
by

David John Houston

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Rehabilitation Sciences
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Abstract

Damage to the spinal cord produces sensorimotor impairments below the level of injury leading to significant balance deficiencies. Individuals with an incomplete spinal cord injury (iSCI) are highly susceptible to falls during periods of walking or standing. Balance training interventions provide an opportunity to decrease the risk of falling and increase the level of independence and mobility for individuals with iSCI. Our objective was to evaluate the effectiveness and meaningfulness of a therapeutic tool for standing balance that combined functional electrical stimulation with visual feedback balance training (FES+VFBT). Five adults with iSCI completed a total of 12 FES+VFBT sessions. Balance abilities were assessed pre- and post- training using clinical and biomechanical assessments. Two semi-structured interviews were completed by each participant following the end of the training program. FES+VFBT showed potential as an intervention for standing balance as it effectively improved standing balance abilities post-training and proved meaningful to the participants.
Acknowledgments

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Last, but not least, my family. Thank you for your support and your encouragement throughout these last two years. Thank you for allowing me to talk your ear off about the research I was doing, the conferences I attended, and for showing such an invested interest in it all.

“Commit to the Lord whatever you do, and He will establish your plans.”

Proverbs 16:3 NIV
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Chapter 1

Introduction

1.1 Introduction

This concurrent, multi-methods study investigated the effect of combining functional electrical stimulation (FES) with visual feedback balance training (VFBT) to improve standing balance among individuals with motor incomplete spinal cord injury (iSCI). Using a novel therapeutic tool (FES+VFBT), individuals with iSCI completed a training program targeting standing balance. The ability to maintain upright standing balance is important for mitigating fall risk and maintaining functional independence. The primary aim of this study was to investigate the efficacy of this novel therapeutic tool to elicit and maintain improvements in standing balance performance. Balance abilities were assessed using clinical scales (i.e. Berg Balance Scale (BBS), Mini-Balance Evaluation Systems Test (mini-BESTest), and Activities-specific Balance Confidence (ABC) Scale), biomechanical measures (i.e. centre of pressure (COP) velocity, and limits of stability (LOS)), and a series of semi-structured interviews that queried impact on daily living, perceived benefits of participation, and changes in balance confidence/fall risk. The findings suggest that FES+VFBT is a potentially efficacious intervention for improving standing balance performance, but that improvements are individual and vary between participants.

1.2 Rationale for Study

Balance is an integral component of many daily activities. On standardized clinical tests used to assess gait, balance and sensory function, individuals with iSCI exhibit significant deficiencies (Wannapakhe et al., 2014; Amatachaya et al., 2015). These individuals often remain ambulatory
within their own homes, but are more susceptible to experiencing a fall during periods of standing or walking. Therefore, improving standing balance may play a crucial role in fall prevention, lead to greater functional independence in the home and community, and increase life satisfaction.

Following the occurrence of an iSCI, the main goal for both patient and clinician is often restoring walking abilities through locomotor training. As a result, few studies have investigated interventions targeting standing balance in individuals with iSCI (Sayenko et al., 2010; Tamburella et al., 2013; Villiger et al., 2013; Wall et al., 2015). In order to maintain upright standing posture and decrease fall risk, it is important to be able to regulate the COP, which refers to a single point representing whole body pressure over the feet (Ruhe et al., 2011), within the base of support (BOS). Controlling COP position is often difficult for individuals with sensorimotor deficits in the lower limbs. One potential solution is functional electrical stimulation (FES), which involves the application of a low-level electrical current to the peripheral nervous system causing the stimulated muscles to contract. FES has been previously used in gait (Kapadia et al., 2014) and upper limb (Kapadia et al., 2013) rehabilitation following motor iSCI, but is now being considered as a supplement to balance interventions. For example, FES was applied to the ankle plantarflexors of an individual with von Hippel-Lindau Syndrome during quiet stance and demonstrated a positive orthotic effect on COP regulation as evidenced by a reduction in postural sway (Vette et al., 2007).

Individuals with iSCI exhibit greater dependence on visual inputs to maintain postural steadiness (Lemay et al., 2013). Previous work has demonstrated the effectiveness of task-specific visual feedback during balance training (VFBT) to significantly improve static and dynamic stability in individuals with iSCI (Tamburella et al., 2013; Sayenko et al., 2010). Our colleague, Dr. Kei
Masani, developed a novel system combining FES with VFBT (FES+VFBT) as a means to improve balance control. This system was validated in a sample of young healthy adults (Chow et al., 2017). The use of FES+VFBT as a therapeutic tool for individuals with iSCI has not been previously explored.

The aim of this research was to explore the effects of FES+VFBT on static and dynamic balance control in individuals with iSCI. Novel insights into the experiences of individuals with motor iSCI undergoing FES+VFBT were also investigated. The findings suggest that FES+VFBT has potential as a therapeutic intervention to retrain balance control in individuals with iSCI but that it is an individualized experience.

1.3 Objectives of Study

Objective 1: To evaluate the efficacy of FES+VFBT to elicit and maintain changes in standing balance performance for individuals with iSCI using clinical scales (i.e. BBS, Mini-BESTest and ABC Scale) and biomechanical measures (i.e. COP parameters during quiet stance and limits of stability).

Objective 2: To understand participants’ perspectives concerning the impact of FES+VFBT on their activities of daily living, balance confidence, and risk of falling through semi-structured interviews.

1.4 Potential Impact of Study

This study investigated the use of a novel therapeutic tool combining FES with VFBT to produce changes in standing balance abilities within individuals with iSCI. The use of interviews provided an opportunity to capture the meaningfulness of the experienced changes and produced novel insights regarding the perceived impact of FES+VFBT in daily living. The findings
suggest the efficacious nature of FES+VFBT to improve standing balance abilities among individuals with iSCI. Combining the clinical and biomechanical results with the knowledge gleaned from the interviews offers the opportunity to refine the FES+VFBT system for individuals with iSCI and potentially adapt the system to suit other neurological populations with similar balance deficits. Therefore, this thesis contributes to the understanding of the effects of FES+VFBT on standing balance control among individuals with iSCI that can guide future research and may be incorporated into standardized care for standing balance training.
References


Chapter 2

Literature Review

2.1 Spinal Cord Injury

The occurrence of a spinal cord injury (SCI) is a life-changing event that has persistent, negative effects on the affected individual’s sensory, motor and autonomic function, often leading to reduced independence, functioning, mobility, and overall quality of life. SCI is the result of damage to the spinal cord that produces sensorimotor changes below the level of injury. Damage to the spinal cord can occur through traumatic (e.g. motor vehicle accident) or non-traumatic (e.g. tumour) causes. In 2010, it was estimated that 43,974 individuals with traumatic SCI and 41,582 individuals with non-traumatic SCI were living in Canada (Noonan et al., 2012).

Depending on the extent of the damage to the spinal cord, a SCI can be classified as complete or incomplete. With a motor iSCI, individuals preserve some residual motor functioning below the level of injury. Motor iSCI can be further subdivided, in accordance with the American Spinal Association Impairment Scale (AIS), as AIS C or AIS D depending on the extent of functional strength retained in the muscles below the damaged region of the spinal cord (Kirshblum et al., 2011).

Damage to the spinal cord disrupts communication between the descending efferent fibres from the motor cortex and the ascending afferent fibres travelling from the effectors via the spinal cord to the brain (Hamid & Hayek, 2008). Intrinsic spinal circuits below the level of the injury remain intact, but do not receive sufficient descending input (Hamid & Hayek, 2008). This absence of neural innervation produces weakness or paralysis in the muscles below the level of
injury rendering them unable to produce the necessary force required to perform functional tasks (Doucet et al., 2012).

2.2 Upright Postural Control

2.2.1 Standing Balance and Impact of SCI

Under conditions of normal quiet standing, upright balance is maintained through small postural rotations around the ankle joint which are dependent on the amount of ankle stiffness present within the joint (Baudry, 2016). Different sensory inputs (i.e. vision, somatosensory, vestibular) are integrated to modulate the neural inputs to the plantarflexor muscles and adjust the amount of ankle stiffness (Baudry, 2016). The maintenance of quiet stance depends on the successful integration of somatosensory, visual and vestibular inputs (Baudry, 2016). Following the occurrence of an SCI, individuals are subject to somatosensory impairments that reduce their ability to modify movements relative to task demands (Amatachaya et al., 2015; Jorgensen et al., 2017). Previous work has demonstrated the importance of visual inputs on quasi-static postural steadiness in individuals with SCI. Lemay et al (2013) showed that individuals with SCI are less stable during stance than healthy controls and exhibit greater dependency on visual inputs to maintain postural steadiness during standing. Individuals with SCI exhibit decreased postural stability stemming from an inability to effectively control their centre of pressure (COP). An increased reliance on visual inputs provides an opportunity to incorporate visual feedback into the rehabilitative process for balance control. By providing visual feedback of their COP location, individuals with SCI may improve their ability to regulate balance and increase their postural stability.
2.3 Falls and Balance

2.3.1 Risk of Falling

Individuals with motor iSCI present a greater risk of falling, as they are often able to ambulate, but have poor balance control. Up to 75% of individuals with a motor iSCI (i.e. AIS C or D) will regain some walking ability within their first year post-injury (Burns et al., 2012). Falls are of significant concern among individuals with iSCI due to the likelihood of injury or hospitalization following a fall (Krause, 2004). Each year, ~78% of ambulatory individuals with iSCI sustain at least one fall (Khan et al., 2019), often during periods of standing or walking, with the majority occurring within their own homes (Brotherton et al., 2007; Amatachaya et al., 2011). Even if an injury is not sustained, the occurrence of a fall may lead to behavioural changes, resulting from a learned fear of falling, intended to restrict the individual’s level of mobility (Fletcher & Hirdes, 2004). Therefore, the experience of a fall can severely restrict an individual’s ability to engage in meaningful activity and participate in the community (Brotherton et al., 2007). Falls among individuals with iSCI often occur due to a loss of balance. Balance deficiencies have been observed on standardized clinical tests used to assess gait, balance and sensory function (Wannapakhe et al., 2014; Amatachaya et al., 2015), but decreased strength in the lower extremities may also play a role (Brotherton et al., 2007).

2.3.2 Balance Confidence

Individuals with SCI do not possess the same level of confidence in their ability to maintain balance while performing specific daily activities as age-and-sex-matched healthy controls (Shah et al., 2017). The Activities-specific Balance Confidence (ABC) scale is used by individuals to rate their level of confidence in their ability to maintain balance while performing a variety of standing and walking tasks. Performance on the ABC scale has been shown to exhibit significant
moderate to excellent correlations with clinical measures of gait, balance, and lower extremity strength. ABC scores were also significantly correlated with COP velocity in the anterior-posterior (AP) direction during stance (Shah et al., 2017). The relationship between decreasing COP velocity in the AP direction and increasing ABC scores suggests that balance confidence is linked to postural steadiness. Therefore, among individuals with iSCI, a high degree of postural sway, poor dynamic balance, and decreased lower limb strength is associated with a reduced confidence in their ability to maintain balance while performing daily activities. These findings have strong implications for rehabilitation as improving these factors should improve balance confidence and increase functional independence and willingness to engage in meaningful activity.

2.4 Balance Training

The ability to stand independently, without being at a high of a risk for falling, as a result of improved balance abilities, is important to the quality of life for an individual with SCI. Aside from the psychosocial factors such as increased feelings of independence and improved self-efficacy, individuals with SCI who engage in periods of prolonged standing report improved function in circulation, bowel and bladder functioning, as well as fewer pressure injuries (Eng et al., 2001). Very few studies have investigated interventions targeting COP control as a means to improve standing balance in individuals with iSCI. The effects of a perturbation-based and a conventional intensive balance training program are currently being investigated within the iSCI population (Unger et al., 2019). Previous research focused on supplementing task-specific balance exercises with video games (Wall et al., 2015), virtual reality (Villiger et al., 2013), and visual feedback (Sayenko et al., 2010; Tamburella et al., 2013) during standing.
2.4.1 Visual Feedback

Previous work has demonstrated the effectiveness of visual feedback balance training (VFBT) to improve postural control in individuals with iSCI. Sayenko et al. (2010) investigated the effects of balance training and visual feedback on upright stability. Six individuals with SCI participated in a total of twelve, one-hour training sessions over a period of four weeks (Sayenko et al., 2010). During the training sessions, participants were instructed to stand on a force platform and shift their COP, represented on screen as a marker, in the direction of a target presented at varying locations on the screen. Following completion of the training intervention, the participants showed significant improvements in their static and dynamic stability (Sayenko et al., 2010). While this study was able to demonstrate improvements in stability following the balance training intervention, they did not determine whether these observed changes were associated with clinically relevant changes on standardized balance assessment tools. Changes from baseline are important to provide evidence as proof of concept for the intervention, but clinically relevant changes represent meaningful improvements to the patient.

