The Effect of Neurofeedback in Post-concussion Syndrome

By

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Declaration

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Abstract

Introduction:

Concussion in sport as well as the risk of repeated concussion if athletes return too soon, is well documented. Current intervention guidelines recommend rest followed by graded return to physical activity. There are however increasing interventions aimed at speeding up the recovery process. Similarly, there is a drive to include assessment of postural control, especially dynamic balance (with and without cognitive loading) after a person has sustained a concussion and to monitor recovery to ensure persons who have sustained a concussion injury do not return to play too soon.

Aim

This study aimed to investigate the effects of a novel intervention, namely neurofeedback, on postural control recovery in sport related concussion. This study also aimed to explore the use of selected postural control measures, namely the Functional Gait Assessment (FGA) and Tandem Gait time (TG), without and with cognitive loading in assessment and determine whether there is any correlation between these and the Sport Concussion Assessment Tool (SCAT 5).

Methodology

A randomised controlled, double blind study design was used to determine the effect of neurofeedback on postural control as measured by the SCAT 5, FGA and TG, with and without loading in young collegiate adults who reported to Stellenbosch University Campus Health with a concussion sustained during participation in sport. Participants were randomly assigned to either an intervention group (neurofeedback) or a control group (sham feedback). Neither participants nor the researcher knew to which group participants were assigned. Baseline measurements (SCAT 5, FGA and TG, with and without loading) were recorded at baseline. Participants in both groups were given 4 treatment session. The FGA and TG measures were also repeated before each treatment session. The SCAT 5 was repeated at the time to return to play or after the 4th treatment session (due to time constraints). Data was processed and analysed using Stata version 14 with the help of a statistician.

Results:

Sixteen participants were finally recruited into the study, 7 in the intervention group and 9 in the control group. Data was not normally distributed and as such results are reported as medians (ranges) and were analysed using non-parametric analyses. A significant change in the treatment group compared to the

placebo group was found on the TG without loading measurement. The FGA and TG with loading showed a positive trend.

All participants scored below the norms for the postural control assessments (FGA and TG, with and without loading), suggesting dynamic balance is affected in persons with concussion. Significant correlations between the TG without loading and the SCAT 5 number of symptoms (ICC=0.512)($p<0.05$) and severity of symptoms (ICC=0.419)($p<0.05$) was found. Similarly significant correlations were also found for TG with loading and the SCAT 5 number of symptoms (ICC=-0.271)($p<0.05$) and severity of symptoms (ICC=-0.153)($p<0.05$). Gender differences were found in that males participants significantly under-reported both the number of symptoms and severity of symptoms when comparing these with their dynamic balance scores on the FGA and TG ($p=0.01$).

Conclusion:

Neurofeedback may be an effective intervention to impact recovery after concussion injury. The current study showed that neurofeedback had a significant effect on gait speed as measured by the TG with both loading and had a positive effect on postural control compared to a placebo group. Sport related concussion does affect postural control as measured by FGA, TG time, with and without loading. The FGA showed a moderate negative correlation to the SCAT 5 number of symptom and severity of symptoms reported indicating that as the number of and severity symptoms increases, the FGA scores decreased. Similar findings were found for TG time without loading.

There were a difference in gender in their TG time with and without loading as well as their reporting of symptoms on the SCAT. It is clear that male students under report their symptoms as well as their severity in order to return to sport sooner.

Our recommendation is that further studies be done on the effect of neurofeedback as a treatment in the recovery of postural control after sport related concussion. Furthermore that FGA, TG time with and without loading be taken into consideration when the return-to-play decision is made especially if a pre-seasons time can be established.

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Keywords: *Concussion, Neurofeedback, Functional Gait Assessment, Tandem Gait, postural control.*

Opsomming:

Inleiding:

Konkussie in sport asook die risiko vir herhaalde konkussie indien atlete te vroeg terugkeer tot sport, is reeds literatuur beskryf. Huidige riglyne stel rus voor tot simptoomvry en dan ’n gegradeerde program van fisiese aktiwiteit. Daar is egter al hoe meer navorsing wat kyk na intervensies wat die herstel proses kan bespoedig. Daar word in literatuur groter poging aangewend om , veral dinamiese balans, as evalueerings metode in die standaard konkussie evalueering in te sluit. Posturale beheer word aangedui as n sensitiewe meet instrument om sodoende te bepaal of ‘n atleet herstel het na sport geinduseerde konkussie en nie te vinnig terugkeer tot sport nie.

Doelwitte

Hierdie studie bestudeer die effek van ’n nuwe behandelings metode, naamlik “neurofeedback”, op die herstel van posturale beheer na ’n sport verwante konkussie. In hierdie studie word die gebruik van Functional Gait Assessment (FGA), Tandem Gait tyd (TG) met en sonder kognitiewe lading as n evalueirng van die effek van konkussie ondersoek, asook die korrelasie tussen hierdie instrumente en die “Sport Concussion Assessment Tool “(SCAT 5).

Metodologie:

’n Dubbelblinde, ewekansige studieontwerp is gebruik om die effek van “neurofeedback” op posturale beheer, soos gemeet deur die FGA en TG (met en sonder kognitiewe lading) onder Stellenbosch universitiets studente wat ‘n konkussie tydens sport opgedoen het, te ondersoek. Deelnemers was ewekansig toegewys in ‘n “neurofeedback”/ intervensie groep of n “neurofeedback sham”/ plasebo groep. Nie die studie leier of die deelnemers het geweet wie aan watter groep toegewys is nie. Basislyn evalueeing van die SCAT 5, FGA asook TG (met of sonder kognitiewe lading) is gedoen net na konkussie. Al die deelnemers het 4 behandelings sessies ondergaan waar tydens die FGA, TG met en sonder lading weer herhaal is. Die SCAT 5 is herhaal voor terugkeer tot sport of na die 4de sessie (a.g.v. tyds beperking). Data is verwerk met behulp van Strata program en n statistikus.

Resultate:

Daar was 16 deelnemers gewerf vir die studie waarvan 7 aan die intervensie groep toegewys is en 9 aan die plasebo groep. Daar was nie ’n normale verspreiding van data nie en daarom is nie- parametriese toetse gebruik om data te analiseer en word resultate aangedui in mediaan en verspreiding. Daar was n

beduidende verskil tussen die intervensie en plasebo groep op die TG sonder kognitiewe terwyl die FGA en TG met lading ook n positiewe trant getoon het. Al die deelnemers het tellings onder die norm vir posturale beheer, behaal wat aandui dat dinamiese balans wel aangetas is na sport verwante konkussie. Daar was ‘n beduidende korrelasie tussen die TG sonder lading en die aantal symptome (ICC=0.512) (p,.05) asook die ernstigheid graad van simptome (ICC=0.419) ($p<0.05$) soos gemeet deur die SCAT 5. Verder was daar verskille tussen die geslagte in die aanmelding van aantal en ernstigheids graad van simptome. Die manlike studente het hulle simptome asook die ernstigheid daarvan onderskat of nie aangemeld nie in vergelyking met die FGA en TG..

Gevolgtrekking:

“Neurofeedback” blyk n effektiewe behandelingsmetode te wees om herstel na sport verwante konkussie te bespoedig. Hierdie studie wys dat “neurofeedback” n beduidende effek het op stap spoed soos gemeet deur TG met en sonder lading asook op posturale beheer soos gemeet deur die FGA, in vergelyking met die plasebo groep. Sportverwante konkussie het ‘n duidelike effek op postruale beheer soos gemeet deur die FGA, TG met en sonder kognitiewe lading. Die FGA het n matige negatiewe korrelasie getoon teenoor die SCAT 5 (aantal asook ernstigheid graad van simptome) wat beteken dat indien simptome en die ernstigheids graad toeneem, so neem die telling op die FGA af. Die TG met en sonder lading het ‘n matige positiewe korrelasie getoon, wat beteken hoe erger die simptome op die SCAT hoe langer het deelnemers geneem op die toets.

Daar was duidelike verskille tussen mans en vrouens in hulle stap spoed asook hulle raportering van simptome. Hieruit blyk dat die mansstudente simptome onder rapporteer om te kan terugkeer na sport.

Dit is ons aanbeveling dat verdere studie gedoen word om die effek van “neurofeedback” as behandelings metode in die herstel van posturale beheer na sportverwante konkussie te ondersoek. Verder, dat die gebruik van die FGA en TG met en sonder lading oorweeg word tydens die besluitnemings proses om te bepaal of atlete kan begin terugkeer na sport veral as daar n basislyn vasgestel kan word voor die seisoen begin.

Sleutel woorde: Sportverwante konkussie, “neurofeedback”, Functional Gait Assessment, Tandem Gait, Posturale beheer.

Table of Contents

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List of Figures

List of Tables

List of abbreviations

ANOVA	Analysis of Variance
BESS	Balance Error Scoring System
CTE	Chronic Traumatic Encephalopathy
DGI	Dynamic Gait Index
EEG	Electroencephalogram
FGA	Functional Gait Assessment
MRI	Magnetic Resonance Imaging
NFL	National Football League
QEEG	Quantitative Electroencephalogram
SAC	Standardised Assessment of Concussion
SCAT	Sport Concussion Assessment Tool
SRC	Sport-related Concussion
SLS	Single leg Stance
TBI	Traumatic Brain Injury
TG	Tandem walking heel-to-toe touching
TG time without loading	Time to complete the track walking heel-to-toe- without doing a cognitive task
TG time with Loading	Time to complete the track walking heel-to-toe while doing a cognitive task.

Chapter 1: Introduction

Concussion in sport is common and occurs at all levels and amongst all age groups (Clay, Glover & Lowe 2013). Alarmingly though, it has been reported that athletes who suffered a concussion are 4 to 6 times more likely to have another concussion (Manley, Gardner, Schneider, Guskiewicz, Bailes, Cantu, Castellani & Turner 2017), which if poorly managed, can lead to reduced threshold for further concussion and possible longer duration of residual symptoms thus correct and timeous return to sport must be made. To date this has remained a clinical decision based on patient symptomatology. A need for various clinical tests and tools is apparent to assist in this clinical decision making and assist in allowing the clinician to make return to play decisions. This suggests assessment and monitoring is possibly inadequate and athletes / players are returning to sport too soon. From the literature, it also is evident that concussion can affect postural control and it has been postulated that including assessment of postural control and implementing interventions targeting balance and postural control mechanisms may be indicated (Parker, Osternig, Lee, van Donkelaar & Li-Shan 2005; Broglio Williams, Mucha & Kontos 2009; Sosnof, Broglio, Sunghoon & Ferrara 2011; Blume, Lucas & Bell 2013).

Any impact to the head, neck or face of which the mechanical force is high enough to be transmitted to the brain may cause concussion (McCrory, Meeuwisse, Johnston, Dvorak, Aubry, Molloy & Cantu 2009; Sahler & Greenwald 2012). These mechanical forces induce changes on a neuro-metabolic level and not on a structural level that can be seen on traditional imaging (Churchill, Hutchinson, Richards, Leung, Graham & Schweizer 2017; Kontos, Huppert, Beluk, Elbin, Henry, French, Dakan& Collin. 2014). An international special interest group, the “Concussion in Sport Group” (CISG) who every 5 years and through systematic review and expert consensus, provide a global best practise summary of diagnosis, prevention and management of concussion. According to the 5th International Conference on Concussion in sport held in Berlin 2016, concussion is defined as follows: “Sport-related concussion is a traumatic brain injury induced by biomechanical forces" (McCrory, Meeuwisse, Dvorak, Aubry, Bailes, Cantu, Cassidy & Guskiewicz 2017)”. Contrary to popular belief, athletes do not necessarily need to have directly impacted the head to sustain a concussion, nor does the athlete have to lose consciousness. In 95% of cases, the person is never “knocked out” (Thompson, Thompson & Reid-Chung, 2015).

