may have promoted processes involved in sensorimotor integration and accelerated the development of compensatory strategies to counter the sensory and cognitive deficits caused by his injury [29].

It is important to note that CC missed close to half of his scheduled PT sessions at the pro bono center due to transportation availability. Nevertheless, in addition to making it to five VR therapy sessions, CC reported that he continued to go to the gym to lift weights and walk on the treadmill, and he sometimes practiced standing balance, as part of his HEP. While the limited amount of PT sessions may have restricted his potential to maximize recovery, CC still exhibited a minimally clinically important difference in the Mini-BEST after five VR interventions and scored above the predictive cut-off scores for fall risk in both DGI and Mini-BEST [20], [30].

Due to the summer break, the pro bono center was closed for a month after CC’s 3rd re-evaluation. CC’s was invited back to perform a one-month follow-up assessment, where he scored 24/24 on his DGI and maintained similar scores for his other assessments. When asked about his physical activities during the break, he reported that he continued to work on his balance at home, performing different standing balance tasks, and he started going to shopping malls and recreational parks with his family more often. He further stated that he could watch as others played video games with less headaches and dizziness. Additionally, his friends and family were able to recognize his improvements and reported that he was now going out in the community more than before. After the follow-up, we concluded that CC had maximized his functional potential and could be discharged from the center.

To further assess the patient’s perceived change in his abilities from VR training, CC filled out a Patient-Specific Functional Scale at pre-VR and post-VR evaluations, which involved him self-scoring his “street crossing” and “multi-tasking” abilities on a scale of 0 (unable) to 10 (excellent). CC gave himself 0/10 in street crossing at pre-VR but improved to 4/10 at post-VR. Likewise, he initially gave himself 1/10 in multi-tasking, which improved to 5/10 at post-VR. During the follow-up interview, CC still voiced being uncomfortable walking across the street by himself and was reluctant to leave his house without someone accompanying him.

During the course of his treatment, CC was taken outside by the clinicians on two separate occasions to practice crossing a busy intersection in order to give him additional training in community ambulation and to assess the generalizability of VR training to a real-world task. The first session of crossing trials occurred during the 1st VR session and a second session occurred at the 3rd re-evaluation, post-VR. During both real-life crossing sessions, CC ambulated with a stiff trunk and seldom looked to his sides while walking, with no noticeable change in gait speed between both sessions. A number of factors may have contributed to the limited transfer from VR to real world on this specific task. The current VR test protocol did not allow for locomotion and we did not include auditory simulation. The lack of body translation and auditory inputs could have reduced the immersion of the VR, and thus limited the carryover effects of walking in a real intersection. Nevertheless, the current setup still provided a cost-efficient, user-friendly, safe, consistent, visually-stimulating, and task-relevant environment for CC that led to meaningful improvements in CC’s functional mobility, self-perceived abilities, and community participation.

VI. CONCLUSION

Over the course of rehabilitation, including VR therapy combined with traditional PT intervention, an individual with a penetrating brain injury affecting the posterior regions of his head displayed improvements in balance and functional mobility. The VR therapy provided the patient with a safe and engaging treatment that stimulated visual processing during static balance and dynamic gait training to improve his overall postural stability. Despite not returning to his pre-injury level of activities such as confidently walking across a traffic intersection by himself without supervision, the patient reported increased tolerance to strong visual stimulus intensity such as watching television and being in crowded environments. With recent advances in VR technology, virtual rehabilitation is an accessible and cost-effective intervention. This case report provides an example of how VR intervention can be a practical and effective adjunct to traditional PT.
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REFERENCES