Tamburella et al. (2013) investigated the efficacy of providing visual biofeedback balance (vBFB) training to improve gait and balance performance in six individuals with chronic motor iSCI (experimental group) in comparison to individuals receiving conventional over-ground rehabilitation (control group). Each group participated in an eight week training regimen where they received 60 minutes of rehabilitation for five days each week. Individuals in the experimental group received 20 minutes of vBFB training following 40 minutes of conventional over-ground rehabilitation. vBFB training exercises addressed postural steadiness, symmetry and dynamic stability (Tamburella et al., 2013). Balance was assessed using the Berg Balance Scale (BBS) and mean values of stabilometric COP parameters (i.e. COP velocity) at baseline, after every 10 vBFB sessions, following the end of the training period, and at one and two months
post-training. Individuals who received vBFB achieved significant improvements in balance that were maintained at follow-up. These individuals also exhibited greater improvements in gait compared to the individuals who only received conventional over-ground rehabilitation.

2.5 Functional Electrical Stimulation

Functional electrical stimulation (FES) is an intervention that has often been used in rehabilitation of the upper extremities (Kapadia et al., 2013) and gait (Kapadia et al., 2014), but has only recently been considered as a complimentary intervention to balance training (Vette et al., 2007) among individuals with iSCI. FES works by placing electrodes on a muscle, or a peripheral nerve, and administering an electrical current to stimulate the axons of the motor neurons to elicit a muscle contraction. FES combines electrical stimulation of the peripheral sensorimotor system to produce muscle contractions within the context of performing a functional task (Auchstaetter et al., 2016). Using FES, electrical stimulation can be applied to injured regions of the neuromuscular system to restore or achieve function (Hamid & Hayek, 2008; Martin et al., 2012). Even though FES is applied peripherally, it is possible that central mechanisms may also be activated (Doucet et al., 2012). When FES is applied, the action potential that is generated travels to the neuromuscular junction, eliciting a muscle contraction, while also traveling to the ventral horn of the spinal cord (Martin et al., 2012). Using FES to produce muscle contractions also stimulates afferent fibres, which would send information to the intact spinal circuitry and possibly exhibit neuromodulatory effects. Emerging research has demonstrated that the nervous system is capable of structural and/or functional change in response to electrical stimulation (Martin et al., 2012). Even if FES does not promote neuroplasticity at the level of the spinal cord, electrical stimulation of partially innervated muscle
below the level of injury is still important to counteract muscular atrophy and improve muscle mass and functional strength necessary for independent balance (Hamid & Hayek, 2008).

2.5.1 FES & Balance
A closed-loop FES system was developed to improve standing balance by stimulating the ankle plantarflexors and dorsiflexors. This system continually monitors the position and velocity of the body via COP force plate measures and automatically adjusts the level of stimulation administered to each muscle group (Same et al., 2013). Further evaluation of the closed-loop FES system demonstrated its ability to effectively mimic the physiological control system employed by able-bodied individuals to maintain standing balance (Masani et al., 2003; Masani et al., 2006). This suggests that the closed-loop FES system has the potential to retrain normal movement patterns within a clinical population.

The effects of a single session of FES on balance control were investigated in an individual with von Hippel Lindau Syndrome. Bilateral stimulation was applied to the ankle plantarflexors of the individual due to the role of the ankle joint in maintaining standing balance (Vette et al., 2007). When FES was administered, the individual showed an improved ability to regulate their COP movement during quiet standing leading to a reduction in postural sway (Vette et al., 2007).

2.5.2 FES & Visual Feedback Balance Training
Based on the positive effect observed with visual feedback and FES on COP regulation and balance control, a system combining FES with VFBT (FES+VFBT) was developed as a therapeutic tool to improve standing balance ability for individuals with iSCI. Created in LabVIEW, the system consisted of a force plate, an electrical stimulator (COMPEX) and a computer (Chow et al., 2017). COP was calculated using force plate signals and visually displayed on a monitor facing the participant. Four COP-based games were developed to
encourage the participants to extend their COP in a multitude of directions. As participants performed these movements, FES was applied bilaterally to the ankle plantarflexors and dorsiflexors to provide assistance. Preliminary work involving young, able-bodied individuals demonstrated a significant bivariate correlation between balance ability and VFBT performance for three out of the four COP-based exercises (Chow et al., 2017).

The FES controller used with VFBT was an extension of the closed-loop FES control system developed in previous studies (Vette et al., 2007; Masani et al., 2006) and included gravity compensation and directional biasing (Same et al., 2013). Preliminary experiments with able-bodied individuals revealed an asymmetric pattern of muscle activation when COP was voluntarily shifted in the ML direction during standing (Grabke et al., 2018). As the previous controller only regulated ankle torques to assist with COP movement in the AP direction, a newer version was designed to increase left leg stimulation and decrease right leg stimulation when leaning left of the median plane and to increase right leg stimulation while decreasing left leg stimulation when leaning to the right of the median plane (Grabke et al., 2018). This newly developed system has yet to be applied and evaluated within the iSCI population.
References


Chapter 3

Therapeutic effects of functional electrical stimulation plus visual feedback balance training on standing balance performance among individuals with incomplete spinal cord injury: a case series

David J. Houston, Jae W. Lee, Kei Masani, Kristin E. Musselman

3.1 Background & Purpose

Sustaining a spinal cord injury (SCI) is a life-changing event that challenges the affected individual’s level of independence, mobility, and overall quality of life. Damage to the spinal cord produces sensorimotor changes below the level of injury which can occur from traumatic (e.g. motor vehicle accident or fall) or non-traumatic (e.g. tumors or infections) causes.

Individuals with a motor incomplete SCI (iSCI) retain some residual motor functioning below their level of injury. Indeed, the majority of these individuals regain the ability to walk in the community at one-year post-injury (Scivoletto et al., 2014). Their sensorimotor impairments, however, reduce their ability to modify their movements relative to task demands, thereby affecting their balance control and increasing their risk for falling (Amatachaya et al., 2015; Jorgensen et al., 2017).

Falls are of significant concern among individuals with incomplete SCI due to the likelihood of injury or hospitalization (Krause, 2004). Each year, 78% of ambulatory individuals with iSCI sustain at least one fall (Khan et al., 2019), often during periods of standing or walking within their own homes (Brotherton et al., 2007; Amatachaya et al., 2011). The occurrence of a fall, regardless of injury, can produce changes in behavior that stem from a learned fear of falling and
are intended to restrict an individual’s level of mobility (Fletcher & Hirdes, 2004). This can severely limit an individual’s ability to engage in meaningful activity and participate in their community (Brotherton et al., 2007; Musselman et al., 2018).

Under conditions of normal quiet standing, upright balance is maintained through small postural rotations around the ankle joint which are dependent on the amount of ankle stiffness present within the joint (Baudry, 2016). Different sensory inputs (i.e. vision, somatosensory, vestibular) are integrated to modulate the neural inputs to the plantarflexor muscles and adjust the amount of ankle stiffness (Baudry, 2016). Lemay et al (2013) showed that individuals with SCI were less stable during stance than able-bodied individuals and exhibited greater dependency on visual inputs to maintain control of their balance (i.e. maintaining their centre of pressure (COP) within their base of support) during standing. This increased reliance on visual inputs has provided an opportunity to incorporate visual feedback into the rehabilitative process for balance control. Visual feedback balance training (VFBT), which involves the visual representation of the COP locations during balance exercises, has been shown to be an effective means to improve postural control of balance among individuals with iSCI (Sayenko et al., 2010; Tamburella et al., 2013).

As the ankle muscles play an important role in maintaining standing balance, interventions that induce the activation of the weakened ankle muscles may be a beneficial complement to balance training within the motor iSCI population. Functional electrical stimulation (FES), which applies an electrical current to the peripheral nervous system to produce muscle contractions within the context of functional task performance (Auchstaetter et al., 2016), can lead to increased motor unit recruitment in the muscles of individuals with upper motor neuron damage (Newsam & Baker, 2004). While FES has been used in the rehabilitation of upper extremities (Kapadia et al.,
2013) and gait (Kapadia et al., 2014) after motor iSCI, it has only recently been considered as a complementary intervention to standing balance training for this population.

Masani and colleagues (Vette et al., 2009) developed a closed-loop FES system that targets the ankle musculature during standing. Using COP position, as measured by force plates, this system continuously monitors the position and velocity of the body and automatically adjusts the level of electrical current administered to the plantarflexors and dorsiflexors bilaterally (Same et al., 2013). The closed-loop FES system effectively mimics the physiological control system used by able-bodied individuals to maintain standing balance control (Masani et al., 2003; Masani et al., 2006). Recently, a novel a therapeutic tool integrating FES and VFBT (FES+VFBT) has been developed and validated among young, able-bodied individuals (Chow et al., 2017). However, the efficacy of this system has not been evaluated within a neurological population.

Here we evaluated the therapeutic potential of the FES+VFBT system for standing balance control in five individuals with chronic, motor iSCI. We hypothesized that following the FES+VFBT intervention, participants would show improved balance control, as demonstrated by improved performance on clinical balance scales (i.e. Berg Balance Scale (BBS), mini-Balance Evaluation Systems Test (mini-BESTest), and Activities-specific Balance Confidence (ABC) Scale) and biomechanical assessments (i.e. postural sway measures and limits of stability test during standing). We also hypothesized that these improvements would be retained at follow-up assessments.
3.2 Methods

3.2.1 Subjects

Fifteen individuals with an iSCI were recruited via flyers posted at the Lyndhurst Centre, Toronto Rehab-University Health Network and assessed for eligibility upon obtaining written consent (Figure 3.1).

Following the screening process, five adults with motor iSCI (i.e. American Spinal Injury Association Impairment Scale (AIS) rating of C or D) were enrolled (see Table 3.1). All participants were at least 12 months removed from injury or the onset of neurological symptoms in the case of non-traumatic iSCI, were capable of unassisted standing for 60 seconds, and had a BBS score <46. All study activities occurred at the Lyndhurst Centre. Research ethics approval was obtained from the University of Toronto and the University Health Network.

![Figure 3.1: FES+VFBT Recruitment](image-url)
Table 3.1: FES+VFBT Participant Demographics

M=Male; F=Female; C=Cervical; T=Thoracic

<table>
<thead>
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<th>Subject ID</th>
<th>Sex</th>
<th>Age</th>
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<th>Level of Injury</th>
<th>Time Post-Injury (months)</th>
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</tr>
<tr>
<td>FESB06</td>
<td>F</td>
<td>55</td>
<td>Surgery</td>
<td>T10</td>
<td>31</td>
</tr>
</tbody>
</table>

3.2.2 Clinical Assessment

The BBS, mini-BESTest, and ABC scale were administered by a physical therapist blind to the study aim and intervention. Each scale has been shown to be a valid and reliable measure of balance for individuals with chronic motor iSCI (Jorgensen et al., 2017; Wirz et al., 2010; Shah et al., 2017). The BBS is used to assess balance performance during 14 sitting or standing tasks. Each test item is scored by the examiner on an ordinal scale of 0 to 4 based on the time or distance requirements and the need for assistance or supervision from the examiner (Berg et al., 1989). The highest attainable score is 56. The mini-BESTest uses a 0 to 2 ordinal scale to assess balance on 14 items divided into four categories: anticipatory, reactive postural control, sensory orientation, and dynamic gait. The highest attainable score is 28 (Franchigoni et al., 2010). The ABC Scale requires participants to rate their perceived confidence in their ability to perform 16 different standing and walking activities (Powell & Myers, 1995). For each activity, a value between 0% (no confidence) to 100% (completely confident) is assigned to denote how confident they were that they could complete the task while maintaining their balance. Clinical balance assessments were administered prior to beginning the balance training intervention (three times over four weeks), after completion of training, and four and eight-weeks after the balance training intervention was completed (Figure 3.2).
3.2.3 Biomechanical Assessment

The biomechanical assessment was completed with the research team once prior to beginning FES+VFBT, once after the completion of the training, and at four and eight-weeks following the completion of the intervention (Figure 3.2). Two biomechanical tests were completed with the participants standing while secured in an overhead harness for safety. First, postural sway during quiet standing with eyes opened, followed by the limits of stability were evaluated. For both tests, participants’ feet were placed on two adjacent force plates, with one foot on each force
plate (Advanced Mechanical Technology Inc., Watertown, USA), as they stood with both arms crossed across their chests. All force plate data was sampled at 2000Hz and a 4th order low-pass Butterworth filter (10Hz) was used. For the measurement of postural sway, participants were instructed to stand still for 60 seconds while focusing on a circle located at eye level on the computer monitor. Two quiet standing trials were performed with a short rest in between trials. To characterize postural sway, COP velocity and the root-mean-square (RMS) of the COP displacement were calculated in both the anterior-posterior (AP) and medial-lateral (ML) directions using custom-written MATLAB (The MathWorks Inc., Natick, MA) programs. These postural sway measures are valid and reliable for the iSCI population (Tamburella et al., 2014). Each quiet standing trial was divided into two 30 second windows. Mean COP velocity and COP RMS displacement were determined in each window for both AP and ML. Hence, four values (2 trials x 2 windows per trial) for each of AP COP velocity, ML COP velocity, AP COP RMS and ML COP RMS were obtained. The mean and SD of each measure was determined for each assessment time point. Changes in performance on the postural sway measures were reported relative to the average baseline value and evaluated using the two-standard deviation band method.