The most common symptoms reported after concussion are headaches, dizziness, memory deficits, insomnia, as well as anxiety and tiredness (Pellmann, Powell, Viano, Casson, Tucker, Feuer, Lovell & Waeckerle 2004). Dizziness, including vertigo, is reported in athletes (45.7%) and non-athletes (53%) that have suffered trauma to the head. Dizziness after concussion is an indication that the vestibular system is affected (Pellmann et al. 2004). Although in the majority, these symptoms will subside within 7 to 10 days, in 30% of cases they are present longer. Headaches can also persist after concussion (Schneider, Meeuwisse, Nettel- Aguirre, Barlow, Boyd, Kang & Emery 2016). After concussion, the brain undergoes serious neuro-metabolic changes for it to regain homeostasis (Giza & Hovda 2001). These changes take 30 days to return to baseline and 45 days in cases of athletes that sustained a second concussion (Giza et al. 2001). There is growing evidence that concussion has a lasting negative effect that include early onset of cognitive decline and dementia (Giza et al. 2011). Concussion can also affect static and dynamic balance (Basford, Chou, Kaufman, Brey, Walker, Malec, Moesner & Brown 2003; Parker, Osternig, Lee, van Donkelaar & Chou 2005; Parker, Osternig, van Donkelaar & Chou 2008; Slobounov, Cheng, Sebastianelli & Newell 2008; Sosnoff, Broglio, Sunghoon-Shin, & Ferrara 2011), which in some cases can last up to 4 years after injury (Kleffelgaard, Roe, Soberg & Bergland. 2012).

Given the sometimes-subtle symptoms, different methods for assessing severity post-concussion injury are proposed. Blume et al. (2011) found that some athletes showed persistent postural instability and proposed that it might be a good way to track recovery following concussion injury. Similarly, Parker et al. (2005) also found concussion had a measurable effect on dynamic balance and found that postural balance took up to 1 month to recover fully in athletes with mild concussion. These authors similarly proposed that a more complex assessment of postural balance and vestibular function is indicated including testing balance while attention is diverted, and that postural balance could be included as an indicator of return-to-play. McCrory et al. (2017) concluded that there is a strong need for investigation into the long-term effect of rest as well as multimodal physiotherapy treatment of individuals with vestibular dysfunction sustained in sports-related concussion.

Assessing patients with dizziness and balance disorders (i.e. vestibular function) however, is challenging and can be misdiagnosed in a clinical setting (Basford,Chou, Kaufman, Brey, Walker, Malec, Moesner & Brown 2003 as quoted by Lei-Rivera, Sutera, Galatioto, Hujsak & Gurley 2013). In most of our daily tasks we combine balance with a cognitive task for example walking and talking. Similarly, most sports require that a motor task is performed whilst attention is divided (Teel, Register-Mihalik, Blackburn, Guskiewicz. 2013). There are many tools and tests batteries for assessing balance, such as the Dynamic Gait Index (DGI), Functional Gait Assessment (FGA) and/or the Balance Error Scoring System (BESS). These are commonly used to detect balance or postural control after concussion, however, they are limited in their assessment. Force plate data have shown, for example in Catena, van Donkelaar & Chou 2011, that patients with concussion had a 26% increase in body sway when given a cognitive task while walking. In this case participants had to count backwards in increments of 7 (Catena et al 2011). Athletes diagnosed with concussion have also shown a longer recovery period for performing complex motor task especially in dual motor tasks (Howell, Osternig & Chou 2013). The ability to multi-task is currently; however, still not part of the standard assessment and monitoring post-concussion (Parker et al. 2005; Notebaert & Guskiewicz 2005).

Management of Concussion:

In most instances, a patient with concussion is assessed using the Sport Concussion Assessment Tool (SCAT) 5 and only rest and gradual return-to-play is prescribed (McCrory, Meeuwisse, Aubry, Echmendia, Engebretsen, Johnston, Davis, Ellenbogen, Guskiewicz, Herring, McCrea, & Schneider 2017). The SCAT 5 assessment tool uses an abbreviated version of the Balance Error Scoring System (BESS) assessment to evaluate balance but there is no assessment of dynamic postural control. BESS only evaluates static balance while standing on a hard and soft surface with feet together, 1 leg or 1 foot in front of the other and heel and toes touching (tandem). This is conducted with the eyes open and the eyes closed. It does not look at balance while moving or with head movements although during sport this is what is required of athletes. This has been reported to lead to concussion being under-diagnosed or athletes returning to play too soon (Parker et al. 2005; Howell et al. 2015).

According to the Consensus Statement on Concussion rest is still the most commonly prescribed intervention (McCrory et al 2017), despite evidence to support that complete rest will minimise the energy demands of the concussed brain and thereby mitigate Post-Concussion Syndrome. In the same statement, it is also noted that there is some evidence that other treatment options including psychological, cervical and vestibular rehabilitation may be beneficial, but the evidence at present is scant (McCrory et al 2017). Once the concussed athlete is symptom free, a graded exercise program should be prescribed (McCrory et al 2017). Dosage guidelines concerning rest and exercise however, need further research. Kenzie, Parks, Bigler, Lim, Chesnut & Wakeland (2017) maintains that there is still a lack of effective diagnosis, prognosis and treatment. In their literature review they found that between 5-43% of all concussed athletes still experience postural, emotional or cognitive disorders 3 months after sustaining a concussion.

One intervention however that warrants further investigation is **Neurofeedback or Electro-encephalogram (EEG) biofeedback.** Neurofeedback uses audio or visual feedback to ‘reward’ certain patterns of brain activity and has been shown to normalise dysfunctional brain wave activity in adults with neurological conditions. Since the 1960’s, studies have shown that neurofeedback can restore brain wave activity especially in the case of excessive slow wave activity (Duff 2004). Salazar, Warden & Schwab 2000) showed that cognitive therapy and psychological support alone are not effective in addressing the deficits of Post-Concussion Syndrome (Salazar et al 2000). During neurofeedback, real time quantitative EEG (QEEG) is displayed on a computer and the patient is given visual and auditory rewards for producing more normal brain patterns.

Our setting:

All sport matches played at Stellenbosch University have an attending doctor. If collegiate athletes sustained a blow to the head during the match the attending doctor will assess the patient using a standardized Head Injury Assessment (HIA) and the Glasgow Coma Scale (GCS). If the student has a deficit on the GCS, the student will be transferred for further assessment at the emergency room at the local hospital. If not, the student is prevented from continuing the match and referred to the Campus Health Services, a collegiate medical facility on Stellenbosch Campus, the following day for an assessment using the SCAT 5. If they still have symptoms the student is diagnosed with Post-Concussion Syndrome and rest is prescribed until all symptoms are cleared. Concussed athletes are repeatedly evaluated at weekly intervals until the SCAT 5 score is normalised and a graded return-to-play programme is followed. Currently students receive no other interventions.

Within the current context the assessment of a person's balance who has experienced a concussion injury is limited to static balance assessment and in most cases relative rest is prescribed according to the consensus guidelines. It is postulated that the long-term effect of concussion is under-diagnosed and there is a need for more comprehensive assessment of postural control especially during cognitive loading or divided attention (McCrory et al. 2017). Similarly given the current evidence for neurofeedback on postural control it is also hypothesized that Neurofeedback may be indicated as a treatment to enhance balance recovery in patients with Post-Concussion Syndrome.

The purpose of the current study is therefor to describe the effect of concussion sustained during sport on postural control in healthy young adults and to determine whether neurofeedback can enhance recovery post-concussion. A secondary objective of this study was to compare measures as recorded using the SCAT 5 with postural control measures as determined by the FGA and TG (with and without loading). The findings from this study may assist in the management of concussion, future research in the field, as well as decision making with regards to readiness to return-to-play.

Chapter 2: Literature Review

2.1 Introduction:

A literature review was conducted to obtain an overview of the research conducted in the field. The following search engines were accessed through the Stellenbosch University library**:** Cinahl, Pubmed, Medline and Proquest**.** Public search engines including Google Scholar and Semantic Scholar and SUNScholar were also searched. The main keywords used were concussion, sport, vestibular balance, dynamic balance**,** postural control, post-concussion syndrome, neurofeedback, EEG biofeedback and neurotherapy. The search was limited to articles between 2012 and 2018 although if articles referenced an earlier article that was relevant to the topic, it was also included. As the focus of the current study was on postural control (dynamic balance) in young healthy athletes, articles/studies were exclude if they pertained to children or adolescents, or referred to static balance assessment.

2.2 Concussion

2.2.1 Definition

According to the 2012 Zurich Consensus Statement, concussion is defined as “A complex pathophysiological process affecting the brain, induced by biomechanical forces” (McCrory 2013). However, 4 years later an updated and expanded version called the Consensus Statement on concussion in sport (McCrory et al 2017) re-defined concussion as: “Sport-related concussion (SRC) is a TBI induced by biomechanical forces”. Several common features that may be utilised in clinically defining the nature of a concussive injury include: (McCrory et al 2017)

- SRC may be caused by either a direct blow to the head, neck or elsewhere on the body with an impulsive force transmitted to the head.
- SRC typically results in the rapid onset of short-lived impairments of neurological function that resolves spontaneously. However, in some cases the signs and symptoms evolve over a number of minutes to hours.
- SRC may result in neuropathological changes, but the acute clinical signs and symptoms largely reflect a functional disturbance and, as such, no abnormality is seen on standard structural neuroimaging studies.

- SRC results in a range of clinical signs and symptoms that may or may not involve the loss of consciousness. Resolution of the clinical and cognitive features typically follows a sequential course. However, in some cases the symptoms may be prolonged.

The American Medical Society for Sports Medicine defines concussion as “a traumatically induced transient disturbance of brain function that involves a complex pathophysiological process” (Harmon, Drezner, Gammons, Guskiewicz, Halstead, Herring, Kutcher, Pana, Putukian & Roberts. 2013). In this report it is stated that experimental evidence suggest that a person’s brain that sustained a concussion injury, is less responsive to neural activity and if physical or cognitive activities occurs prematurely, then the person might suffer from long term dysfunction (Harmon et al. 2013).