For the limits of stability test, participants were asked to shift their COP in one of eight directions, offset by 45 degrees, as indicated by a target displayed on the computer monitor. Ankle markers were placed on the lateral malleoli to locate ankle position on the force plates and collected using a 3D motion capture system (Vicon, Culver City, CA, USA). As the individual leaned in each of the directions, a red dot visually representing their COP (calculated from the force plates and previously determined using the quiet standing trials to set the origin) moved accordingly to provide visual feedback. Participants were instructed to shift their COP as far as possible and hold their maximal endpoint for 2-3 seconds before returning back to their initial
standing position. The limits of stability test was performed twice with a short rest between trials. To characterize performance on the limits of stability test, maximal COP excursion was reported relative to the ankle joint using the mean of the two collected trials. Maximal COP excursion was calculated using peak COP displacement recorded from the force plate data and relative to the position of the ankle joint using a custom-written MATLAB (The MathWorks Inc., Natick, MA) program. In addition, total sway area during the limits of stability test was calculated using the sum of the area of eight triangles (Equation 1) corresponding to the maximal COP endpoint of each direction.

\[
\text{Area} = \sum_{i=1}^{8} \left[ \frac{\sqrt{2}}{4} (l_1 \cdot l_2) \right] \quad (Eq. 1)
\]

Where \( l_1 \) and \( l_2 \) are the maximal COP excursion in two successive directions.

A change in performance was expressed as a percentage relative to baseline performance (Equation 2) for each assessment time point.

\[
\text{Change in Performance} = \left( \frac{y-x}{x} \right) \cdot 100 \quad (Eq. 2)
\]

Where \( x \)=baseline value and \( y \)=value at post-training, or four or eight-weeks post-training.

3.2.4 FES+VFBT

Participants completed three one-hour training sessions per week for four weeks, resulting in a total of 12 training sessions. Each training session consisted of 15 minutes to identify the motor thresholds and maximum tolerable stimulation levels for the ankle dorsiflexors, 5 minutes to don/doff the safety harness, 5 minutes to calibrate the VFBT exercises, 20 minutes to complete the VFBT exercises, and 10-15 minutes to take rest breaks between exercises as
needed. Tests of quiet standing and limits of stability, as described above, were completed prior to each training session to determine the average COP location during the natural standing posture and to identify the range of COP movements in order to calibrate the VFBT exercises for each individual. During the training exercises, visual feedback was provided regarding COP location (i.e. visually represented as a red dot on the computer monitor). Four different training exercises were performed as part of the balance training program (see Appendix 1 for a description of the training exercises).

FES (Compex Motion II, Compex Motion, Switzerland) was applied bilaterally to the ankle plantarflexors (gastrocnemius) and dorsiflexors (tibialis anterior) of the participants while they completed the VFBT exercises.

Figure 3.3: FES+VFBT Intervention
*Taken from Chow et al., (2017) with permission*
The range of stimulation intensity applied during FES+VFBT was determined at the beginning of each training session by identifying each participant’s minimal contraction threshold and 80% of their maximal tolerable stimulation intensity for each muscle group in a sitting position. Frequency was set to 40Hz and the pulse duration was set at 300µs. During the training sessions, stimulation intensity was regulated via the COP position in a closed-loop manner. The location of the participant’s COP and the location of the desired target was sent to the computer and fed back to the two Compex 2 stimulators (Keller et al., 2002), one for each leg, to apply the amount of current needed to assist the participant in completing the task (Figure 3.3).

3.3 Outcomes

Participant demographic and injury-related variables (Table 3.1), as well as their baseline scores on the clinical and biomechanical measures (Table 3.2), are provided. Participants were between 55 to 68 years of age and four out of five participants had non-traumatic iSCI. Average baseline BBS and mini-BESTest scores ranged from 24.3-45.3/56 and 5.3-15.3/28, respectively. All participants completed twelve FES+VFBT sessions and no training-related adverse events were reported. No biomechanical assessment data were reported for FESB02 due to her inability to consistently complete the two tests at all assessments due to fatigue.

3.3.1 Clinical Assessment

Following the completion of FES+VFBT, improvements from baseline scores that exceeded 2SD (see Figure 3.4A) were observed on the BBS at four-weeks post-training (FESB01, FESB04 & FESB06) and eight-weeks post-training (FESB01). Improvements >2SD were observed on the mini-BESTest (see Figure 3.4B) immediately post-training (FESB01, FESB02 & FESB06), four-weeks post-training (FESB01 & FESB06), and eight-weeks post-training (FESB06). Improvements >2SD were observed on the ABC Scale (see Figure 3.5) immediately post-
training (FESB06), four-weeks post-training (FESB01), and eight-weeks post-training (FESB06). Only two individuals (FESB01 & FESB06) demonstrated improvements >2SD on each of the three clinical assessments for at least one time point.

<table>
<thead>
<tr>
<th>Mean (SD) Baseline Performance</th>
<th>FESB01</th>
<th>FESB02</th>
<th>FESB04</th>
<th>FESB05</th>
<th>FESB06</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Clinical Assessments</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBS (/56)</td>
<td>24.3 (1.53)</td>
<td>28.3 (4.62)</td>
<td>38.0 (3.46)</td>
<td>45.3 (1.53)</td>
<td>27.3 (3.06)</td>
</tr>
<tr>
<td>Mini-BESTest (/28)</td>
<td>5.3 (0.577)</td>
<td>11.3 (1.15)</td>
<td>11.3 (2.31)</td>
<td>15.3 (0.577)</td>
<td>6 (0)</td>
</tr>
<tr>
<td>ABC (%)</td>
<td>66.25 (0.625)</td>
<td>39.79 (4.02)</td>
<td>73.33 (7.91)</td>
<td>62.71 (1.91)</td>
<td>39.38 (1.65)</td>
</tr>
<tr>
<td><strong>Biomechanical Assessments</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AP VEL (mm/s)</td>
<td>46.35 (5.03)</td>
<td>N/A</td>
<td>16.75 (4.56)</td>
<td>17.07 (3.49)</td>
<td>17.27 (4.18)</td>
</tr>
<tr>
<td>ML VEL (mm/s)</td>
<td>37.93 (3.45)</td>
<td>N/A</td>
<td>14.52 (3.02)</td>
<td>10.54 (2.25)</td>
<td>8.90 (1.25)</td>
</tr>
<tr>
<td>AP RMS (mm)</td>
<td>12.29 (1.73)</td>
<td>N/A</td>
<td>6.27 (1.75)</td>
<td>6.37 (0.851)</td>
<td>8.16 (1.48)</td>
</tr>
<tr>
<td>ML RMS (mm)</td>
<td>11.62 (2.67)</td>
<td>N/A</td>
<td>7.67 (0.878)</td>
<td>3.59 (1.46)</td>
<td>5.22 (0.937)</td>
</tr>
<tr>
<td>LOS Sway Area (mm²)</td>
<td>15725.42</td>
<td>N/A</td>
<td>11567.63</td>
<td>7658.52</td>
<td>6423.01</td>
</tr>
</tbody>
</table>

Table 3.2: Mean (Standard Deviation) of Baseline Clinical and Biomechanical Performance

**Clinical (average of 3 baseline values):** BBS=Berg Balance Scale; Mini-BESTest=Mini-Balance Evaluation Systems Tests; ABC=Activities-specific Balance Confidence Scale; **Biomechanical:** AP=Anterior-posterior; ML=Medial-lateral; VEL=Mean velocity; RMS=Root mean square displacement; LOS=Limits of stability test
**Figure 3.4:** Change in Clinical Balance Scale Performance
A) Berg Balance Scale (BBS); B) Mini-Balance Evaluation Systems Test (mini-BESTest)
*denotes a change greater than 2 standard deviations compared to the mean baseline value

**Figure 3.5:** Change in Balance Confidence (Activities-specific Balance Confidence Scale Performance)
*denotes a change greater than 2 standard deviations compared to the mean baseline value
3.3.2 Biomechanical Assessment

Following the completion of FES+VFBT, a decrease in mean COP velocity >2SD was seen in the AP direction for one participant (FESB01) immediately post-training and at four and eight-weeks post-training. A decrease in COP RMS displacement was seen in the ML direction for one participant (FESB04) at four and eight-weeks post-training (see Table 3.3).

<table>
<thead>
<tr>
<th></th>
<th>AP Mean COP Velocity (mm/s)</th>
<th>FESB01</th>
<th>FESB04</th>
<th>FESB05</th>
<th>FESB06</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td></td>
<td>46.35</td>
<td>16.75</td>
<td>17.07</td>
<td>17.27</td>
</tr>
<tr>
<td></td>
<td>Post-Training</td>
<td>27.96</td>
<td>16.14</td>
<td>14.73</td>
<td>16.01</td>
</tr>
<tr>
<td>4-Weeks Post-Training</td>
<td></td>
<td>25.92</td>
<td>13.74</td>
<td>20.23</td>
<td>16.90</td>
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<tr>
<td>8-Weeks Post-Training</td>
<td></td>
<td>31.64</td>
<td>9.57</td>
<td>18.08</td>
<td>19.31</td>
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<table>
<thead>
<tr>
<th></th>
<th>ML Mean COP Velocity (mm/s)</th>
<th>FESB01</th>
<th>FESB04</th>
<th>FESB05</th>
<th>FESB06</th>
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</thead>
<tbody>
<tr>
<td>Baseline</td>
<td></td>
<td>37.93</td>
<td>14.52</td>
<td>10.54</td>
<td>8.90</td>
</tr>
<tr>
<td></td>
<td>Post-Training</td>
<td>32.23</td>
<td>10.73</td>
<td>18.16</td>
<td>8.88</td>
</tr>
<tr>
<td>4-Weeks Post-Training</td>
<td></td>
<td>31.16</td>
<td>10.66</td>
<td>18.16</td>
<td>8.88</td>
</tr>
<tr>
<td>8-Weeks Post-Training</td>
<td></td>
<td>34.81</td>
<td>8.75</td>
<td>9.28</td>
<td>11.07</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>AP COP RMS Displacement (mm)</th>
<th>FESB01</th>
<th>FESB04</th>
<th>FESB05</th>
<th>FESB06</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td></td>
<td>12.29</td>
<td>6.27</td>
<td>6.37</td>
<td>8.16</td>
</tr>
<tr>
<td></td>
<td>Post-Training</td>
<td>12.32</td>
<td>5.90</td>
<td>7.57</td>
<td>5.72</td>
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<td>4-Weeks Post-Training</td>
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<td>9.88</td>
<td>5.01</td>
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<td>6.81</td>
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<td>8-Weeks Post-Training</td>
<td></td>
<td>13.94</td>
<td>4.28</td>
<td>8.10</td>
<td>8.81</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>ML COP RMS Displacement (mm)</th>
<th>FESB01</th>
<th>FESB04</th>
<th>FESB05</th>
<th>FESB06</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td></td>
<td>11.62</td>
<td>7.67</td>
<td>3.59</td>
<td>5.22</td>
</tr>
<tr>
<td></td>
<td>Post-Training</td>
<td>9.28</td>
<td>10.48</td>
<td>8.79</td>
<td>4.54</td>
</tr>
<tr>
<td>4-Weeks Post-Training</td>
<td></td>
<td>8.75</td>
<td>4.88*</td>
<td>9.71</td>
<td>4.43</td>
</tr>
<tr>
<td>8-Weeks Post-Training</td>
<td></td>
<td>11.07</td>
<td>5.38*</td>
<td>8.24</td>
<td>4.95</td>
</tr>
</tbody>
</table>

**Table 3.3:** Mean (Standard Deviation) COP Parameters during Eyes Open Quiet Stance

AP=Anterior-posterior; ML=Medial-lateral; COP=Centre-of-pressure

VEL=Mean velocity; RMS=Root-mean-square

*denotes a change greater than 2 standard deviations compared to the mean baseline value

Following the completion of FES+VFBT, an increase in sway area during the limits of stability test (see Figure 3.6) was observed immediately post-training, with improvements ranging 7.3-74.2% greater than baseline values across participants. Improvements were either maintained or further increased relative to baseline values at four- and eight-weeks post-training (see Table
3.4. Due to errors or values that were physiologically impossible, maximal COP excursion values in the backwards direction at the baseline and eight-weeks post-training assessments for FESB06 and at the baseline assessment for FESB04 were omitted.

<table>
<thead>
<tr>
<th>Subject ID</th>
<th>Post-Training</th>
<th>4-Weeks Post-Training</th>
<th>8-Weeks Post-Training</th>
</tr>
</thead>
<tbody>
<tr>
<td>FESB01</td>
<td>35.8</td>
<td>32.7</td>
<td>61.9</td>
</tr>
<tr>
<td>FESB04</td>
<td>7.3</td>
<td>22.3</td>
<td>11.2</td>
</tr>
<tr>
<td>FESB05</td>
<td>74.2</td>
<td>84.4</td>
<td>88.0</td>
</tr>
<tr>
<td>FESB06</td>
<td>59.3</td>
<td>90.9</td>
<td>84.0</td>
</tr>
</tbody>
</table>

Table 3.4: Percentage Change (%) of Sway Area from Baseline during Limits of Stability Test

3.4 Discussion

The therapeutic effects of a four-week FES+VFBT program on the balance ability and balance confidence of five individuals with chronic motor iSCI are described here. This case series provides quantitative evidence that FES+VFBT can impact static and dynamic balance performance as assessed using clinical and biomechanical measures of balance.

Improvements exceeding two standard deviations were seen on all three clinical balance assessments. When analyzing single-subject data, the two-standard deviation band method is appropriate, but should only be used when the baseline data are stable without any obvious trend (Nourbakhsh & Ottenbacher, 1994). The baseline data collected in this study were stable (Table 3.2). Three of the five participants demonstrated improvements on the BBS and the mini-BESTest following training, while only two participants exhibited increases on the ABC scale. While improvements in standing balance ability and balance confidence were observed following training, only one participant for each clinical assessment continued to exhibit changes >2SD at eight-weeks post-training. When using the two-standard deviation band method, a meaningful change is generally considered to have been observed if at least two consecutive
values fall outside the band (Gottman & Leiblum, 1974). Applying this condition to our clinical assessment data, one participant experienced a meaningful change on the BBS, two participants experienced a meaningful change on the mini-BESTest, and no participants experienced a meaningful change on the ABC scale. FES+VFBT had a limited effect on balance confidence, at least according to the ABC Scale. The two-standard deviation band method is not considered the gold-standard way of evaluating meaningfulness which is why intervention studies should include a qualitative component, like a semi-structured interview, in order to provide participants with the opportunity to share their perspectives regarding the impact of the intervention.

Many of the tasks queried on the ABC Scale (Powell & Myers, 1995) are ambulatory tasks (e.g. how confident are you that you will not lose your balance or become unsteady when you walk outside the house to a car parked in the driveway?). As FES+VFBT focused only on standing tasks, it is not surprising that the intervention had minimal impact on ABC Scale scores. Motor skill learning is known to be task-specific, for example, spinalized cats who practiced standing on all four limbs did not improve their ability to step, and vice versa (Edgerton et al., 1997). Hence, repetitive practice of standing may lead to improvements in standing ability and confidence, but may not improve the ability to perform more dynamic tasks, such as walking. The focus on standing balance was an appropriate choice of intervention for the participants of this study as none were able to ambulate without a gait aid and/or physical assistance at study outset.

All five individuals showed large improvements in the maximal COP excursion area following FES+VFBT that ranged from 7.3% to 90.9% times greater than initial baseline performance. Since three out of four VFBT exercise encouraged the participants to shift their COP in a similar manner to the limits of stability test, it is possible that there was some transfer from training to
this task. In contrast, few participants showed improvements in measures of postural sway during quiet standing after FES+VFBT.

**Figure 3.6:** Change in Maximal Centre-of-Pressure (COP) Excursion (mm) during Limits of Stability Test
A) FESB01; B) FESB04; C) FESB05; D) FESB06

Again, this finding may reflect the task-specific nature of motor learning. Only one of the four VFBT exercises involved standing still; hence participants spent more time practicing dynamic balance tasks than static balance tasks. Sayenko et al., (2010) found significant decreases in postural stability measures during eyes open quiet stance following training completion except
for mean COP velocity in the ML direction. Participants in this study also completed three one-hour training sessions per week for a total of 12 sessions; however, they performed six COP-based games in total, with only one game involving quiet standing. The improvements in postural sway measures observed during quiet stance may be attributed to a greater dosage of training. Due to the simpler experimental set-up in the study by Sayenko et al. (2010), it is possible that more time could have been allocated to VFBT during the one-hour training sessions.

While a number of participants demonstrated improvements clinically, only two participants maintained the improvements at eight-weeks post-training on one of the clinical measures and one of the biomechanical measures. It is possible that the intensity (one hour, three days/week) or the duration (four weeks) of the training program was insufficient to produce long-lasting effects. Tamburella et al., (2013) sustained significant improvements in all balance parameters two months following the completion of an eight week training program that involved a total of 40 hours of training (40 sessions; 5 times/week; 40 minutes of gait training; 20 minutes of visual biofeedback balance training). Increasing the total dosage of FES+VFBT (i.e. 18-24 hours of total training) could be pursued in further research. The fact that only about 20 minutes of the one hour FES+VFBT session was being spent on the actual therapy necessitates increased efficiency in the delivery of the FES+VFBT intervention. One way to improve the efficiency of FES+VFBT would be to reduce the amount of time spent calibrating the electrical stimulation parameters. Despite this small dosage we did manage to observe improvement on clinical and biomechanical assessments of balance, which suggests that VFBT is a promising intervention for people living with motor iSCI.
3.5 Conclusions

Improvements were seen in four of five participants on at least one of the clinical balance scales following training, with less impact on balance confidence as measured by the ABC Scale. The area of maximal COP excursion increased for all participants, while there was little effect on quiet stance assessments. While the majority of participants did not sustain their improvements at eight-weeks post-training, the fact that FES+VFBT was able to elicit these changes despite a small training dosage suggests that it is a feasible and promising intervention for standing balance rehabilitation among individuals with iSCI. Further research should be conducted to identify optimal intensity and duration of FES+VFBT in order to increase retention.


Chapter 4

Perspectives of individuals with chronic motor incomplete spinal cord injury following balance training involving functional electrical stimulation with visual feedback

David J. Houston, Janelle Unger, Jae W. Lee, Kei Masani, Kristin E. Musselman

4.1 Introduction

Damage to the spinal cord disrupts the communication between the motor cortex and the spinal cord resulting in sensorimotor impairments below the level of injury. Individuals with motor iSCI often regain some degree of standing and walking abilities (Scivoletto et al., 2014), due to residual motor functioning preserved below the level of injury.

The ability to stand independently is an important contributor to an improved quality of life among individuals with SCI. It has been reported that individuals with SCI who engage in prolonged periods of standing experience psychosocial benefits, such as increased feelings of independence and self-efficacy, as well as physical benefits, such as improved circulation, and bladder and bowel functioning (Eng et al., 2001).

Independent standing, however, is often difficult for individuals living with motor iSCI to achieve. Their control of balance during standing is compromised due to the sensorimotor deficits associated with spinal cord damage leading to an increased reliance on visual inputs (Lemay et al., 2013; Arora et al., 2017) and an inability to appropriately modulate movements relative to task demands (Amatachaya et al., 2015; Jorgensen et al., 2017). As a result, individuals with iSCI are highly susceptible to experience a fall. Falls primarily occur during periods of walking or standing within the home (Amatachaya et al., 2011) and are of significant
concern due to the likelihood of injury or hospitalization (Krause et al., 2004). In instances where an injury is not sustained, the occurrence of a fall is still sufficient to influence behavioural changes intended to restrict mobility on account of a learned fear of falling (Fletcher & Hirdes, 2004). Among individuals with iSCI, 50% report a fear of falling (Shah et al., 2017). Individuals with a fear of falling have been shown to exhibit reduced postural control (John et al., 2010) and increased fall risk (Phonthee et al., 2013).

Individuals with SCI exhibit lower levels of confidence in their ability to maintain balance while performing specific daily activities, as assessed by the Activities-specific Balance Confidence (ABC) Scale, than age-and-sex-matched able-bodied controls (Shah et al., 2017). Significant moderate to excellent correlations have been shown between performance on the ABC Scale and clinical measures of gait and balance (Shah et al., 2017). Significant correlations between ABC Scale scores and anterior-posterior (AP) centre of pressure (COP) velocity suggests a link between balance confidence and postural steadiness, as evidenced by the relationship between decreasing AP COP velocity and increasing ABC Scale performance (Shah et al., 2017). Therefore, individuals who exhibit a high degree of postural unsteadiness will report decreased confidence in their ability to maintain balance while performing daily activities. Means to improve postural steadiness may result in increased balance confidence which will encourage individuals to engage in activities and increase their functioning and independence.

We recently reported the efficacy of a 12-session balance training intervention combining functional electrical stimulation with visual feedback balance training (FES+VFBT) on standing balance abilities among five individuals with motor iSCI (see Chapter 3). Participants received visual feedback regarding their COP position as they completed four balance training exercises while FES was applied to their lower limbs. We demonstrated a positive effect on standing balance ability as assessed by the Berg Balance Scale (BBS), the Mini-Balance Evaluation
Systems Test (mini-BESTest), and the limits of stability test, following the completion of FES+VFBT.

The above study, however, lacked insight into the perceived impact of the intervention on the participants’ lives. Meaningfulness, or whether the intervention outcome is important to the target population, is an important construct to assess early in the development of a new intervention (Musselman et al., 2018). As well, eliciting feedback from the end users of a new technology or intervention is needed to improve the design and delivery. Therefore, the purpose of this study was to understand the experiences of five individuals who had completed the FES+VFBT intervention. More specifically, we aimed to understand how the intervention impacted their lives, as well as seek feedback on how the intervention could be improved.

4.2 Materials & Methods

Research ethics approval for this exploratory qualitative study was obtained from the University of Toronto and the University Health Network.

4.2.1 Participants

Five individuals with a motor iSCI (i.e. American Spinal Injury Association Impairment Scale (AIS) rating of C or D) took part in this study (Table 4.1). Each individual was at least 12 months removed from injury, capable of unassisted standing for 60 seconds, had a BBS Score <46, and had completed 12 sessions of the FES+VFBT intervention.
<table>
<thead>
<tr>
<th>Participant Pseudonym</th>
<th>Age</th>
<th>Cause of Injury</th>
<th>Level of Injury</th>
<th>Time Post-Injury (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charlie</td>
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<td>Staph Infection</td>
<td>T6</td>
<td>97</td>
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<tr>
<td>Sharon</td>
<td>68</td>
<td>Virus</td>
<td>C5</td>
<td>52</td>
</tr>
<tr>
<td>Ruth</td>
<td>60</td>
<td>Fall</td>
<td>C1</td>
<td>22</td>
</tr>
<tr>
<td>Carol</td>
<td>63</td>
<td>Surgery</td>
<td>C3</td>
<td>32</td>
</tr>
<tr>
<td>Suzanne</td>
<td>55</td>
<td>Surgery</td>
<td>T10</td>
<td>31</td>
</tr>
</tbody>
</table>

Table 4.1: FES+VFBT Participant Demographics  
C=Cervical; T=Thoracic

4.2.2 FES+VFBT Intervention

Participants completed 12 one-hour training sessions of FES+VFBT over four weeks. Four COP-based exercises designed to encourage the participants to shift their COP in a multitude of directions were performed at each session. As participants performed these movements, FES was applied bilaterally to the ankle plantarflexors and dorsiflexors to provide assistance as they attempted to control the position of their COP. FES was regulated in a closed-loop manner via the COP position to continually monitor the amount of electrical current needed to assist the participant reach the desired target. Further information pertaining to the specifics of the training intervention can be found in the previous chapter.

4.2.3 Data Collection

Two semi-structured individual interviews were completed with each participant. One interview was completed immediately (i.e. 2-3 days) post-training and the second interview was completed eight-weeks post-training. Participants were interviewed at these two time points to examine whether the participants’ perceptions about FES+VFBT and its impact changed over time. At the eight-weeks post-training interview, participants were provided with the opportunity to review the transcripts from their initial interview in order to clarify or add to any of their responses. Individual interviews were conducted following a semi-structured interview guide. The guide
consisted of open-ended questions (Table 4.2) that encouraged participants’ to express their thoughts and experiences regarding the FES+VFBT intervention and its perceived impact. This interview guide was designed by clinical researchers and was adapted for the purposes of this study. It has been used previously in other intervention studies investigating participant perspectives (Singh et al., 2018). Each interview was conducted in person or over the phone by a researcher not involved in the delivery of the FES+VFBT intervention (JU or KEM). Interviews were audio-recorded and transcribed verbatim by a researcher (DJH) with all personal identifiers removed to protect the privacy of the participants.