It is stated in the same report, that the SCAT 5 is a useful checklist to be used immediately after injury to assist in differentiating concussed from non-concussed athletes. Unfortunately, its validity decreases significantly after 3 to 5 days (Parker et al. 2008). This symptoms checklist has limited utility in tracking recovery. Most of the current check list assess functioning as a stand-alone, for instance only static balance is tested and not dynamic balance with cognitive loading. Furthermore gait/balance assessment and reaction time could be used to add clinical value to assess recovery (Parker et al. 2008). This is further highlighted by Howell et al (2015) that in spite of best-practise recommendation, there is no standard for monitoring recovery in concussion. Dessy et al (2017) evaluated different assessment tools used to determine return-to-play and found that the Standard Assessment of Concussion (SAC) and SCAT 5 are sensitive enough to determine the presence of a concussion, but should not be used as a stand-alone to determine return-to-play (Dessy, Yuk, Maniya, Gometz, Rasouli, Lovell & Choudri. 2017)

2.2.2 Pathophysiology of concussion

Sports related trauma-induced injury leads to changes in the brain function although no structural abnormalities are present on current investigative methods Magnetic Resonance Imaging (MRI) (Churchill, Hutchinson, Richards, Leung, Graham & Schweizer 2017). Functional Magnetic Resonance Imaging (fMRI) however, shows that alteration in cognitive and physical functioning is related to neuro-metabolic alteration rather than structural injury (Kontos, Huppert, Beluk, Elbin, Henry, French, Dakan & Collins 2014). Functional Magnetic Resonance Imaging (fMRI) assess the fluctuation of blood oxygenation levels that correlates to the functional connectivity between different brain regions. (Churchill et al 2017)

The biomechanical forces exerted on the brain initiate a complex chain of changes to the delicate neuronal homeostatic balance (Signoretti, Lazzarino, Tavazzi & Vagnozzi 2011). According to these authors, the immediate effect of the impact on the brain is a stretch-strain effect that changes the structure of neurons, glial cells, and the extracellular matrix. These changes in structure result in, or are accompanied by, changes in neuro-transmitters and neuro-metabolic processes at cellular level. Mitochondrial dysfunction occurs, which impairs both focal and general neurotransmission. This network dysfunction after concussion manifests itself in a variety of symptoms including somatic, cognitive and affective symptoms such as mood disruptions, sleep disturbances, migraine/headache impaired sensory-motor integration (balance especially with eyes closed), as well as reduced cognitive processing speed (demonstrated in dual task or cognitive loading) (Kenzie et al 2017). These cells are in a very vulnerable state, which significantly increases the risk for irreversible damage following a second concussion (Signoretti et al. 2011).

After a concussion, there are definite findings visible on an Electroencephalogram (EEG) that represents the injury changes on connectivity (neural network) (Kenzie et al. 2017). Ianof and Anghinah (2017)'s review of the literature (460 articles) found that quantitative electroencephalogram (QEEG) showed changes in alpha-, beta-, gamma- and delta waves in concussed athletes, compared to non-concussed athletes that indicate a slowing down of processing and integration between different networks which are most prominent in the fronto-parietal, temporal and occipital regions (Kenzie et al. 2017). Ianof et al. (2017) also report that these changes persisted in 63% of athletes in their study at 1 year post-concussion. Similarly Thornton & Carmody (2009) in their study showed that these change could last up to 6 months. As these changes do not always recover spontaneously, interventions such as neurofeedback, physical therapy or cognitive- behavioural therapy may be indicated (Kenzie et al. 2017, Ianof et al. 2017).

2.2.3 Risk of second concussion and long term effects

There is evidence that repeated concussions can be related to Chronic traumatic encephalopathy (CTE) which is a neurodegenerative disease (Saigal & Berger. 2014). Although the symptoms of CTE are variable they may include: progressively impaired memory and cognition, affective disorders such as impulsivity and aggression, depression and decreased motor control (Seichepine, Stamm, Daneshvar, O'Riley, Baugh, Gavett, Tripodis, Martin, Chaisson, McKee, Cantu & Nowinski. 2013). A study investigating the recovery pattern after concussion found that athletes with one previous self-reported concussion were 2.2-times more likely to sustain another concussion than those with no previous history of concussion. Furthermore, those with two or more previous concussions were 4.2-times more likely to sustain another concussion (Kamins, Bigler, Covassin. Henry, Kemp, Leddy, Mayer, McCrea, Prins, Schneider, McLeod, Zemek & Giza 2017). Of those athletes that have a repeated incident of concussion, 91.7% happen within 10 days of the first and 75% within the first seven days (Guskiewiez et al. 2003). Harmon et al. (2013) also found a correlation between multiple concussions and chronic cognitive dysfunction, but the authors did state that larger epidemiological studies are needed to confirm this.

Bodil et al. (2018), in their systematic review, found strong evidence that previous concussion is related to depression later in professional football players (Bodil, Nieuwenhuijsen & Sluiter. 2018). Rice et al (2018) found the same link between concussion and depression later in elite athletes of different sport.(Rice, Parker, Rosenbaum, Mawren & Purcell. 2018)

The decision to return-to-play currently depends on self-reported symptoms which does not accurately reflect the recovery of the brain on a cellular level (Churchill et al. 2017). Functional MRI, however, used in a study to assess athletes between one week post-concussion and one month (subacute phase) still showed abnormal brain activity despite athletes being asymptomatic (Kenzie et al. 2018). If one considers that this could cause permanent damage to mitochondrial functioning (Signoretti 2011) then more rigorous assessment before return-to-play becomes crucial (West & Marion. 2014).

2.2.4 Symptoms associated with concussion injury

The most common symptoms reported after concussion are headaches, dizziness, memory disorders, insomnia, anxiety, tiredness and balance disorders (Pellmann et al. 2004, Kontos 2014). Dizziness, including vertigo, is reported not only in athletes (45.7%) but also in non-athletes (53%) following a concussion injury, indicating that the vestibular system can be affected (Pellmann et al. 2004). Although these symptoms (self-reported) will typically subside within 7 to 10 days, in 30% of cases they (mostly headaches) can present for longer (Schneider et al. 2016).

Concussion can also affect static and dynamic balance (Guerts, 1996; Parker, 2005; 2006 & 2008; Basford, 2003; Slobounov, 2006; Sosnoff, 2011). Kleffelgaard et al. (2012) found in their study that a third of patients with concussion had long-term balance disorders and that, in some cases this lasted up to 4 years after injury. Blume et al. (2011) found that some athletes showed persistent postural instability and the authors proposed that it might be a good way to track recovery following concussion injury. Similarly, Parker et al. (2005) suggested that concussion has a measurable effect on dynamic balance and also proposed that postural balance could be an indicator of return-to-play. The authors found that postural balance took up to 1 month to recover fully in athletes with mild concussion and suggested that before return-to-play a more complex assessment of postural balance, that includes testing balance while attention is divided, is indicated.

Kamins et al 2017 also found that the recovery of cognitive function and balance deficits lagged behind the recovery of self-reported symptoms. Power et al (2013) reported that participants (athletes) in their study still presented with balance control deficits upon return-to-play. (Power, Kalmar & Cinelli 2013). Similarly, Yogev-Seligman et al (2013) reported that the athletes in their study also presented with gait stability deficits even at 2 months after concussion.(Yogev-Seligman, Hausdorff & Giladi. 2013) The authors also stated that this was most profound when dual tasking was used to assess gait stability. It has been reported that in some cases this can persist for several years. a Study by Kleffelgard et al. (2012) found that 31% of athletes still reported balance disorders 4 years after the concussion and found disorders with dual tasking as well as sport activities.

2.2.5 Post-concussion Syndrome

Post-concussion Syndrome is diagnosed when a person has persistent symptoms although their score on the Glasgow Coma Scale (GCS) is normal. Depending on the diagnostic criteria used, 11 - 64% of athletes are diagnosed with Post-concussion Syndrome and many present with persistent symptoms of balance disorders. This significantly contributes to anxiety and difficulty returning to sport and work (Fino 2016).

Guskiewicz, McCrea & Marshall (2003) tested 2905 football players pre-season in 1999, 2000 and 2001. These players were followed-up prospectively to ascertain concussion occurrence. One of the key findings reported in this study were that headache (82.5%) was the most commonly reported symptom followed by dizziness(79%) and balance difficulty (77%). As stated earlier, the brain undergoes significant neuro-metabolic changes after sustaining a concussion. These changes can take up to 30 days to return to baseline and in cases where the athlete sustained another concussion up to 45 days (Giza & Hovda 2001; Shaw 2002; Schramm, Klein, Pape, Berres, Werner & Engelhard. 2011; Thompson et al. 2015). Somatosensory integration is affected which makes it problematic to maintain dynamic balance during gait velocity and acceleration. Since balance is key in sport, as well as most acts of daily living, not detecting these balance deficits could increase the risk of a 2nd concussion (Kleffelgaard et al. 2012).

According to the American Medical Society's 2014 guidelines, balance testing provides an ideal model for determining sensory-motor deficits in concussed athletes (West et al. 2014). This is further supported by E Willer & Leddy (2016) who proposes to move away from the traditional symptom-based model to a more comprehensive detailed motor function assessment. Motor function requires integration of sensorimotor information and involve a complex integration of information from the cortex, cerebellum, basal ganglia, brain stem as well as the spinal cord. Integrated sensory-motor can be assessed by reaction time, balance, changes in focus as well as dual task gait strategies (Ellis et al. 2016).

Although balance disorders are reported to be one of the most common physical symptoms in Post-concussion Syndrome, the frequency and development of long-term balance disorders are not well-documented (Kleffelgaard et al 2012). The author compared self-reported balance disorders in concussed athletes with balance assessment just after concussion and at 4 years. They found that 4 years after concussion, 28% of the athletes still had balance disorders, self-reported and with dual task testing. It was concluded that the rate of recovery specific to concussion was not well understood (Kleffelgaard et al 2012). Persistent dizziness still experienced at 3 months after concussion may be an indication of vestibular disorders (Pellmann et al. 2004). Howell et al. (2013) further emphasized this when he found that these symptoms affect proprioceptive performance, reaction time, balance and dual task gait strategies. Given these functional deficits, clinical analysis of postural control and oculomotor efficiency have been proposed as a valid measure for identifying athletes with concussion.

2.3 Balance in concussion

Maintaining balance depends on the ability to sense the body's position in space to adopt and/or sustain that desired posture and requires the integration of visual, vestibular and somatosensory information (Guskiewiz 2011). The vestibular system aids with that by estimating our body position as well as the body's motion (Hain & Helminski 2014). The vestibular nuclear complex derives information from the inner ear (3 semi-circular canals), proprioception or position sensation as well as visual signals. It integrates the information and communicates to the cerebellum, cortex and brain stem (Hain et al. 2014). Coordinated motor function as needed in sport, requires the processing of sensory-motor information that involves complex integration of information between the cerebral cortex, cerebellum, basal ganglia and the brainstem (Johnston, Coughlan & Caulfield. 2017). These authors found in their study that concussed athletes show impairments of proprioceptive performance, reaction time and dynamic balance, especially during dual task gait and concluded that these impairments are due to a disruption of cortical pathways and functioning of the vestibular system.

Traditionally the assessment of balance has focused on static balance with and without visual input. The moment visual input is removed there is an increased reliance on somatosensory and vestibular cortical integration. Since the cerebellum plays a major role in maintaining posture and balance during coordinated movement (heel-to-toe), a static test might not be sufficiently sensitive to detect impairment in dynamic balance (Oldham, Difabio, Kaminski, Dewolf, Howell & Buckley 2018). One of the most widely used tests is the Balance Error Scoring System or BESS, but it has consistently been shown to lack sensitivity as a diagnostic test after concussion (Johnston et al 2017). It has therefore been suggested that quantifiably challenging balance and motor assessment needs to be integrated as part of the assessment to determine return-to-play (Johnston et al. 2017).