<table>
<thead>
<tr>
<th>We would like to hear about your experiences with FES for standing balance.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) What went well?</td>
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<tr>
<td>2) What was challenging?</td>
</tr>
<tr>
<td>3) What were you hoping to achieve by taking part in the balance training with FES?</td>
</tr>
<tr>
<td>a. Did you achieve these goals?</td>
</tr>
<tr>
<td>b. Were there any effects that you were not expecting?</td>
</tr>
<tr>
<td>4) Has your participation in the FES balance training impacted your life? How so?</td>
</tr>
<tr>
<td>5) Has your participation in the FES balance training affected your risk of falling? How so?</td>
</tr>
<tr>
<td>6) Has your participation in the FES balance training affected your balance confidence? How so?</td>
</tr>
<tr>
<td>7) Would you recommend balance training/walking training to another individual with an incomplete spinal cord injury? What advice would you give to someone who was about to begin the training program?</td>
</tr>
<tr>
<td>8) What did you like most about program? What did you dislike?</td>
</tr>
<tr>
<td>9) How do you think the program could be improved? Do you have suggestions for things that we could do differently?</td>
</tr>
</tbody>
</table>

*At the second interview, participants were instructed to reflect on the period of time following training completion when answering questions 4-6.

**Responses to questions 1-3 and 7-9 were reviewed prior to the second interview and participants were asked to add or clarify as they felt necessary.

<table>
<thead>
<tr>
<th>Table 4.2: FES+VFBT Semi-Structured Interview Guide</th>
</tr>
</thead>
<tbody>
<tr>
<td>FES=Functional Electrical Stimulation</td>
</tr>
</tbody>
</table>
4.2.4 Data Analysis

Conventional content analysis (Hsieh & Shannon, 2005) was used to analyze the interview transcripts. Each transcript was read multiple times by two independent reviewers (DJH & JU). One researcher (DJH) was directly involved in administering the FES+VFBT program while the other (JU) was not. The immediate post-training transcripts were read and analyzed separately from the eight-week post-training transcripts. Quotes were highlighted from the text and placed in a table. Following steps from Erlingsson et al., (2017) quotes were condensed in a manner preserving the core meaning and then assigned codes. Categories were formed by grouping together related codes. Themes were identified by interpreting the underlying meaning of the categories. An additional reviewer (KEM), who was not directly involved in the delivery of FES+VFBT, was incorporated to assist with the review of the themes and their associated categories. The primary reviewer (DJH) is a registered kinesiologist who has conducted quantitative research in non-SCI populations. The secondary reviewer (JU) is a physiotherapist with ~3 years of experience in SCI rehabilitation and has engaged in both quantitative and qualitative research within this population. The tertiary reviewer (KEM) is a physiotherapist with 16 years of SCI rehabilitation experience who is well-versed in both quantitative and qualitative research.

To describe the perceived impact of the FES+VFBT intervention on their lives, the International Classification of Functioning, Disability and Health (ICF) framework was used to organize and describe the perceived benefits in terms of functioning and disability (WHO, 2001).

4.3 Results

Five participants (1 male and 4 female, mean age 62.4 (4.4)) completed two interviews each (Range: 17-52 minutes). Age, cause of injury, neurological level of injury and time post-injury
for each participant are reported in Table 4.1. Four themes were identified through the analysis of interviews. Each theme was comprised of several categories with supporting quotes listed in Table 4.3. The four main themes were: 1) Perceived benefits across ICF levels, 2) Factors impacting training performance, 3) Change in perceived fall risk and confidence, and 4) Motivation to keep going. These themes were consistent across the interviews completed immediately post-training and the interviews completed eight-weeks post-training, hence the findings from the two interview time points are reported together. However, one difference was noted for the first theme (perceived benefits across ICF levels) when comparing these two time points. At the eight-week post-training interview, participants tended to describe activity-level and participation-level impact of the intervention on their lives, whereas they tended to describe impairment-level impact immediately post-training.

4.3.1 Theme 1: Perceived benefits across ICF levels

Following the completion of FES+VFBT, participants reported physical improvements including increased muscle strength and endurance, greater body awareness and control, and improved sensory functioning. Psychological improvements, including a feeling of pride and happiness, increased confidence, and a reduced fear of falling, were also reported following training completion. These improvements led to functional benefits in activity and participation as participants reported feeling more comfortable moving about their homes as they performed activities of daily living and engaged in social activities.

4.3.1.1 Impact on Impairment

Following the completion of the training program, participants reported a multitude of perceived improvements in body structure and functions, such as increased range of motion and muscular strength and a reduction in muscle spasms and neuropathic pain. Charlie felt that his “degree of
"dorsiflexion" may have increased immediately post-training, but was then more convinced that he had improved his range of motion at eight-weeks post-training because he was "activating [his] toes all the time." Charlie believed that the electrical stimulation used to activate his muscles "helped some kind of neural pathway" because it was more active and he had greater control over it.

Participants reported that they were able to stand with fewer signs of weakness in their legs. Charlie commented that prior to his participation in FES+VFVT, sometimes his "leg would just give out." However, after completing the training he claimed that it was "not happening anymore." Ruth thought that she was able to "stand for a little more without the wiggling."

Starting out Carol was hoping to be stronger and to "trust [her] legs" more and by the end of the program she felt she had achieved "80% of [her] goals." She mentioned that her doctor had commented that her legs were getting "stronger and stronger" during a recent visit. Carol also reported that she hadn’t had "spasms for a while" but later clarified that while she still had them, they were not "as bad as before." Carol also indicated that she had experienced a decrease in the frequency of neuropathic pain episodes, claiming that since beginning FES+VFVT it happened "one time, but for a few minutes and it was gone."

One unexpected benefit was the perceived improvement in sensory functioning experienced by Charlie in "[his] feet, and [his] skin and [his] muscles." While these changes were small, Charlie emphasized that to have "a sense of feeling down there" was pretty big and provided him with a feeling of accomplishment.

4.3.1.2 Impact on Activity

Following completion of FES+VFVT, individuals reported numerous perceived improvements with respect to activity, particularly within their home. Cooking, cleaning, self-dressing, and
washroom use were all activities where participants felt that they had noticeably improved, in large part due to their increased confidence and ability to stand. Charlie remarked that he could “reach higher”, “stand higher”, and “stand longer”, while Sharon commented that her standing endurance had increased as evidenced by her ability to stand “at [her] walker out on the balcony” for longer periods of time. Ruth noticed that she when she is “doing something on the stove, [she] can stand a little bit more than before.” Carol commented that she didn’t like how “before [she] used to sit on [her] walker and do the chopping.” Now she reminds herself that “the walker is only when [she goes] long distances, but it’s not for standing for 10-15 minutes.”

Suzanne felt that her confidence was increasing because now she “can move around, [she] can take things from [the] floor, [and she] can even reach a little bit from the shelf.” She explained how when using the broom to try and clean her floor she will “always put the walker, brake it and sweep a little bit, then move with the walker and sweep.”

Carol reported that before, when she needed to use the washroom at night, she used to wait a few seconds before walking with her walker to the washroom. Now, she is able to “get up, bring [her] walker, and...stand up and go to the washroom” without needing to wait or think about what she is doing.

Ruth explained that once she can “stand better then [she] can also use [her] rollator” and was looking forward to being able to do things by her herself. Ruth also commented that within her home she has noticed that, “some of the things [she] can do better than before.” She mentioned how she used to “call [her] daughter to do those things in [her] room” but now thinks she is capable of doing them herself. Suzanne echoed those sentiments, commenting that she is no longer “waiting for other people to come and help [her]” and emphasized that she would like to either maintain that level of independence or continue to progress further.
Charlie commented that his wife has “noticed [him] walking a lot straighter” around their home. He also believed that he was continuing to increase his stamina since he is able to “go for longer distances” when walking. Suzanne reported that she felt increased “confidence to walk around the house.” She mentioned “using [her] walker inside the house and also short distance [she] can go with [her] walker, but wheelchair if [she goes] with long travels.” Ruth felt that her mobility had improved but admitted that “once [she gets] into the chair [she doesn’t] feel like [getting] up and [doing] something.”

4.3.1.3 Impact on Participation

Charlie indicated that he had “been to the beach twice” with his family and that he was “going golfing” in a couple of weeks, which were activities he had not been doing prior to FES+VFBT. During her time in the study, Ruth found herself having to use the washroom at the Lyndhurst Centre which helped increase her confidence that she can “go out for 2-3 hours” and be able to use an accessible washroom, if necessary. Suzanne explained that she “went to the mall and went to the bank” using only her walker. Carol commented that her friend has a large van which requires her “to use the stool because it’s a high step.” Before the training she also required the walker to use the stool and step into the vehicle. However, after FES+VFBT she explained that she no longer needed the walker to use the stool and told her friend “to take the walker, [and] put it in the trunk” when he came to pick her up.

4.3.1.4 Inter-related across ICF

On several occasions participants described perceived benefits across more than one ICF level due to the inter-related nature of impairment, activity and participation. Charlie felt a benefit of FES+VFBT was the “feeling of confidence and having those muscles activated.” He explained how “in [his] daily life [he uses] them more because [he’s] aware of them more” and has “more
of a sense where [his] feet are.” Charlie reported feeling increased “confidence in overall body awareness [and] overall body control.”

Charlie explained that “because [he’s] balanced it’s easier to keep [his] weight off the walker” as he can now “activate [his] feet and [his] toes and [his] calves.” When Charlie visits his son’s home, he finds he is able to “go up and down the stairs like easy” claiming that he knows “where [his] feet are and they’re activated.” When visiting his daughter, Charlie used to go from the car to the front door in his wheelchair, “but now it’s a walker and [he] just [walks] across her front and [goes] in.” Charlie also mentioned how his private physiotherapist was able to “notice subtle differences too in what [he] was doing” and that she had “noticed [his] posture” when walking around the house.

Ruth felt that her “balance and the wiggling and to keep standing for a little more” had improved following FES+VFBT. She mentioned that she has “tried some household things” and noticed that she “can perform a bit, not too much, but a little bit better than before.” As she felt herself getting a little more balanced she felt confident enough to “at least try by holding some table or chair or something” to move around inside her home. Ruth commented that “inside [she feels] happiness” and explained that she is “a little more stronger than before.”

In her home, Carol noticed that she found herself “standing more in the kitchen.” She explained how before she “used to stand, but the walker used to be behind [her].” Carol commented that now she forgets about the walker and feels that her “legs are stronger.”

4.3.2 Theme 2: Factors impacting training performance

Aspects of the training program that were perceived as being beneficial included the repetition and routine of the VFBT standing exercises, the addition of the stimulation, and the support
from the research team and the safety harness. Participants felt that the training program provided a safe environment to practice the VFBT exercises and other challenging activities. The presence of the safety harness and the research team allowed them to focus their attention on performing the movements that the exercises promoted without having to be concerned with falling. Participants also noted that participation in the program required commitment as not only was the program physically challenging, but traveling to the training sessions was challenging for some participants as well. Despite the required commitment, all participants indicated that they would have liked the program to last longer than 12 sessions.

**The role of VFBT**

Participants reported a number of different factors related to the nature of VFBT that they felt contributed to the success of the program; namely movement, repetition, challenge and feedback. Charlie explained how he likes activity and believes that “any movement is good movement [and] any activity is good activity.” Ruth mentioned that she actually liked most parts of the program including learning “how to put your, both legs, in certain positions that help to actually stand better.” Sharon explained that she enjoyed the program “because it makes [her] work.” She also commented that she liked “the routine and the habit that [she gets] into coming.” Carol liked that completing the exercises required “using the muscles, the right leg, the left leg.”

Sharon felt her confidence was positively affected by the repetition associated with FES+VFBT and believed that “practice makes perfect.” Carol mentioned that she started looking forward to standing in front of the computer screen because “[she] felt very independent, [she] felt stronger, that [she] can do it while standing.”

Carol found that the standing exercises presented a “good, high level of challenge.” Carol explained that she liked “when you stand in front of the computer and then you have to follow
the red dot.” She commented that because you don’t know which direction you will need to shift to reach the target “it was very challenging for [her].” Similarly, Sharon commented that she “did like the challenge of it” and commented that the games “got a little bit easier, but not a lot.” Ruth found the standing itself to be quite challenging as she explained that she “was not in that position for almost two years now. So all [her] leg, [her] brain, everything, forgot how to stand properly.” Ruth commented that “to stay standing still, even for a couple of seconds seems like a lot to [her].” She found that to “stay inside the center [of the target], that is the most challenging part.” She explained when standing “to be normal, you have to use the whole body.”

In contrast, on several exercises Charlie thought that he was “almost to the point with some of them, you know give me something challenging” and felt he had “mastered a lot of it.” He commented that as he watched the red dot travel towards the target he felt it was “a very smooth shift back-to-back; smooth and controlled.” He also admitted, that even though he was only doing two sets, he was “working by the end of the second set.”

Charlie didn’t seem to mind receiving feedback on his performance, mentioning that “everybody’s sort of results-oriented”, but claimed he “didn’t base [his] effort on it though.” He did think that “it might be, you know, a little more motivating” but was unsure how much, as he explained that “you come into it with motivation anyways.”

Sharon expressed some confusion regarding the calibration process and wished that it had been “explained to [her] a little better, a little more fully how that was done.” She explained how understanding the calibration process can influence how difficult the exercises are because they are set up “based on your first movements right at the very beginning.”
Ruth felt that she was able to perform the exercises “a little better when the cursor moves from in the left side” but felt she was weaker “when it comes to the right side.” She was aware of the games being “designed in such a way so that…[her] body will rotate into left and right, and front and back.”

The role of FES

Charlie reported being really aware of the FES at the beginning and explained that “as we were approaching [his] level of calibration, when they were cranking up to that point, [he] could feel [his] toes tingle.” Charlie explained that “during the games, yeah [he] was aware of it…especially if [he] was going out somewhere…out of [his] range…like really trying to hit this or trying to catch that, [he] felt them; they were on.” He emphasized that “it’s a good feeling though, it’s a good feeling.” Charlie believed that one of the benefits of the FES was that he had “reawakened those muscles.”

Ruth explained that with the FES she initially “focused too much on the games so [she] didn’t pay attention to what [was] going on there.” She commented that it could feel quite strong once she would “start standing and start playing the games.” She noticed that “when [she was] almost falling, [she] might feel a little bit more there, the stimulation, but [she] didn’t manage to focus on that part.”

Carol felt that “with the stimulation…like the muscles were working.” She thought that “the stimulation helped [her] a lot; helped her standing, moving right, moving left, forwards, but not…backwards.”
Suzanne believed that the application of FES is the reason “why [she] got more confident” as she “didn’t change anything other than that” and “didn’t do any outside exercise” aside from the FES+VFBT program.

**The role of the research team**

Participants found that the encouragement and support offered by the members of the research team had a positive impact on their training experience: “The people. That’s what makes everything, right? I mean they were really, really a great group of people. They were keen, and they were knowledgeable, and they were enthusiastic, and they were supportive, and they were encouraging...you can’t beat those attitudes” (Sharon). Sharon felt that the “team and [her] got more efficient setting it all up.” She was also appreciative of the fact that “everybody was supportive of [her] physically and emotionally.” Suzanne felt more confident the lab because “they are here, the harness is here, [she] can practice...but at home, no, [she] can’t do that; [she doesn’t] want to get worse.”

**The role of the harness**

Throughout the training sessions, participants were securely fastened in a safety harness to protect against a fall as they performed the four FES+VFBT exercises. The majority of the participants found the harness beneficial because it made them feel secure and encouraged them to practice the exercises without worrying. However, Ruth commented that “sometimes [she didn’t] want to wear the harness.” She explained that “if the harness is not there then maybe...the participant can see...how much she can get, how much she is doing.”

**Scheduling and commitment to FES+VFBT**

Participants found the FES+VFBT training schedule to be manageable, but explained that they would have preferred the program to last for longer than 12 training sessions. As Carol said, the
FES+VFBT intervention was quite short and she wished it could be a “little bit longer.” Participants completed three training sessions per week for four weeks. Charlie explained that “in a way it’s nice to have the day break, but one time [he] went back-to-back and there was no issue.”

Sharon noticed “that [she] was able to improve a little bit...play the games better.” She felt that “[her] balance and mobility improved, but it was sporadic and wasn’t consistent.” She explained how “one day [she] would be fabulous and the next day it would be horrible.” She described feeling “like [she] took two steps forward and then the next day [she] went back one.” Sharon admitted that “there were times where it was very tiring and [she] just couldn’t get [her] body to do what [she] wanted it to do.” She explained how she “found that frustrating.”

Ruth commented that she liked how participating in the FES+VFBT intervention required her “to get up from the bed, force [herself] to get dressed and go out.” While she found the days with the training sessions to be quite draining, she did “feel like it [was] helping [her] somewhat.” Ruth believes that “everything has [a] good and bad side, so to [her] it is better to try.”

Suzanne mentioned that she would like “to do more activity, but the travelling is killing [her].” She explained that getting to the training sessions was challenging because for “one and a half hours [she has] to sit in the WheelTrans. After that [she feels] tired; [she doesn’t] want to do exercise.”

4.3.3 Theme 3: Change in perceived fall risk & confidence

Risk of Falling
Participants reported feeling as if their risk of falling stayed the same or was slightly minimized:

“Has it affected my risk? I don’t know. It’s minimized it more than ever. I’ve never really [been] afraid of falling, but I put myself in positions now where I don’t think that quite through...I don’t take risks, but I become less cautious sometimes...you’re more likely to try things” (Charlie).

Charlie was able to prevent a fall from happening when he slipped during a vehicle transfer. He explained how “both of [his] legs shot out and caught [him]...maintained it and got [himself] balanced again and back into the car.” In contrast, Carol did experience a fall during the follow-up assessment as she attempted to step over an obstacle. While she was not pleased to have fallen, Carol explained that she was fine with it “cause there was a reason...[she] was tired and [she] had a lot of spasm in [her] right leg and [her] right foot hit the [brick].” Suzanne felt that “after the program [she] got less risk to fall” and likewise, Sharon believed that her FES+VFBT participation has decreased her risk of falling “because [she is] more flexible, and [she is] stronger, and [she has] been practicing so much.”

Willingness to try new activities

Individuals indicated that they felt more confident in their physical abilities and that the translation of physical improvements into functional improvements helped to strengthen their feeling of confidence and willingness to try new activities. However, several individuals cautioned against feeling over-confident and trying activities that would put them at greater risk of experiencing a fall.

After completing the FES+VFBT program, Sharon explained that she “certainly [feels] more confident at home trying stuff in a safe manner because [she thinks she is] stronger and [she has] more endurance.” She explained that she is “as [she gains] confidence [she tries] more things, but then [she] also [is] afraid sometimes that [she is] going to be overconfident and fall;
there’s a balance.” Sharon believes her participation helped with her confidence as there was “one day when [she] sat down on [her] toilet and realized [she] hadn’t put the PT rail down and [she] didn’t go crashing down.” She admitted that sometimes when she notices herself shifting her weight between her legs while standing at home she has to remind herself “to be careful because what happens if [her] knee gives out and [she] falls.”

Ruth believes that her participation in the program “has given [her] a little more confidence than before.” However, she admitted that still wants “to take [her] power chair everywhere.” She commented that she is “not still there to start [her] life with all the rollators, so that is a big drawback.”

Charlie spoke about visiting his son’s house when he “was invited for dinner there and [his] son wasn’t there.” He explained how “[his] son is [his] safety net because there is one step going from his landing into his house...and there’s nothing for [him] to hold onto except for [his] son.” Charlie commented that he was well-balanced which enabled him to “free step up into the wheelchair...within the house, which [he has] never done before without aid or a cane or something, so that’s really good...that was new for [him].” He explained that he “might not have attempted that without the confidence factor...and body awareness.” Charlie mentioned that he had “gone back to walking with walking sticks since the last time [he] spoke with [us].” He commented that he was “not taking a lot of steps...maybe six steps forward, but good steps, balanced steps; there’s no danger.” Charlie explained that the difference between using walking sticks compared to using a walker is that “when you’re on the walker you can cheat very easily because it’s there. But if you’re on walking sticks...your legs better be doing something, and you better have a good balance, good cadence, because the sticks are going to help you a little bit, but they’re not going to support you; you have to have the body working to support you.”
4.3.4 Theme 4: Motivation to keep going

*Ability to continue*

Participants expressed a desire to continue with the program as they felt that their improvements had not plateaued and that they would continue to benefit from additional time in the program. Several participants also indicated that they were considering continuing using FES as part of their home routine. Charlie mentioned how he had spoken with his physiotherapist about continuing with FES and that they had decided they were “going to start doing stim maybe once a month.” He explained how he “found that if [he doesn’t] maintain a routine, it’s easy to go back...so when [he doesn’t] work [his] legs, there’s a difference right away.” Others commented that they would appreciate the opportunity to participate in future research studies as they had limited options, either privately or within the community, to continue with their recovery.

*Factors driving motivation*

Participants reported several factors contributing to their motivation to continue to improve their balance and mobility. One such factor was observing physical changes in their bodies. Following completion of the training program, Charlie found himself using his more affected limb more “now because it’s sort of got a new life.” He noticed he would “use it a lot and [he is] aware of using it so if [he is] going to do an action [he will] try to push off on it and try and activate it.”

The desire to achieve their rehabilitation goals also provided ongoing motivation. Sharon was hoping her participation in FES+VFBT would help her to achieve more endurance, strength, stability, balance and mobility. While she felt she did increase, it was “not as much as [she] would ideally like. It’s not finished; it’s an ongoing project.” Similarly, while Ruth felt that she had improved, “[she is] still not confident...to go to the grocery store and pick up something,
especially milk and juice and heavy things.” She explained how “right now [her] first step is to go by [herself] to do something alone that [she needs] somebody to help [her].” At the beginning of the program, Carol “thought that the program [wouldn’t] help [her]” but by the end of the training she wished “[she] could go back.” Carol believed that “maybe in a year, [she] will start walking with nothing.” She mentioned she has a trainer who comes and does stretching and thinks that “between these training sessions, between her, between [her] exercise, [she feels] that [she is] still progressing.”

Participating in research was important to several of the participants and was another factor that motivated one to continue to improve balance and mobility. Charlie expressed his desire to continue participating in future studies explaining that he doesn’t “know what people are going to find in research. However, if it changes [his] lifestyle, even using the walker, well that’s a plus.” Ruth also commented that “to get the chance to participate in the study, [she feels] like [she has] something to look forward…that [she is] at least participating in something.” She admitted that “now [she is] a little nervous, once [she finishes] this, what [she is] going to do.” Likewise, Suzanne recognized the importance of participating in research mentioning to her friend that even if “this program is benefit or not, if they study, some other patient, future, they will get benefit.”

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<tr>
<th>Category 1a Impact on Impairment</th>
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<tbody>
<tr>
<td>“I can stand [without] too much shaking, I feel like…less shaky…more stable, that’s it.” (Suzanne, Post-Training)</td>
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<tr>
<td>Feeling of accomplishment, I think. Like I say, some of the stuff was minute, but it’s big. And you have the feeling…like to have my muscles come back and have the feeling…like a sense of feeling down there, sensory, that was pretty big.” (Charlie, Post-Training)</td>
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<tr>
<td>“…I honest to God believe it helped some kind of neural pathway…I honest to God believe that something happened between this muscle turning on and my brain because now it’s more active; I can control it to some extent…the stim actually activated that muscle where I might not...” (Carol, Post-Training)</td>
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have been able to do it just on my own...after having it stimulated for that amount of time...it’s for sure improved.” (Charlie, 8-Weeks Post-Training)

### Category 1b
**Impact on Activity**

“I can stand without holding and [get dressed]...before always I sit and put it. Now I stand and put it...also I can pick up things from the floor...before I can’t; now I hold it and take it...from standing...confidently, I can take it.” (Suzanne, Post-Training)

“It’s nice that I do things around the house. I do more things now...I walk out to the backyard a lot, with a walker...over uneven ground, but I’m solid...I BBQ on my own now...I use a walker when I’m there, but I’m standing...I didn’t enjoy my backyard last year as much as I did this year.” (Charlie, 8-Weeks Post-Training)

“...it’s given me more confidence to get up and about around the apartment...in my home, I’m up and about more...taking stuff out of the washing machine and putting stuff in the dryer...yesterday I stood at the kitchen counter and peeled a mango. It doesn’t sound like much, but I stood there and I peeled it and I diced it and I put it into a container.” (Sharon, 8-Weeks Post-Training)

“I don’t use the chair anymore inside the home...only maybe once in a while, like very bad days; maybe then. But I avoid it and I am managing up to now. So I should say this [is] improvement, huge improvement for me...and to go to the washroom...in the day time I always go by myself, without even this...without the walker. Only by holding little support, like even the wall or the door...” (Ruth, 8-Weeks Post-Training)

“I now walk and I follow through...I used to take a step and sort of hold my weight with my hands on the frame and bring my left foot forward and stop...now I walk with flow; I don’t stop...I’m walking like almost a normal person...my left leg is now supporting my body where it never did before...” (Sharon, 8-Weeks Post-Training)