2.3.1 Testing Balance

Assessing patients with dizziness and balance disorders is challenging in the clinical setting (Basford et al 2003). There are a number of clinical tests that can be used to investigate balance or postural control. Clinical tests such Dynamic Gait Index (DGI), Functional gait Assessment (FGA) and Balance Error Scoring System (BESS), amongst others, have been widely used to detect poor balance or postural control after concussion.(Mulligan, Boland & McIlhenny 2013, McCrory et al 2017)

2.3.1.1 Balance Error Scoring System (BESS)

The BESS is widely used in persons with concussion and currently forms part of the SCAT 5 (McCrory et al. 2017). This test uses different stances e.g.; Double Leg Stance (DLS), Single Leg Stance (SLS) and Tandem Stance (TS) on a firm and foam surface with the person standing with hands on the hips. This stance must be maintained for 20s with the eyes closed. Points are given for errors. Examples of errors for which points are given: opening the eyes, lifting the hands off the hips, in 1-leg stance moving the hip in more than 30 degrees of hip abduction to maintain balance, toes or heels losing contact with the surface or giving a step to maintain balance.

Valovich Mcleod, Barr, McCrea & Guskiewicz (2006) used a quasi-experimental, repeated-measures design to test re-test reliability of the BESS in concussed athletes. Fifty athletes were recruited and underwent an initial test and then another test, 60 days later. Using Pearson product moment correlation® a score of 0.7 was found suggesting the BESS is moderately reliable for testing balance in individuals/athletes with concussion.

Chang, Levy, Seay & Goble (2014) compared the BESS to the current gold standard measure for balance - the scientifically graded force plate. Interclass Correlation Coefficients (ICC) using the 2-way random effect, single measure model was used to determine interrater reliability. Test-retest reliability was calculated using the data collected 7 days apart. ICC scores for BESS composite scores ranged from fair to excellent. The criterion validity; however, of the BESS relative to force plate data ranged significantly between 0.31 and 0.79. Demonstrating that BESS criterion validity is not significant compared to the gold standard measure for balance.

McDevitt, Appiah-Kubi, Tierney & Wright (2016) utilised a cross sectional study design in which 60 healthy participants were compared with 12 concussed participants. Different tests were used to test vestibular and oculomotor function. Vestibular function was tested with the BESS and the sensory organization test. When sensitivity of the 2 balance tests were compared, the BESS had a sensitivity of 8.3% meaning that only 1 in 12 concussed participants were correctly identified 48 hours after injury. This implies that BESS is only accurate immediately after injury.

Murray, Meldrum & Lennon (2017) conducted a systematic review of literature to assess the reliability and validity of different balance assessments in concussion. They found that the sensitivity value for the BESS was 0.34 and that there was is an inability to detect balance dysfunction 7 days after the initial concussion. At the same time the BESS relies heavily upon rater interpretation and has in numerous studies shown a low interrater reliability (McCrea, Barr, Guskiewicz, Randolph, Marshall, Cantu, Onate & Kelly. 2005).

In a study conducted by Mulligan, Mark, Boland & Mcllhenny (2013) the authors found there was a significant learned effect using the BESS and concluded that the ability of the BESS to assess athletes balance deficit following concussion should be questioned. Furthermore, Broglio, Zhu, Sopiarz & Youngsik. (2009) found that BESS suffers from learning and fatigue effects.

Bell, Guskiewicz & Clark (2011) confirmed the above in that the BESS can only detect large changes in balance and only within 3 to 5 days. A more recent study by Johnston et al (2017) support this finding. This study showed that that BESS was unable to detect small changes in balance especially after a week. The researchers concluded that more challenging assessments and different return-to play protocols need to be developed

In a further study Munia, Haider, Schneider, Romanick & Fazel-Rezai (2017) took 14 non-concussed and 7 concussed football players and compared their EEG, BESS and Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT). ImPact is the most commonly used assessment tool to assess cognitive function after concussion. The data were collected from 12 days after concussion and the after that every 30 days thereafter. They found that there was no difference between the concussed and non-concussed group on the ImPACT test. Impairments on the BESS were only evident up to 5 days after the concussion and was not sufficiently sensitive enough to detect any residual postural disorders. However, the changes in alpha, beta, gamma waves as measured with an Electroencephalogram (EEG) made it a more sensitive test to detect persistent deficits than cognitive testing.

2.3.1.2 Functional Gait Assessment (FGA)

The FGA is a standardised test,developed to assess postural stability during different walking tasks (Walker, Austin, Banke, Foxx, Gaetano, Gardner McElhiney, Morris & Penn 2007). This test is an enhancement of the Dynamic Gait index (DGI) (Wrisley, Marchetti, Kuharsky, Whiney. 2004). FGA includes tasks that require more postural adjustments as opposed to the more static assessment of the BESS (Leddy, Crowner, Earhart. 2011). It is a clinical gait test that consists of 10 gait activities that are easy to administer in a clinical setting. All that is required is a stopwatch, a walking area that is marked, shoeboxes – (to create obstacles), and steps. The FGA looks at the ability to complete the 6m track and the time it takes to complete it.

Wrisley et al. (2014) evaluated the reliability, internal consistency and validity of the FGA across ten raters in 6 patients with vestibular problems. Each patient performed the FGA twice with an hour rest in-between. Three physiotherapists from various practise settings were taken as well as 3 physiotherapy students. Each therapist was given the FGA beforehand with instructions and 10 minutes to review it. In order to establish the concurrent validity, the FGA was compared to what is accepted as the golden standard (scientific graded force plate) in vestibular function. The results showed good intra-rater reliability for total FGA scores with an ICC of 0.83. The inter-rater reliability was also shown to be good with an ICC of 0.84. Internal consistency was determined using Cronbach alpha and scored 0.81 for Trial 1 and 0.77 for Trial 2 and across both trials, 0.79 suggesting moderate to good internal consistency.

Power et al. (2013) found that athletes compensate for their poor balance by slowing down. They compared athletes without concussion to concussed athletes and found that non-concussed male athletes will walk the 6 m track at a median speed of 1.35m/s and females at a median speed of 1.24m/s. This would mean that non-concussed athletes will take between 4.4s for males and 4.8s for females to complete the 6-m track. Alalaheen (2016) found that a change in gait speed of 0.21m/s is considered a reliable change in gait speed and is indicative of balance disorders. This would mean that if a male athlete takes 5.2s (compared to 4.4s) to complete the track and females take 5.82s (compared to 4.83s) to complete the track, it would be considered a significant change in gait speed to indicate a balance problem.

2.3.1.3 Tandem Gait (TG)

The TG test is commonly used to determine postural control and motor coordination and was therefore incorporated in the SCAT 5 as part of the standard neurological assessment (McCrory et al 2017, Oldman et al 2018). During the TG test, the is participant is asked to walk 1 foot in front of the other while the heel of the front foot touches the toes of the back foot. Normative values were determined by Schneider et al. (2010). The average time for healthy adults to complete the task was 11.2s. Schneider et al. (2013) compared concussed with non-concussed athletes and found that non-concussed athletes could complete the 6m track in a mean time of 11.6s (SD 3.8) while in athletes with concussion a mean time of 14.7 (SD 2.8)

One hundred and thirty-seven healthy adults between 16 to 37 years, participated in a study to determine the intra-rater reliability. The subjects were asked to walk the 6m track and the time to complete the task was recorded. The authors came to the conclusion that the TG test proved to be a precise and reliable test when administered by the same assessor. The Single Leg Stance (SLS) test is part of the BESS that is part of the SCAT 5 that is currently used to determine if athletes have sufficiently recovered to return to play. However SLS was significantly less reliable and the authors recommended that the SLS test should not be included in assessment of recovery from concussion. They did however conclude that the TG test is more practical and a reliable measure of motor performance and that it should be incorporated in the assessment of a person with concussion. (Schneider, Sullivan, Gray, Hammond-Tooke & McCrory 2010)

Oldham et al. (2018) compared the BESS with the TG test in concussed and non-concussed controls. According to their results the BESS test lacks sensitivity in detecting balance deficits and scored poorly with ICC scores of 0.5. Similarly, specificity was also poor also scoring 0.5 for the BESS. The TG test however had slightly better scores with a reported sensitivity of 0.67 and specificity of 0.74. In terms of time to complete the task during repeated measurement, concussed athletes took significantly longer to complete the TG with an increase of 1.2s on the base line time whereas the healthy control group stayed the same. These results reflect the rapid fatigue concerning balance and gait reported in concussed individuals.

2.3.1.4 Dual tasking or Cognitive Loading

The majority of our daily tasks require the ability to dual task, meaning that we perform a cognitive task while simultaneously moving and keeping our balance while doing so. In sport athletes, balance is fundamental in the execution of technical movements as well as the prevention of injury (Rocotti 2011). The ability to perform cognitive tasks while walking is the norm and not an exception (walk and text) but even more so in sport (Yang, Chengqi & Pang 2016).

A number of studies in literature have utilised these test in the setting of concussion. In a dual task study conducted in concussed adolescents Howell, Osternig & Chou (2013) reported a significant disruption in the ability to control forward motion as well as to maintain gait balance while performing a concurrent cognitive task compared to control (non-concussed) group. The results indicate the concussed athletes have a disruption in their ability to maintain balance while performing a cognitive task compared to athletes without concussion. The authors concluded that dual task walking may provide information that can aid the assessment of recovery after concussion and therefore the decision to return-to-play (Howell et al 2013). Similarly, Parker et al. (2006) compared concussed athletes and non-athletes with a control group and found that the concussed individuals had a lower gait velocity and an increased sway especially while doing a dual task. All the participants were asked to walk a 10-m track and as dual task to count backwards in 7's or 8's or to recite the months of the year backwards. The data from this study also showed that that motor stability, particularly balance control under divided attention, was impaired up to a month following what was considered a mild concussion (Parker et al. 2006).

Fino, Parrington, Pitt, Martini, Chesnutt, Chou & King (2018) conducted a systematic literature review on concussion and gait. These authors reported on 26 articles that used different methods of assessing single task simple gait. Most studies used motion capture cameras to assess gait in concussed and non-concussed populations. The findings of studies show that gait speed was largely affected during the acute phase of concussion. Ten articles assessed dual task complex gait. Complex gait consisted of TG, stepping over obstacles and turning while performing a cognitive task like spelling a 5-letter word backwards, counting sequentially backwards from 100 in 7 or 6. Only 1 study looked at deficits during the acute phase, the rest looked at acute phase through to the subacute phase and 1 study looked at the subacute phase as well as the intermediate phase. TG was slower in the acute and subacute phase and the total tandem walk time was slower compared to control even 30 days after concussion. The authors concluded that cognitive recovery takes place within 5 days, deficits as recorded on the BESS recover between 3 to 5 days and furthermore, single task simple gait also seemed to recover within 5 days. Most of these tests however, were conducted in isolation and as such not directly comparable. The review also concluded that abnormal gait as measured by the TG can persist well into the subacute phase, namely 11 to 90 days post-concussion.

2.4 Concussion: Interventions

2.4.1 Rest and recommended return-to-play

According the SCAT 5 the recommended management of concussion should start with rest until the athlete is symptom free. After a few days the athlete can start with daily activities and gradually increase as long as symptoms do not worsen. Once all the usual daily activities can be completed without concussion related symptoms and a six stage rehabilitation exercise programme has been conducted then gradual return-to-sport or play can be started. The gradual return to sport consists of the following 6 steps:

1. Symptom limiting activity (activities of daily living do not provoke symptoms)
2. Light aerobic exercises (slow or medium aerobic exercise but no resistance training)
3. Sport-specific exercise (no head impact activities)
4. Non-contact training drill (this can include progressive resistance training)
5. Full contact training (includes all normal training activities)

6. Return to full participation.

2.4.2 Physical exercises after concussion

There is some evidence that exercise can speed up recovery, but the evidence is scant. Broglio et al. (2016) found that rest alone can in fact lead to neurocognitive decline and depression especially amongst those athletes that have not fully recovered after 14 days. Early exercise intervention though may be more beneficial than no exercise. Broglio et al. (2016)'s systematic review compared the effects of different types of management strategies after concussion and although their findings are based on very limited literature, showed that athletes should avoid sport in the acute phase to avoid a secondary injury but that if symptoms persist after the acute phase then athletes could benefit from moderate exercise in a controlled environment to decrease recovery time.

Despite the above, exercise and the benefits thereof post-concussion, were unclear and assumed. For this reason, Lal, Kolakowsky, Ghajar & Balamane. (2018) conducted another systematic review and meta-analysis and found that exercise rehabilitation showed clear benefits in recovery from concussion (as determined by a decrease in the post-concussion syndrome score). The review also found that exercise can improve reaction time. They did however not look at postural control and its recovery. O'Brien et al. (2017), in a case-control study, found that 12% of participants experienced a return of symptoms after they started exercising, suggesting that the exercise intervention and or readiness to resume exercise, warrant further investigation.

2.4.3 Vestibular Rehabilitation after concussion

Schneider et al. (2016) conducted a randomised-controlled study in which participants with persistent symptoms after concussion were assigned randomly to either an intervention or control group. The control group received postural education, range of motion exercises and cognitive and physical rest once a week for eight weeks. The intervention group received the same except they also received cervical spine and vestibular rehabilitation. According to their results the treatment group was 10.3x more likely to return-to-play within the eight-week period than the control group. In the intervention group 73.3% of the participants were cleared to return to sport compared to the 7.1% of the control group. They concluded that significantly higher proportion of athletes treated with cervical and vestibular rehabilitation were medically cleared to return to sport that the control group.

Murray, Meldrum& Lennon (2017) conducted a systematic review to determine the efficacy of vestibular rehabilitation on recovery after concussion. He found weak evidence of positive improvement and increased rate of clearance to return-to-play but recommended that more, and higher level studies are needed. In an earlier study Hoffer et al. (2007) investigated the effect of vestibular rehabilitation on participants serving in the military and who had sustained a concussion and found that after 6 to 8 weeks of vestibular rehabilitation there was a significant improvement in dizziness, and perception of balance. Similarly Ellis et al. (2016) found in their review of the literature further evidence that support vestibular rehabilitation for athletes that have suffered concussion.

2.4.4 NEURO-FEEDBACK

Brainwave activity is believed to be caused by electrical activity in cortical neurons that are driven by subcortical structures like the thalamus and hippocampus (Silberstein 2006). There is general consensus amongst neuroscientist that thalamo-cortical oscillations are responsible for the initiation and transfer of information between the different structures in the brain (Pfurtscheller & da Silva 1999). These brainwaves can be recorded and visualised using Encephalographs or EEG (Pfurtscheller et al 1999). Excessive or decreased activity in delta, theta, alpha or beta activity can be seen with abnormal/poor regulation of thalamo-cortical activity which is then responsible for the range of symptoms seen in Post-Concussion Syndrome (Abarbanel & Evans 1995; Pfurtscheller et al 1999; Otmer & Kaiser 2000; Munia et al 2017).

Neurotherapy or neurofeedback uses the real time Quantitative Electroencephalogram (QEEG) to give a patient audio or visual feedback. The software is driven by selected QEEG parameters to enhance normal brain activity (fast beta and alpha waves) and to inhibit excessive slow activity (for example, excessive slow theta activity). This intervention has shown significant improvements in persons with Attention Deficit Hyperactivity Disorder (ADHD) Studies have shown that with neurofeedback participants can learn to produce normal alpha/theta/beta ratio again (Lubar 1997; Barabsz & Barabsz 2000; Barr, Prichep, Chabot, Powell & McCrea 2012)

Post-concussion Syndrome as stated before has a cluster of symptoms that include amongst others attention deficit, difficulty in sustaining mental effort, fatigue and tiredness, impaired balance and headaches (Duff 2004). Fenton et al. (1996) found in their study that immediately after concussion there was an increase in theta activity seen on QEEG, which resolved after 10 days. Patients who had persistent symptoms showed residual slow wave activity on QEEG. The slow wave activity was registered over temporal-, parietal- as well as occipital regions.

2.4.4.1 Neuro-feedback in concussion

There are very few studies that investigated the effect of neurofeedback on recovery in concussion. Hoffman and colleagues in the mid 1990's first used neurofeedback to treat patients with Post-Concussion Syndrome at 6 months post-concussion (Hoffman, Stockdale, Hicks & Schwaninger 2008). After an average of 40 treatment sessions, 70% of the patients reported an improvement. Six years later, Keller & Garbacenkaite (2015) used neurofeedback during the early (acute) recovery period following concussion. A control group was exposed to a standardized computer program aimed at enhancing attention whereas the intervention group received Neurofeedback with the focus on increasing beta activity. The intervention group improved their attention measurements significantly more and sustained it for a longer period than the control group. In the same period, Walker et al. (2007) treated 26 patients with persistent Post-Concussion Syndrome, 3 to 70 months post event. On average 19 sessions resulted in all patients returning to play with 88% of the group showing a 50% improvement in symptoms.

The above-mentioned studies suggest that neurofeedback can have a positive effect on the symptoms of Post-Concussion Syndrome, although no additional recent studies could be found.

2.4.4.2 Neuro-feedback in the treatment of balance disorders

In a randomized control trial by Azarpaikan, Torbati & Sohrabi. (2014) in a group of persons with Parkinson's disease, Neurofeedback was compared with 8 weeks of sham EEG signalling. Both groups received 8 sessions and at post-intervention measurements of static and dynamic balance suggested the intervention was more effective than placebo. The study also concluded that 8 sessions were enough to show an improvement in static and dynamic balance in this population.

A similar effect was reported in persons with stroke (Young-Shin, Sea-Hyun, Sung-Hee & Kyung-Yoon. 2015). In this study participants were assigned randomly to either a neurofeedback group or a placebo group. Both groups received treatment 3 times per week for 8 weeks. Only the neurofeedback group received feedback based on an analysis of the EEG signal. Dual task performance was tested by an attention demanding task during a 10m walk (Haggard, Cockburn, Cock, Fordham & Wade 2000). During this gait assessment participants had to count backwards from 100 in increments of 7. The number of wrong answers was compared to assess performance and infer an improvement in cognitive ability. There were significant differences between groups and within groups ($p<0.001$) with the neurofeedback group scoring significantly better. The authors concluded that dual task assessment reflects motor- as well as cognitive functioning and is therefore a practical assessment of dynamic balance. Our ability to process information plays an important role in our ability to make postural adjustment and thereby regulate our balance automatically without additional cognitive loading (O'Shea, Morris & Iansek 2002, Young-Shin Lee et al. 2015).

In Barati, Mahmoudi, Frahan & Lofti (2015), 20 male students with a mean age of 21.38 years were randomly assigned to either a neurofeedback or sham group. They received 3 sessions per week for a month and static and dynamic balance was tested before and after the interventions. There was a marked difference between the placebo and intervention group on all the static and dynamic balance measurement using ANOVA repeated measure and a significance level of p,0.05. They therefore concluded that neurofeedback had a positive impact on balance that it can be used as a complimentary training program to enhance performance.

The above studies suggest that neurofeedback may have a positive effect on dynamic postural control during dual task performance.

2.5 Statement of the Problem

It is evident from the literature that there is currently no agreement on the treatment of concussion except that athletes should rest until they are symptom free, and then a graded return-to-play program should be instituted. Since full recovery is crucial to prevent another concussion (and also because repeated concussion can lead to eventual CTE in susceptible individuals) it is imperative to ensure that an athlete has fully recovered before return-to-play is initiated. QEEG has shown to be 96% accurate in identifying concussed athletes. In neurofeedback QEEG is used to help restore patient's EEG to a normal values. There is very limited evidence that neurofeedback can decrease symptoms of Post-Concussion Syndrome more so than cognitive training alone. It has also shown to improve balance, including balance under cognitive loading in other populations with neurological deficits/diagnoses.

Another gap in the literature is the limited assessment for determining return-to-play (RTP). One of the current recommended assessments, the BESS section on the SCAT 5 has been shown to *not be* sensitive after 3 to 5 days for detecting balance impairment and even in the acute phase can only detected balance issues in 1 in 12 concussed athletes (Munia et al. 2017). It is recommended that more complex gait evaluation is included as part of the assessment post-concussion (and possibly to assist with RTP).

It is hypothesized that Neurofeedback can be used as a treatment method to assist concussed athletes to regain their balance quicker and decrease their time to full recovery. This study will also aim to explore relationships between the SCAT 5 (and BESS) and selected gait measures, namely the Functional Gait

Assessment (FGA) and Tandem Gait (with and without loading). If relationships exist between these measures and they are able to detect balance issues currently not detected using BESS alone, this may assist coaches, doctors and researchers to better understand the impact of concussion in athletes.

Chapter 3: Methodology

In this chapter the objectives, measurement instruments, specifics of the intervention and data analysis of the study will be discussed in detail.

3.1 Aim

The primary aim of this study is to determine the effect of neurofeedback on dynamic balance and complex gait with cognitive loading, compared to placebo, in young collegiate adults with concussion. A secondary objective is to compare selected postural control measures with the current SCAT 5 assessment.

3.2 Objectives

The specific objectives are therefore, in a sample of in young collegiate athletes who have sustained a concussion injury, to:

3.2.1 describe the effect of concussion on postural control after concussion (as determined by the Functional Gait Assessment (FGA) and Tandem Gait time (TG) (with and without loading)

3.2.2 determine the effect of neurofeedback on postural control

Hypothesis

H_0 *Neurofeedback has no effect on postural control as measure by FGA and TG with or without cognitive loading*

H_1 *Neurofeedback has a significant impact on functional gait (as determined by the FGA)*

H_2 *Neurofeedback has a significant impact on tandem gait speed (as determined by TG) – without cognitive loading*

H_3 *Neurofeedback has a significant impact on tandem gait speed (as determined by TG) – with cognitive loading*

3.2.3 and to explore relationships between the SCAT 5 and FGA, and TG (with and without cognitive loading)

3.3 Study Design

A double blind pre- to post intervention experimental design was deemed suitable to investigate the effects of neurofeedback in this population. All participants, that met the inclusion, criteria were randomly assigned to either a neurofeedback group or a sham/placebo group. The neurofeedback software was designed by BEE Medic GmbH (Germany) and uses the Neurocybernetics EEG amplifier (www.eeginfo.com). The company provides specially design software that allowed for double blinding in the current study. The software assigns participants randomly to either an intervention or placebo/sham group. This allowed the therapist as well as the participants to be blinded as to who received which intervention.

3.4 Sampling

During the 2015 season, Stellenbosch University Campus Health reported 132 new cases of concussion while participating in a variety of sports namely rugby, cycling, hockey and soccer. In 2016, between March and end of May, there were 69 reported new concussion cases. If the injury occurred during an off-campus match, and the attending doctor diagnosed a concussion, the student is referred to the student health clinic for appropriate assessment. All students that sustained a concussion (Between February and September 2018) were assessed using the SCAT 5, a self-reported questionnaire that collates information on 22 possible symptoms and asks the person to rate the severity of his/her symptoms which allows for a maximum score of 132. A cognitive assessment also known as the Standardized Assessment of Concussion (SAC), a modified BESS test, a SAC-delayed Recall and a Coordination Examination form part of the SCAT 5 (refer to Ch 2).