### Category 1c
**Impact on Participation**

“...I used to carry a stool...I used to jump to go inside a car...so I don’t know why, from the stimulation, my legs are stronger. So now when I go out with a friend for lunch, for dinner, and I go with her and her car, now I can lift my leg...things have changed.” (Carol, Post-Training)

“Definitely I walk more than before...around the house, sometimes I go to the mall with the walker...now I walk with my neighbor...I walk around the block; she will come. I sit for times, she stand and wait for me...she is nice...” (Suzanne, 8-Weeks Post-Training)

### Category 1d
**Inter-related across ICF levels**

“...that’s what the FES has done for me; it’s given me this increased endurance and strength, I think...it’s making my activities of daily living easier to accomplish.” (Sharon, 8-Weeks Post-Training)

“...just the other day I was reaching high, high over my head to the top shelf which I would normally do, but do with a little bit of caution...but I
was really comfortable because I activated my calves and my feet…I was solid.” (Charlie, Post-Training)

“I think it helped me more to get stable a little bit and to keep the balance for standing. The posture, where to keep the feet; those things gave me a little more strength than before, to stay standing more time than before.” (Ruth, 8-Weeks Post-Training)

“For me it was a great experience and I feel more confident, stronger, and it was great. It was great.” (Carol, Post-Training)

“…it’s more and more confidence to walk and not fall…before this, less confident…now I know I am putting my leg and I go with my leg.” (Suzanne, Post-Training)

“I walk straighter because I know where my feet are…when I activate my toes now in my right foot…I know where it is when I’m walking, I get easier feedback and I’ve found myself walking straighter.” (Charlie, Post-Training)

“…when we finished off the program with the stim I was pretty excited, still am, because things are still changing and I can feel them. When I do stuff around the house, like say reaching for things…it’s pretty good. Playing catch with my…my grandson. We can stand and play catch; that’s different.” (Charlie, Post-Training)

Quotes for Theme 2: Factors impacting training performance

<table>
<thead>
<tr>
<th>Category 2a</th>
<th>The role of VFBT</th>
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<tbody>
<tr>
<td>“…at the start, if I have a posture that’s leaning forward, if as I warm up, I start to get straighter, they’re reading something different; I can see I could have a hard time putting that red dot where I wanted it.” (Charlie, Post-Training)</td>
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“I wanted to be able to do the games…I had to change my balance. I had to even out my balance, because I stand on my right leg, and I had to try and learn to use my left leg and unless you use a game like that…I don’t do it…” (Sharon, Post-Training)

“…I wanted to see if I did little better than the next time…I was really bad at those colour games…I think most of the time I couldn’t hit black and the purple. I hate that so I want to see if I can at least hit this time…those were actually very challenging…I am very weak in those positions…” (Ruth, Post-Training)

“…I liked the games…it’s fun…I can notice that my muscles are trying to do that one…it’s good for me…activities is good for me. I have to do, I push to do.” (Suzanne, Post-Training)

“…before I used too, the walker was always in front of me…during the
session…when I started I used to sit most of the time and then stand up, put
the walker in front of me…but after that, like yesterday I was standing all
the time. I was standing on my feet all the time…” (Carol, 8-Weeks Post-
Training)

**Category 2b**
The role of FES

“…I was scared…the standing, the stimulation. I said, “Maybe I will feel
pain,” and I was wrong. I was wrong…my muscles were working; I felt the
stretching. The muscles were working fine…I loved it.” (Carol, Post-
Training)

“At the beginning…I was worried that I won’t be able to do the
exercises…I like to be challenged; I like the challenge. And I think that I’m
going to keep going; I’m not going to stop. So…I said, “Okay, [he] is
behind me and if I feel not comfortable, I will tell him to stop.” And then I
realized that it’s really amazing doing the exercises, feeling the stimulation
at the same time; I loved it. It helped!” (Carol, Post-Training)

“…it’s neat to go home after working out downstairs because everything
feels good…it’s done something to the muscles. Plus, just those exercises
alone are enough to start. Your body’s going somewhere different so the
muscles are still trying to help you out and then the stim kicks in.” (Charlie,
Post-Training)

**Category 2c**
The role of the research team

“…the important things were that they always had my water there, they
always had me hooked up…when I said, “I think I’m going to fall,” they
were always there…I had confide

...nce in them and that was important for
me.” (Sharon, Post-Training)

“…when I met them downstairs they were really focusing…I asked them
about their names, then we talked…they told me what they were
doing…you are still working on people with spinal cord injuries…you’re
still doing research…it’s a lovely team…it’s good that people are still
working on it…it was fun…it was a nice hour; amazing, amazing…and I
will miss it. I will really, I will miss my days.” (Carol, Post-Training)

**Category 2d**
The role of the harness

“…the sling is there for safety; it’s not a mobility aid. So you have to be
aware of that to get good results, to make your legs…because if you’re in
the sling your muscles are going to say, “I don’t need to work; I’m
swinging here.” (Charlie, Post-Training)

“For me, without the harness, trying to do those things, you have to focus
on whatever exercise you’re doing; it takes a lot. I had to focus on what my
legs are doing …I’m aware of the sling, I know it’s there. I know that I
don’t have to be apprehensive; I can try and go to the end of my range. If I
miss, so what? The sling is there. I think if I didn’t have the sling and I was
free-standing I’d be pretty apprehensive about doing some of those
things…I think the sling doesn’t impede, I think it encourages because you
know you’re safe…we’re all worried, well I’m worried, about safety all the
time…because you know, if I go down it’s hard to get back up again.”
(Charlie, 8-Weeks Post-Training)
“…some activities I didn’t practice at home…closing eyes I tried to do it, but I couldn’t…I think that here, more confident, right? They are here, the harness is here, I can practice…but at home, no, I can’t do that. I don’t want to get worse.” (Suzanne, 8-Weeks Post-Training)

**Category 2e**

**Scheduling and commitment to FES+VFBT**

“Monday morning was a little bit difficult for results…because if I wasn’t overly active through the weekend I’d come in with a little bit tighter hips than normal.” (Charlie, Post-Training)

“…I think 3 days is enough…gives me a day to recover. And I don’t want my whole life to be…I wanted to keep going; I think I had more in me…a couple of months would have been nice…it takes a couple of sessions, maybe 3, to get into the routine…I think that it’s best to stagger them cause I think one time I did 2 days in a row and we stopped that; it didn’t work. The recovery day is important.” (Sharon, 8-Weeks Post-Training)

“…getting here is hard…even WheelTrans, I put in my request…they didn’t put me on the schedule. Then I cancel it and I call and wait for 4 hours…then they return my call and they said okay we will put it tonight; you will see tonight. This makes me tension; they are going to give me or not? Around 9:30 pm I don’t know.” (Suzanne, 8-Weeks Post-Training)

**Quotes for Theme 3: Change in perceived fall risk & confidence**

**Category 3a**

**Risk of falling**

“If I fall, what can I do? Like I have to take the challenge…if I don’t challenge myself I cannot move forward. I can fall anytime, that is still there all the time, but since I did the study…like I am more vulnerable to get falls? That I don’t think so, no.” (Ruth, Post-Training)

“I feel less risky because…I feel more stability in my legs. So to pick up something from the floor or to reach into something, although my daughter is always helping me in those things, but even if I need to, I can handle…but before I never have the courage to even think of doing this…I will say the falling, the risk of falling is, I feel, slightly less than maybe before.” (Ruth, 8-Weeks Post-Training)

**Category 3b**

**Willingness to try new activities**

“I’ve started going down stairs frontwards which is a real bonus…I’m not afraid of it anymore…I’m cautious stepping down…but that goes back to the confidence, and the confidence comes from my legs being more responsive…my body responds to what my brain tells it [that] it needs to do.” (Charlie, 8-Weeks Post-Training)

“…the more confident I feel in doing things, I think it’s a double-edged sword, because then I’m going to try stuff which puts me more at risk to fall…I have to balance it in that I will try stuff, but not be over-daring.” (Sharon, 8-Weeks Post-Training)

“…it may not be that I’m necessarily more or less confident, I’m more knowledgeable…what I thought 6 months ago I could do, I realize that I can’t now. And it’s not because I’m less confident, it’s because my
expectations I think are more realistic…one of the questions is how confident do you feel that you can walk from the front door to the car. Well I’d never done it before; I was always in a wheelchair. But since I started walking more…not that I’ve tried it, I’m not that confident…I think I’m being realistic; I don’t think that I’m saying to myself you can’t do that therefore you’re not going to try.” (Sharon, 8-Weeks Post-Training)

“You know I walk with a walker…since this training…sometimes I forget that I have to use the walker in the kitchen…between the kitchen and the breakfast room…the kitchen is connected to the breakfast room…before the walker was always next to me, always…two days ago I was making a salad and then the walker was in the breakfast room and I was in the kitchen…so I said, ‘Oh my God! Where is the walker?’ And then I said, ‘It’s okay.’ You know? I started talking to myself and then I said, ‘Why do I need the walker here? I can walk.’” (Carol, 8-Weeks Post-Training)

Quotes for Theme 4: Motivation to keep going

### Category 4a: Ability to continue

“…I’m a little nervous that maybe I’m not, you know at least here I come 2-3 times a week…trying to get better…once I stop coming here…I don’t have too much motivation to do, and it is not possible to do at home, to do those things, so I’m looking forward to, if I can, get another chance to do another study.” (Ruth, Post-Training)

“…I cannot afford physiotherapy…I tried all the resources and almost nothing…I really, really need a lot more…” (Ruth, 8-Weeks Post-Training)

“…I really need to do exercise for my thigh…thigh area is weak right now…the activity machine is here, but they didn’t give me a chance to come as outpatient for the gym…only whatever, I was inpatient…whatever the exercise I am doing in the bed. So those exercises I am doing that, that’s it…almost 3 years…I don’t go anywhere, I only come here…I told them at least 1 hour, once a week; give a chance for everyone…if I got more than I can get more chance to improve myself…add more research programs than we can join…because this place, we used to…we love to come here…” (Suzanne, 8-Weeks Post-Training)

### Category 4b: Factors driving motivation

“To stand a little better, firm, so that I can walk better, while standing a little more time than before…I am looking forward to be getting independent by myself, to do my regular life chores, which I am still far, far back from my goal, but I am forwarding, that much I should say, but I still have to go a long way.” (Ruth, Post-Training)

“I tend to pursue any aids to helping my walking, practically…if my legs continue to stay as they are, and they improve…I’m going to keep up my activity, maybe kick it up a notch, but I want to make sure my legs and my muscles, and whatever I can keep, just in case somebody does come up with something really good, but it would require good muscle tone or good muscles. So that’s my goal: just to be sure that I stay in shape.” (Charlie, 8-Weeks Post-Training)
“…I did a lot of that activity before, but sometimes the complacency comes in and that’s when you get a program like this and all of a sudden things are waking up again and you have a feeling, “Hey, let’s go again…” I think I’m motivated, but it’s pretty easy to say, “Well, I think I’ll stay home,” but when new things happen, away you go.” (Charlie, 8-Weeks Post-Training)

“I don’t push myself to hurt myself, but if it’s hard, what gets me going is I think about that it’s doing me good and I look at the progress I have made…some things now that I do without even thinking, they were was hard as it was when I was in the FES. So, it just keeps me going.” (Sharon, 8-Weeks Post-Training)

Table 4.3: Functional Electrical Stimulation with Visual Feedback Balance Training (FES+VFBT) Themes, Categories and Quotes

4.4 Discussion

The experiences of five individuals with chronic motor iSCI participating in a FES+VFBT intervention are described here. This study provides novel insights into the perceived benefits associated with participation in FES+VFBT, the impact of participation on perceived fall risk and confidence, factors associated with performance in the training program, and reasons for continuing with rehabilitation interventions after program completion.

The perceived benefits of FES+VFBT were similar to those reported by Singh et al., (2018) who found that improved strength and endurance from a personalized adapted locomotor training (PALT) program contributed to greater independence in activities of daily living for individuals with sub-acute iSCI. Likewise, participants in the PALT program reported increased knowledge about their bodies, improved mood, greater confidence and an increased sense of control (Singh et al., 2018). However, individuals enrolled in PALT received, on average, six times more training sessions (range: 49-131 total sessions) than those in FES+VFBT. Training sessions for PALT were also administered four times per week and were 90 minutes in length (Singh et al., 2018). Participants in FES+VFBT indicated that they would have preferred more than 12 training
sessions following completion of the intervention and indicated their desire to participate in future studies in order to continue progressing in their recovery. This suggests that for individuals living with a SCI, recovery is a life-long process.