All patients that recorded a deficit on their SCAT 5 report after 24-hours after injury, were diagnosed as having Post-concussion Syndrome. These patients are followed-up every 2 weeks by Campus Health staff and are typically advised to rest and not participate in any sport. Once all symptoms have cleared, they would be allowed to initiate a graded return-to-play programme.

All students from the University diagnosed with a concussion were asked by the attending doctor to join the study. If they were interested, they contacted the principal investigator and an appointment was made to explain the study and to obtain informed written consent.

3.4.1 Sampling Size

An initial sample size calculation using a 2-sided log rank test determined that a sample size of 82 (41 in the intervention group and 41 in the control group) would be needed, if balance normalized in 20% of the control group and 50% of the treatment group within the intervention period. Schneider et al. (2016) however, found that 20% in their control group and 73% in the treatment group normalized within the intervention period. In this study N=31 and it was therefore deemed appropriate to aim to recruit a similar number of participants for the current study.

3.4.2 Inclusion Criteria

To be included in the study participants had to be:

- male or female
- a student enrolled at Stellenbosch University
- diagnosed with a concussion by the attending doctor

3.4.3 Exclusion Criteria

Students that were unwell or unable to attend the four treatment sessions due to academic or other restraints, were excluded from the study.

There were no other exclusion criteria.

3.5 Procedure

All students who had been diagnosed with concussion by the Stellenbosch University Campus Health doctors were given the researcher's details and requested to contact her if interested in participating in the current study. Once they made contact, the first appointment was scheduled to fit their class schedule.

All study sessions took place at the Stellenbosch High Performance Centre situated at Coetzenburg Sports Centre. The High Performance Centre is a separate enclosed area in the gymnasium, where all sessions took place in private without any interruptions.

During the first sessions participants were given a detailed explanation of the aims of the study, what neurofeedback is, the possible effects and that there were no expected side effects. They were given time to read the informed consent form which was available in English, Afrikaans and isiXhosa [Appendix B]

Once informed consent was given and they had no further questions, baseline testing commenced.

3.5.1. Instrumentation

The SCAT 5, the FGA, and the TG, with and without loading, was used to describe the effect concussion had on postural control and to record concussion symptoms. These all served as baseline measured describing the study sample.

3.5.1.1 Sport Concussion Assessment Tool (SCAT) 5

The Sport Concussion Assessment Tool (or SCAT 5) is an assessment tool published by the Concussion in Sport Group in 2017 after the International Conference on Concussion in sport was held in Berlin in

October 2016. Although there is little description of the psychometric properties of the SCAT 5 (Mrazik, Lenchyshyn, Broza , Naidu & Lebrun (2017), the SCAT is considered the most useful when assessing persons post-concussion. It utilises a self-reporting system where athletes rate their own symptoms of concussion as well as the symptom severity. The SCAT also uses the Balance Error Scoring System (BESS) test as a way to assess balance (McCrory et al. 2017). This test uses different stances e.g. double leg stance (DLS), single leg stance (SLS) and tandem stance on a both firm and foam surfaces with the person standing with hands on the hips. This stance must be maintained for 20s with the eyes closed. Points are allocated for errors, for example when opening the eyes, lifting the hands off the hips, in 1-leg stance moving the hip in more than 30 degrees of hip abduction to maintain balance, toes or heels losing contact with the surface or giving a step to maintain balance.

Valovich (2006) used a quasi-experimental, repeated-measures design to test re-test reliability of the BESS in concussed athletes. Using Pearson product moment correlation® a score of 0.7 was found suggesting the BESS is moderately reliable for testing balance in individuals/athletes with concussion.

The SCAT 5 was completed by an attending medical doctor at Campus Health.

3.5.1.2 Functional Gait Assessment (FGA) [Appendix C]

The FGA is a standardise tool developed to assess postural stability during different walking tasks (Walker et al.2007) by Wrisley et al. 2004) as an enhancement of the DGI. Leddy et al (2011) compared the FGA to the Berg Balance Scale (BBS) that is considered the reference standard for determination of postural control and therefore fall risk and found a good correlation r=0.91. Therefore, this measure was selected to describe functional gait following concussion and infer postural control also because it incorporates different activities that are paramount is sport. It consists of 10 gait activities that are easy to be administered in a clinical setting Wrisley et al. (2004) (see Appendix C)

The FGA has good reliability, internal consistency and is a valid measure of functional gait (Wrisley et al. 2014). The latter study showed good intra-rater reliability with an Interclass Correlation Coefficient (ICC) of 0.83. The inter-rater reliability was also good with an ICC of 0.84. Internal consistency was determined using Cronbach alpha and scored 0.81 for trial 1 and 0.77 for trial 2 and across both trial 0.79 suggestion moderate to good internal consistency.

For the current study a marked track of 6m with a width of 30.48cm was measured out to be used in all testing [Figure 1]. At every 1.5m it was marked with a red line and at the beginning and end points it was marked with white lines including the outline of the of the track. Five standard shoe boxes were used to set up as obstacles at every red line.

Figure 1: Track Used for the Functional Gait Assessment.

Participants were asked to remove their shoes and to perform the following once in the same order:

1. Walk on a level surface (participants were asked to walk the track at their normal speed).
2. Walk slowly and then fast (participants were asked to change their speed at each red line).
3. Walk with horizontal head turns (participants were asked to turn their head left and back at the first red line, and then to the right at the second).
4. Walk with vertical head turns (participants were asked to look up at each red line and then down at the next).
5. Walk and do pivot turns (change direction) (participants were asked to make a full turn at each red line and come to a full stop before continuing).
6. Step over obstacles (shoe boxes as placed at each red line, 1 box [1 at the first red line], 2 boxes on top of another [at the second red line], and 1 [on the third red line]).
7. Walk with a narrow support base (TG) (participants were asked to walk with heel touching the toe to the other end).
8. Walk with eyes closed (participants were asked to complete the track at normal pace with their eyes closed).

9. Walk backwards (participants were asked to complete the track backwards).
10. Up and down steps* (participants were taken to the steps and asked to climb down and up again).

*Climbing stairs is also part of the FGA and points are awarded for climbing stairs with alternating feet and if they can do so without holding on to the hand rail. In the gymnasium a stair case (15 steps) was used with a regular hand rail to evaluate balance during stair climbing. Their time to complete each of the 10 steps were measured with a stopwatch and recorded on the data collection sheet. The quality of the movement was recorded as well.

The quality of the movements were recorded if a participant:

1. stepped out of the track
2. lifted up their arms to brace themselves and thereby aid their balance
3. slowed down to complete a portion of the track for instance to clear the obstacles or to turn their heads
4. had an increased body sway without putting their hands out; or
5. complained of dizziness.

The FGA would score 3/3 if they can complete 10 steps but if the person had increased body sway, slowed down, or they had to lift up their arms to brace themselves this was noted.

The FGA were used at baseline (either on the same day as the SCAT 5 or within 48hrs) and before each of the 4 intervention sessions.

3.5.1.3 Tandem Gait (with and without cognitive loading)

Tandem Gait (TG) is a considered a complex gait whereby the toe of the back foot must touch the heel of the front foot at every and records the time a participant can walk heel-to-toe first without and then repeat it while reciting backwards in increments of 7, 8, 6 or 4 from 100(Howell et al 2017) along a 6m track. Schneider et al (2013) used this measure to determine the difference between concussed and non-concussed athletes and found it a suitable measure able to detect a significant difference between these two groups. Oldham et al (2018) also demonstrated that Tandem Gait has a sensitivity of 0.67 (true positive) and specificity of 0.74 (true negative). Meaning that Tandem Gait can distinguish between concussed and non-concussed athletes in the population by identifying the concussed athletes (true positive) and identifying the non-concussed athletes (true negative). Yang et al. (2016) demonstrated that TG measurements also have good to excellent reliability (ICC=0.80-0.95).

In this study the 6m FGA track was used to record TG with and without cognitive loading. This was in line with Schneider (2013) that also used a 6 m track although 0.5 cm wider. As a pilot, to establish norms we tested 20 non-concussed students (see results Chapter 4 table 15). The non-concussed students' results were in line with Schneider et al (2013) and Howell et al (2017)

3.5.2 Neurofeedback Intervention

A 2-channel EEG amplifier with 32bit resolution, 165 dB dynamic range with 8 peripheral input channels, 5V, 24-bit resolution each and 8 outputs for e.g. tactile feedback was used (BEE medic GmbH). The software that was used is the Cygnet version2.0 developed by NeuroCybernetics, specifically for the abovementioned EEG amplifier.

Figure 2: Neurofeedback Amplifier

The software supplied had a sham/pseudo module included that enabled a random selection of who received actual EEG feedback or who received a sham feedback without the knowledge of the therapist. All participants were entered in the program as a number and the program then randomly assigned the participants to a group. The sham module hid the EEG trace the moment the animation started. The neurofeedback group received feedback from their own EEG signal while the placebo group received feedback on a simulated EEG signal. The therapist was therefore not able to determine which participant received actual feedback, as both had a similar appearance. At the interim analysis and after the completion of the testing of the final participant BEE Medic was informed and provided the code in order to unlock the group assignment of the participants.

Different program can be selected in the software to give feedback to the participant. In this study we chosen to use a popular sitcom (Scrubs season 1/ episode 1-4) as background to the feedback. Participants were informed that as they watch the sitcom black dots will obscure the screen or the screen will flicker grey (Figure 5). The participants had to try and clear the screen from any black dots or endeavour to have no grey screen. The black dots appear as an indication that the frequencies are too slow (high Beta and Alpha waves) whereas the grey screen indication frequencies need to be inhibit (Theta waves) . Audio feedback was given via noise cancelling head phones. The quality of the audio also depend in the EEG frequencies'

The program was loaded on an Acer Spin 5 Intel Core i5-8250U 13.3 convertible notebook with an extra high resolution screen attached to it.

Four Silver chloride electrodes (Figure 3) were used which had superior performance for bio potential measurements from BEE medic. The electrodes were attached in position on the scalp via Ten20 Paste that is easy to remove.

Figure 3: Electrodes and Ten20 Paste

3.5.2.1 Procedure for Intervention

All participants were seated in a comfortable chair in front if a high resolution screen with noise cancelling ear phones on. Electrode placement was conducted according to the international standard 10/20 placements for EEG (Oostenveld et al. 2001). One control electrode was placed at Nz [Figure 4]. In the first 10 min electrodes were placed at T3 and T4 (over the vestibular system) [Figure 4] and the next 10 min the same electrodes were placed over O1 and O2, which was over the cerebellum.

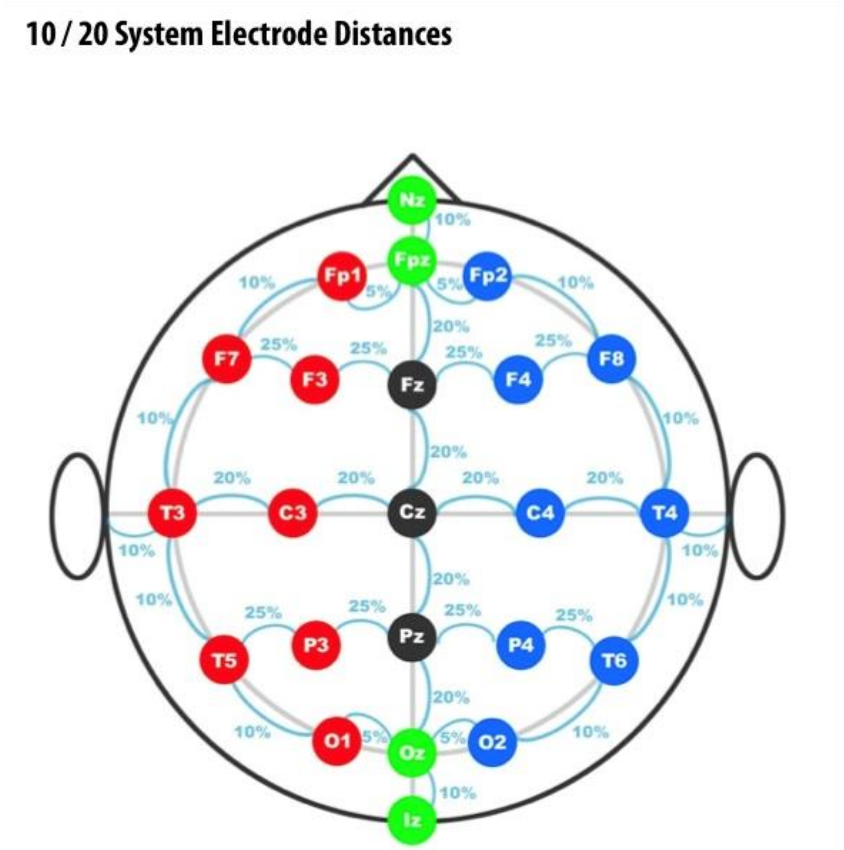

Figure 4: Electrode Placement According to International standard 10/20 for the Electroencephalogram.

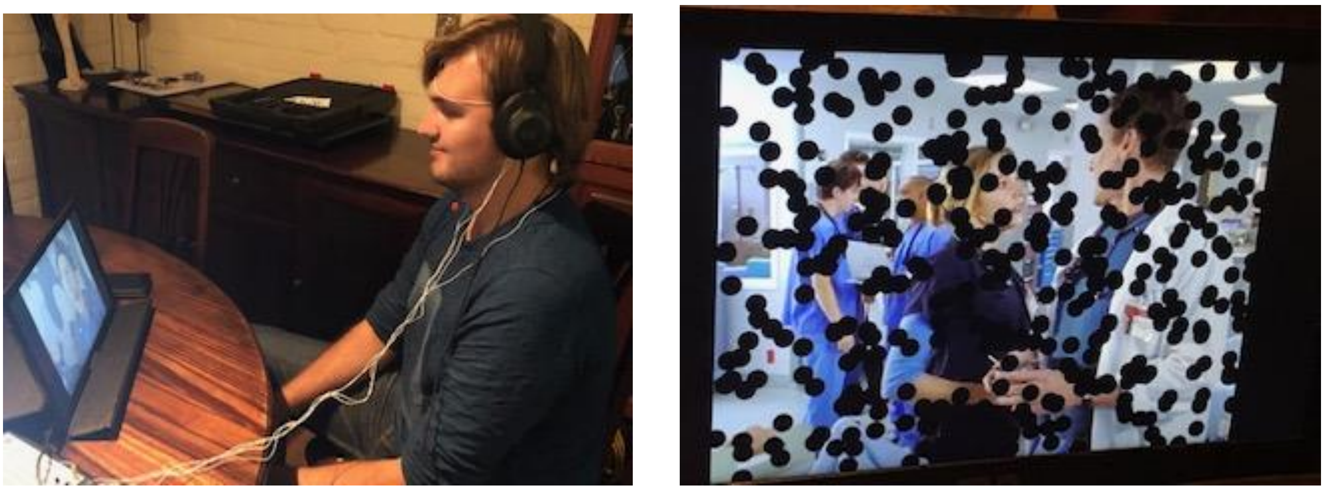

Figure 5: Model receiving Neurofeedback and Screen seen by the model during Feedback.

Participants received 20 min of feedback, 10 min on each electrode placement. Participants received the same instructions during the intervention. They were instructed to relax and watch the television series. The animation itself consisted of dots obscuring the images of episodes of a popular TV series. They had to pay attention. The more focused they were, the less dots would appear on the screen and the better the audio would be. If they lost focus or became too tense the screen would have gone blank for a moment and then they attempt to regain their focus so that the picture and audio would clarify. Participants received 4 sessions at a minimum of 2 days in-between over a period of 2 weeks. The sessions lasted about half an hour.

Figure 6 represents the process followed at each intervention session. All participants were asked to remove their shoes and socks. They were then tested on the FGA, then the TG speed without loading was performed and then TG speed with loading. They were then seated comfortably and electrodes were attached at T3-T4 and they received 10 min of feedback. After 10 min electrodes were moved to O1-O2 and they received another 10 min of feedback. The process took about 30 min. This process was followed for each session.

Figure 6: Process followed at each session.

3.6 Ethical Considerations

The Health Research Ethics committee granted institutional ethics approval (ethics number S16/10/228) (Appendix A). Permission was also obtained from the medical staff at Stellenbosch Campus Health as well as from Stellenbosch University Institutional Planning.

All participants gave written consent [Appendix B] after the study procedures were explained and before any assessment started. Participants were also informed of their right to withdraw at any time during the study. After informed consent was given the participant received a code that was only known to the principal investigator. All data for the study were stored under the code including their SCAT data received from the Campus Health Services. All raw data were stored by the principal investigator in a locked safe and only the participant's code was entered into the neurofeedback software. Thus, the computer assigned participants to the intervention or placebo group and this was only known after the completion of the study. Once the study was completed the code for the assignment of the participants was received from Germany.

All testing and intervention took place at the Stellenbosch High Performace Centre in the Innovation Centre that secluded and ensured participants' privacy.

After completing the 4 sessions, participants were remunerated for their time and effort in participating in the study.

3.8 Data Processing and Analysis

All test results were entered onto an Excel spreadsheet Stata® Version 14 was used to analyse the data with the help of a statistician[1]. Level of significance was set at p-value of < or = 0.05. Due to the small sample size as well as the fact that the data was not normally distributed, the categorical demographic variables between groups were compared with Pearson's chi Square test (non-parametric). Since the number of cells with an expected count of >5 is <=20% the 2 sided asymptomatic significance p was calculated. If the number of a cell with an expected count <5 is> 20% then the Fisher exact test p value was calculated.

The correlation for the whole sample between the SCAT 5, number of Errors on the BESS, the total scored on the FGA, the time measure for Tandem Gait with and without loading was calculated with a Pearson's correlation and a 2-sided asymptomatic significance p was calculated. P value of <= 0.05 was regarded as a strong correlation and above that was considered weak or moderate correlation. For these measures gender differences were also explored using a Spearman's rho correlation. A p-value of 0.05 was considered a strong correlation and anything below that, a moderate to weak correlation.

In order to assess the change in the FGA, TG with and without loading, the median and ranges for each test that was measured for each session are reported. Relationships between these variables and the differences between the treatment and placebo groups where determined using Friedman two way analysis of rank which is an alternative to one-way ANOVA and used with repeated measure (it is used to test differences within groups when the variable is ordinal).

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[1] Tonya Esterhuizen from Stellenbosch University Centre for Biostatistics

Chapter 4 Results

Results are reported below in line with the objectives set out in Chapter 3.

4.1 Description of the Sample

Although the initial aim was to recruit at least 30 participants, recruitment was challenging. Nineteen participants were however recruited into the study of which 8 were randomly assigned to the treatment group and 11 to the placebo group. One in each group left the study 1 after one session and one left after 2 sessions, also from the placebo group. Final sample size N=16 with 7 participants randomly assigned to the intervention group and 9 in the placebo group.

Due to a serious drought experienced in the Western Cape, rugby matches were postponed until later in the year, however most other sporting activities still took place. Despite this, half of the sample (8/16) came from rugby but other sports such as ice-skating and gymnastics were also represented (Table 1).

Table 1: Sample Demographics (n=16)

		Treatment group		Placebo		P (dif btw groups)
		n	Column N %	Count	Column N %	
Gender	Male	2	28.6%	6	66.7%	.131
	Female	5	71.4%	3	33.3%	
Sport:	Rugby	2	28.6%	6	66.7%	.246
	Soccer	1	14.3%	2	22.2%	
	Hockey	1	14.3%	0	0.0%	
	Other	3	42.9%	1	11.1%	
Previous concussion:	Yes	3	42.9%	3	33.3%	.696
	No	4	57.1%	6	66.7%	

Table 3 describes the baseline measurements of the SCAT 5 BESS, FGA and Tandem Time (with and without cognitive loading). The treatment group reported a higher number of symptoms and rated their symptoms as more severe when compared to the placebo group. They also scored more errors on the BESS. The intervention group took longer to complete the TG time test without cognitive load, while the placebo group took longer with cognitive loading. None of these differences between the 2 groups however were significant (Table 2). There was a significant correlation between the BESS and the first FGA with a p=.034

Table 2: Baseline scores for SCAT 5, BESS, FGA and Tandem Time (with and without loading) N=16

Outcome variables	Treatment group	Placebo group	
	Median (range)	Median (range)	P-value
Number of symptoms* (/22)	17 (14)	12 (21)	.109
Severity rating of symptoms* (/132)	82 (70)	17(12)	.199
Total number of errors on BESS (/3)	2 (5)	1 (3)	.579
Total for the FGA (/30)	24 (13)	22(4)	.546
Tandem Gait Time (without cognitive loading) (s)	18.89 (28,33)	12.76 (11,04)	.098
Tandem Gait Time (with cognitive loading) (s)	27.15 (29,86)	40.87 (50,17)	.439

* Sport Concussion Assessment Tool variables; BESS: Balance Error Scoring System; FGA: Functional Gait Assessment; s: seconds

4.2 Effect of Concussion on Postural Control as Determined by the Functional Gait assessment and Tandem Gait Time (with and without Cognitive Loading)

To describe the effect of concussion on postural control it was deemed appropriate to describe it within the context of the SCAT 5 scores (number of symptoms and reported severity of symptom scores). Gender differences were also explored.

4.2.1 Correlation between the SCAT 5 (no of symptoms) and Functional Gait Assessment (FGA)

Pearson's correlation was used to ascertain if there was a correlation between the number of symptoms and the FGA as measured at baseline. The correlation was negative but not significant (p=.070) (Table 3)

Table 3: Correlation between SCAT 5 (no of symptoms) and the FGA. (N=16)

		No of symptoms	FGA
Number of symptoms total /22 vs Total FGA / 30	Pearson's correlation	1	-.464
	Sig. (2 Tailed)		.070
	N	16	16

4.2.1.1 Gender differences:

There was no significant correlation between the number of reported symptoms and the FGA scores when exploring gender differences (p =.988 for males and .119 for females) (Table 4)

Table 4: Correlation between SCAT 5 (no of symptoms) and the FGA: gender comparison. (N=16)

Spearman's rho Correlation				
		Number of symptoms	**Total FGA**	**Gender**
Male: Number of Symptoms vs Total FGA /30	Correlation Coefficient	1.000		
	Sig. 2		.988	
	N	8	8	8
Female: Number of Symptoms vs Total FGA / 30	Correlation Coefficient	1.000	-.596	
	Sig (2 Tailed)		.119	
	N	8	8	8

4.2.2 Correlation between the SCAT 5 (severity of symptoms) and the FGA

There was no correlation found between the severity of symptoms and the FGA (p=.078) (Table 5)

Table 5: Correlation between SCAT 5 (severity of symptoms) and the FGA . (N=16)

		Severity of symptoms /132	FGA
Severity of symptoms total /132 vs Total FGA /30	Pearson's correlation	1	-.443
	Sig. (2 Tailed)		.078
	N	16	

4.2.2.1 Gender differences

There was no significant correlation between severity of symptoms and FGA when exploring gender differences (Table 6).