Participants in FES+VFBT highlighted several specific components of the program that worked well, including the repetition of the VFBT exercises and the challenges associated with the unpredictability of the target locations. The ability to practice these movements in a safety harness and under the supervision of the research team enabled participants to focus on performing the exercises in a safe and controlled manner without worrying about a fall. Participants emphasized that three sessions per week was appropriate, but expressed their desire to extend the duration of the program a few more weeks (i.e. 18-24 total training sessions).

After completing FES+VFBT, all participants expressed feeling more confident in their balance abilities and felt that they were at less risk of falling. However, in the previous chapter there was little effect of FES+VFBT on balance confidence, according to the ABC Scale. It has been suggested that, in higher functioning individuals, perceived balance confidence, as measured by the ABC Scale, may more closely reflect actual balance performance (Shah et al., 2017). However, our results do not support this assertion. It is possible that the tasks queried on the ABC Scale were not similar enough in nature to the tasks that the participants reported feeling more confident performing in their own homes. This discrepancy between quantitative and qualitative results highlights the importance of including qualitative inquiry in intervention studies. Without the inclusion of this qualitative inquiry it is difficult to evaluate the meaningfulness of the intervention. Participants reported an impact at all levels of the ICF (e.g. impairment, activity, and participation) following FES+VFBT, suggesting that the perceived benefits of the intervention resulted in a meaningful impact on their lives.
There are several limitations to this study which warrant consideration. Our study consisted of a small sample of participants with iSCI that were recruited using purposeful sampling. Therefore, the findings may not reflect the larger iSCI population and researcher and recruitment bias may have occurred (Palys, 2008). Some interviews were completed over the phone, which prevented the observation of non-verbal cues during the interview. Non-verbal cues are useful for qualitative analysis as they can help prevent misunderstandings (Hermanowicz, 2002) and encourage engagement (Irvine et al., 2012) between the interviewee and interviewer during conversation. Interview texts were analyzed using conventional content analysis which limits interpretation due to its descriptive nature (Hsieh & Shannon, 2005).

4.5 Conclusions

Participation in the FES+VFBT program resulted in perceived physical and physiological benefits leading to improvements in daily life. Individuals expressed a desire to continue with the training program for a longer amount of time as they felt they still had the capacity to improve. Fall risk was thought to have been minimized and balance confidence was thought to have increased. However, individuals were wary of over-confidence placing them in situations where they would be more susceptible for experiencing a fall. Individuals reported a positive and enjoyable experience, and while benefits differed between participants, each valued their participation in the study.
References


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Chapter 5
Discussion

Summary of results

This concurrent, multi-methods study explored the effects of a novel therapeutic tool (FES+VFBT) combining functional electrical stimulation (FES) with visual feedback balance training (VFBT) on standing balance among individuals with a motor incomplete spinal cord injury (iSCI). The first objective of this study was to quantitatively evaluate the efficacy of FES+VFBT to elicit and maintain changes in standing balance using clinical (i.e. Berg Balance Scale (BBS), Mini-Balance Evaluation Systems Test (Mini-BESTest) and Activities-specific Balance Confidence (ABC) Scale) and biomechanical (i.e. centre of pressure (COP) parameters during quiet stance and limits of stability) measures. The second objective of this study was to qualitatively evaluate the meaningfulness of FES+VFBT and its impact on activities of daily living, balance confidence, and risk of falling from the perspective of the participants via semi-structured interviews.

In Chapter 3, the two-standard deviation band method was used to detect true changes in performance following the completion of FES+VFBT relative to the mean baseline values on the clinical assessments. Changes exceeding two standard deviations (>2SD) were observed among four of the five participants on at least one of the BBS or Mini-BESTest following FES+VFBT. However, at eight-weeks post-training, only a single participant for each clinical balance scale maintained their improvements. FES+VFBT did not have a large impact on balance confidence, at least according to the ABC Scale, as only two participants reported increases >2SD following the training completion, and only one at eight-week post-training. FES+VFBT also had a small impact on COP parameters during quiet stance as changes >2SD were only observed in one
participant for the anterior-posterior COP velocity and one participant for the medial-lateral RMS displacement. Increases in sway area during the limits of stability test, across participants, ranged from 7.3-74.2% greater than the mean baseline values immediately post-training. These were either maintained or increased at four and eight-weeks post-training.

In Chapter 4, meaningfulness of FES+VFBT was evaluated among the five participants. Using conventional content analysis, four themes were identified: 1) Perceived benefits across ICF model, 2) Factors impacting training performance, 3) Change in perceived fall risk and confidence, and 4) Motivation to keep going. Participants reported the impact of FES+VFBT on impairment, activity and participation, and explained which aspects of the intervention they believed helped contribute to these perceived benefits. Participants also explained the impact of FES+VFBT on their risk of falling, their confidence and willingness to try new things, and their desire to keep building on the progress they have made to continue with their recovery.

This thesis highlights the importance of including qualitative inquiry in the development of rehabilitation interventions. In Chapter 3, we reported large increases in maximal COP excursion area during the limits of stability test indicating improved dynamic stability. This was supported by the functional improvements reported by the participants in Chapter 4 during daily activities involving cooking, cleaning and reaching tasks. In contrast, Chapter 3 showed that participation in FES+VFBT had little impact on balance confidence, as measured by the ABC scale, yet participants reported increased confidence in their ability to maintain balance while performing their activities of daily living via the semi-structured interviews and how this increased confidence encouraged them to try new things (e.g. using walking sticks, clearing items from dining table). One participant (FESB05/Carol) did not exhibit any improvements >2SD on any of the three standardized clinical balance scales or any of the COP parameters during quiet standing.
likely due to her higher level of functioning captured at the baseline assessment. However, in her interviews she reported that her legs felt stronger, that she was less fearful of falling, and that she was noticing herself walking less with the walker following completion of FES+VFBT.

Therefore, it is possible that relying solely on the use of quantitative measures may be insufficient to fully capture the experiences of some individuals participating in intervention studies.

**Limitations**

Fifteen individuals were recruited via flyers, but only five participants were included in our sample. A 2:1 screening to recruitment ratio for SCI rehabilitation interventions (Craven et al., 2014) has been reported, which may explain our small sample. We reported a 3:1 screening to recruitment ratio for this study. The use of FES in this study may have contributed to this increased ratio. While the application of surface FES is not an invasive intervention, it may be viewed as more intrusive than other exercise-based interventions. Participation in FES also requires clearance of numerous contraindications and precautions (Houghton et al., 2010) that may result in a higher number of screens fails. Our inclusion criteria also excluded individuals with balance abilities $>46$ on the BBS and individuals with a neurological level of injury below T12.

Within the studied sample, all participants were older adults, 80% of participants were female, and 80% had a non-traumatic SCI. The characteristics of this sample do not reflect the prevalence of SCI among the Canadian population. Of the individuals with an SCI living in Canada, 26% are female and 49% have a non-traumatic SCI (RHSCIR, 2017). The increased representation of female participants within our sample may be explained by a greater fear of falling reported by female older adults in comparison to males (Greenberg et al., 2012). As a
result, this may increase their willingness to participate in balance training activities. However, due to our limited sample, it is not possible to say whether there are sex and gender influences to participation in balance interventions, but future studies should consider this interaction.

The experimental design of the study (i.e. uncontrolled) could also be considered a limitation. However, given the early stages of the development of FES+VFBT, we believe it to be appropriate. When developing and evaluating novel rehabilitation interventions, uncontrolled trials evaluating feasibility, appropriateness, meaningfulness and efficacy often precede larger randomized controlled trials (Musselman et al., 2018).

**Potential of FES+VFBT as an intervention**

The development of a closed-loop FES system, its combination with VFBT, and the application to standing balance, is in itself, quite novel. As previously discussed, VFBT has been used to target standing balance among individuals with iSCI (Sayenko et al., 2010; Tamburella et al., 2013), while FES has been primarily used for upper limb and gait rehabilitation (Kapadia et al., 2013; Kapadia et al., 2014). Participants found the addition of the FES helped them perform the VFBT exercises and felt that it helped their muscles work. Due to the focus of FES+VFBT on standing balance tasks, participants may not expect to see improvements in walking or other more dynamic movements. Adapting the FES+VFBT system to incorporate more dynamic aspects of balance control is worth exploring in the future. Future work should also investigate the use of an open-loop FES system as it may be more clinically feasible and may offer similar benefits to the closed-loop FES system.

While FES+VFBT has shown potential to be an effective and meaningful intervention for standing balance, changes must still be made to increases its clinical utility. When evaluating the potential clinical utility of an intervention, several important factors to consider include time,
cost, training and portability of equipment (Tyson & Connell, 2009). In the current iteration, participants receive only 20 minutes of FES+VFBT per one-hour training session. Spending only 33% of the intervention targeting standing balance is not an efficient use of resources or time and will not encourage clinicians to incorporate this therapeutic tool into their standardized care for SCI rehabilitation. Set-up time could be reduced if the stimulation parameters were maintained between training sessions for each participant and were only adjusted when necessary. The use of the closed-loop FES system requires force plates to provide the COP feedback in order to adjust the intensity of the electrical stimulation being applied. The equipment required to administer FES+VFBT may need to be simplified in order to maximize its clinical potential.

This system specifically focused on targeting the ankles as strategy for standing balance control. However, maintaining balance can involve the use of the hip or step strategy. Among individuals with iSCI, reactive stepping ability is impaired (Chan et al., 2019). Therefore, modifying this closed-loop FES system to encourage use of the hip strategy, or during reactive balance tasks where the step strategy is evoked, may lead to improved standing balance control among individuals with iSCI.

**Future research directions**

Rehabilitation following iSCI is an individualized experience. In our study we observed that some participants benefitted more than others. Perhaps with a larger sample, we may be able to identify characteristics that would make FES+VFBT more appropriate for some individuals. As rehabilitation following SCI is limited, and little time is already spent on balance training (Teeter et al., 2012), it is important to maximize the window for recovery and maximize the time available to the patients and clinicians. This study also investigated the effects of FES+VFBT among individuals with chronic iSCI. In the future, investigating the effects of FES+VFBT in
individuals with sub-acute iSCI may be beneficial. This study also highlighted the importance of using semi-structured interviews to capture the meaningfulness of the intervention. Relying solely on quantitative measures of balance does not fully capture the impact of an intervention on the participant. Therefore, a greater emphasis should be placed on utilizing mixed-methods in the rehabilitation literature. The findings of this qualitative study should be used to refine the quantitative measures to be used to evaluate the efficacy of FES+VFBT in future trials. Incorporating clinical assessments that are able to measure the perceived benefits being reported by individuals in activities that are specific and meaningful to them may allow us to better evaluate the impact of the intervention.

**Conclusions**

In summary, FES+VFBT showed potential as an intervention for standing balance as it was able to effectively improve standing balance post-training and proved meaningful to the individuals who participated. Further work should be pursued to optimize the training intensity and dosage in order to prolong and maintain the standing balance benefits associated with FES+VFBT.
References


Appendices

Appendix 1: Description of the Visual Feedback Balance Training Exercises

Visual feedback regarding centre of pressure (COP) location was visually represented as a red dot on the computer monitor. Four different visual feedback training exercises were performed as part of the balance training program (Figure A.1). Each exercise was performed for 100 seconds and was completed twice per training session.

1) **Bullseye**: A large target was presented in the center of the screen. Participants were instructed to stand as still as possible to try to maintain their COP within the center of the “bullseye”.

2) **Hunting**: Participants were required to shift their COP towards a randomly presented target located within one of four quadrants on the computer monitor. The target would turn green once the participant managed to shift their COP inside the presented target. A new target in a different location would appear after 15 seconds had passed or if the individual was able to accumulate five total seconds of their COP within the target. Participants were then told to repeat the task with the newly presented target. The number of targets successfully “cleared” was presented in the top right corner of the computer monitor.

3) **Ellipse**: Participants were required to track a target as it moved around an ellipse on the computer monitor in either a clockwise or counter-clockwise manner. The target travelled at a constant speed around the ellipse. Individuals were instructed to shift their COP and track the target around the ellipse. When the COP was within the target, the target turned green. The percentage of the ellipse travelled was displayed on the computer monitor.

4) **Colour Matching**: Participants were presented with colour-coded targets located around the edges of the computer monitor. Large text that read “Colour Matching” was located in the middle of the computer monitor and would turn the colour of the desired target. The participant was instructed to locate the target matching the colour of the text and shift their COP towards that target. Once the COP was within the target, the target would turn green. Participants were instructed to remain within the target until a new colour was presented. Colours changed after 15 seconds had elapsed or if the COP was maintained.
within the target for a total of five seconds. The number of colours successfully “matched” was displayed on the computer monitor.

Figure A.1: Visual Feedback Balance Training Exercises
a) Bullseye, b) Hunting, c) Ellipse, d) Colour Matching