Table 6: Correlation between SCAT 5 (severity of symptoms) and FGA: gender comparison. (N=16)

Spearman's rho Correlation				
		Severity of symptoms	**Total FGA**	**Gender**
Male: Severity of Symptoms vs Total FGA /30	Correlation Coefficient	1.000	.099	
	Sig. 2		.816	
	N	8	8	8
Female: Severity of Symptoms vs Total FGA /30	Correlation Coefficient	1.000	-.590	
	Sig (2 Tailed)		.123	
	N	8	8	8

4.2.3 Correlation between the SCAT 5 (no of symptoms) and Tandem Time (without loading)

The Pearson's correlation was used to assess the correlation between the no of symptoms and Tandem Time (s) without loading. A significant correlation with p=.043 was found (Table 7). Participants who reported a higher number of symptoms are scored lower on the Tandem Time without loading test.

Table 7: Correlation between SCAT 5 (no of symptoms) and Tandem Time (s). (N=16)

		No of symptoms	Tandem Time (s)
Number of symptoms total /22 vs Tandem Time (s)	Pearson's correlation	1	.512
	Sig. (2 Tailed)		.043
	N	16	16

*s= seconds

4.2.3.1 Gender differences

There was no significant correlation between the SCAT 5 (number of symptoms) and Tandem Time without loading when divided according to gender (Table 8).

Table 8: Comparison between SCAT 5 (no of symptoms) compared to Tandem time(s) without loading: gender comparison. (N=16).

Spearman's rho correlation				
		Number of Symptoms	Tandem Time (s) (without loading)	Gender
Male: Number of Symptoms vs Time to complete (s)	Correlation Coefficient	1.000	-.455	
	Sig. 2		.257	
	N	8	8	8
Female: Number of Symptoms vs Time to complete (s)	Correlation Coefficient	1.000	.405	
	Sig (2 Tailed)	.	.319	
	N	8	8	8

4.2.4 Correlation between the SCAT 5 (severity of symptoms) and Tandem Time (s) without loading

For this measurement a weak correlation was found with p = 0.53 (Table 9). The more severe participants rated their symptoms, the longer they took to complete the Tandem time without loading test.

Table9: Correlation between SCAT 5 (Severity of symptoms) and Tandem time without loading. (N=16)

		Severity of symptoms /132	Tandem Time (s)
Severity of symptoms total /132 vs Tandem Time(s)	Pearson's correlation	1	.419
	Sig. (2 Tailed)		.053
	N	16	16

4.2.4.1 Gender differences

For this measurement there was no significant correlation was found p= .531.There was no significant correlation between severity of symptoms and the TG according to gender differences (Table 10).

Table 10: Comparison between SCAT 5 (severity of symptoms) and Tandem time (without loading): gender comparison.(N=16).

Spearman's rho Correlation				
		Severity of Symptoms	Time to Complete Tandem (s)	Gender
Male: Severity of Symptoms vs Tandem Time (s)	Correlation Coefficient	1.000	-.262	
	Sig. 2		.531	
	N	8	8	8
Female: Severity of Symptoms vs Tandem Time (s)	Correlation Coefficient	1.000	.381	
	Sig (2 Tailed)	.	.352	
	N	8	8	8

4.2.5 Correlation between the SCAT 5 (no of symptoms) and Tandem Time (with loading)

For this measurement no significant correlation as found with p=.310 [Table 11]

Table 11: Correlation between SCAT 5 (no of symptoms and tandem time (s) with loading. (N=16)

		No of symptoms	Tandem Time (s)with loading
No of symptoms total /22 vs Tandem Time (s)	Pearson's correlation	1	-.271
	Sig. (2 Tailed)		.310
	N	16	16

4.2.5.1 Correlation between SCAT 5 number of symptoms and Tandem Time(s) with loading: gender comparison

There was a significant correlation found between the number of symptoms and Tandem Time (s) with loading for male students with p=.011 (Table 12). There was a negative correlation meaning that as number of symptoms increase the Tandem Time with loading decreased. There was however no significant correlation found between number of symptoms and Tandem Time for female participants. Post hoc analysis however, suggests a positive trend meaning that as their number of symptoms increase so did the Tandem Time.

Table 12: Correlation between SCAT 5 (no of symptoms) and tandem time (with loading): gender comparison. (N=16)

Spearman's rho Correlation				
		No of Symptoms	**Time to Complete Tandem (s) With Loading**	**Gender**
Male: Number of Symptoms vs Tandem Time with loading (s)	Correlation Coefficient	1.000	-.826	
	Sig. 2		**.011**	
Female: Number of Symptoms vs Tandem Time with loading (s)	Correlation Coefficient	1.000	.442	
	Sig (2 Tailed)	.	.273	

4.2.6 Correlation between SCAT 5 (severity of symptoms) and Tandem Time (s) with loading

There was no correlation between reported severity of symptoms and the time to complete the Tandem speed test (s) with loading (p=.572) (Table 13).

Table 13: Number of Symptoms and tandem time (s) with loading. (N=16)

		Severity of symptoms	Tandem Time (s)with loading
Severity of symptoms total /132 vs Tandem Time with loading (s)	Pearson's correlation	1	-.153
	Sig. (2 Tailed)		.572
	N	16	16

4.2.6.1 Correlation between SCAT 5 (severity of symptoms) and Tandem Time (s): gender comparisons

A significant moderate correlation was found between severity of symptoms compared to TG with loading for the male participates (Table 14) **(p=.028).** This relationship is negative meaning that as the severity of symptoms increase the TG with loading decreased. This was unexpected and is discussed further in the next chapter. For females, a positive trend was found during post hoc analysis, meaning that as their reported severity of symptoms increased, the time to complete the TG time increased.

Table 14: Severity of symptoms and tandem time (s) with loading: gender differences. (N=16)

Spearman's rho Correlation				
		Severity of Symptoms	**Time to Complete Tandem (s) With Loading**	**Gender**
Male: Severity of Symptoms vs Tandem Time (with loading) (s)	Correlation Coefficient	1.000	-.762	
	Sig. 2		**.028**	
	N	8	8	8
Female: Severity of Symptoms vs Tandem Time (with loading (s)	Correlation Coefficient	1.000	.357	
	Sig (2 Tailed)	.	.385	
	N	8	8	8

4.3 Effect of Neurofeedback on post-concussion recovery versus placebo

The aim of the study was to ascertain if a neurofeedback will assist concussed athletes to regain the balance quicker that a placebo group. This was measured at 4 time points with the FGA, tandem TG with and without loading.

4.3.1.Pilot study to determine norms for the amended TG test:

Methodology: A group of 20 non-concussed students were tested on the FGA track and their time to complete the track with Tandem Gait (with and without cognitive loading) was recorded. Table 1 reports on the mean time taken to complete the test. These students had the same age distribution as the sample participants as well as gender distribution.

Table 15: Time scored by non-concussed participants for 6m Tandem Gait test (with and without loading) (N=20)

Non concussed students	Mean Time (s)	SD
Tandem Time without loading (Average)	11,08 s	1.99
Tandem Time with Loading (Average)	17,69 s	4.12

*s= seconds, SD = standard deviation

4.3.2 Effect of neurofeedback on postural control as determined by FGA

Table 16 reports on the scores for FGA at each time point. Although no significant difference was found between the treatment and placebo groups (p =.108), both groups showed significant improvement from pre to post (placebo group **p=.014** and treatment group **p=.014**).

Table 16: Change over 4 sessions in treatment and placebo group as measured by FGA

			First FGA Total /30	Second FGA Total /30	Third FGA total /30	Fourth FGA Total /30
Treatment group	N	Valid	7	6	6	6
	Median (Range)		24 (13)	24 (7)	27 (4)	30 (3)
	Absolute min.		14	20	23	27
	Absolute max.		27	27	27	30
Placebo group	N	Valid	9	9	8	8
	Median (Range)		22 (4)	24(7)	23.5(5)	26.5 (9)
	Absolute min.		21	19	22	21
	Absolute max.		25	26	27	30

FGA: Functional Gait Assessment; max: maximum; min: minimum

4.3.3 Effect of neurofeedback on postural control as determined by Tandem Time (without loading)

For this outcome measure the results show that the treatment group responded significantly better than the placebo group **(p=.008)** (Table 17) and the null hypothesis was therefore rejected. Both groups improved from pre to post with placebo group p=.34 and the treatment group p=.14

Table 17: Change over 4 sessions for treatment and placebo group sessions measured by tandem Time (s)without loading .

			First Tandem time (s)	Second tandem time (s)	Third tandem time(s)	Fourth tandem time(s)
Treatment group	N	Valid	7	6	6	6
	Median(range)		18,9 (18,31)	13,6(15,5)	10,7(11,38)	9,83(10,19)
	Absolute min		11,19	10,25	9,45	8,36
	Absolute max		29,52	26,00	20,83	18,55
Placebo	N	Valid	9	9	8	8
	Median(range)		12,7(11,04)	12,1(11,69)	12,0(11,74)	11,5(14,41)
	Absolute min		8.92	8.00	8.72	8.49
	Absolute max		19.96	19.69	20.46	22.90

max: maximum; min: minimum

4.3.4 The effect of neurofeedback on postural control as measured by TG (with loading)

Table 18 reports on the measurements as recorded for each of the 4 time points. No significant difference was found from pre to post between the two groups (p=.282). For the treatment group however a significant difference from pre to post (**p=.014**) was found, compared to the placebo group where no significant difference was found (p=.157) within the group.

Table 18: Change over 4 sessions in treatment and placebo group as measured by TG (s) with loading

			First Tandem time (s)	Second time (s)	Third time (s)	Fourth time (s)
Treatment group	N	Valid	7	6	6	6
	Median (Range)		27,1(29,86)	24,8(34)	24,8(16,9)	18,3(11,2)
	Absolute min		19.33	15.0	12.5	11.06
	Absolute max		49.19	48.9	29.4	22.35
Placebo	N	Valid	9	9	8	8
	Median (Range)		40.8(50,2)	44,2(63,8)	41,3(34,5)	33,4(30,5)
	Absolute min		11.43	14.8	16.8	14.10
	Absolute max		61.60	78.6	51.3	44.68

***max: maximum; min: minimum*.**

max: maximum; min: minimum

4.4. Summary of return-to-play (RTP) and postural control as measured by FGA, TG with and without loading.

At each session participants was asked if they had already returned to their sport. If they have then that session's FGA, TG speed with and without loading was marked and are reported below in Table 19. In some cases that was half way through the study and in some cases at the end of 4 sessions of treatment. Three of the 16 participants have not returned to their sport after 4 treatment sessions.

Table 19: FGA, Tandem Time with and without loading at the time of participants return-to-sport

		FGA	Tandem speed (s) without loading	Tandem speed (s) with loading
Did not return-to-sport	Median	25,33	11,50 (3,95)	31,89 (33,71)
	Std deviation	2,88	2,12	16,06
	Minimum	22	9,98	18,67
	Maximum	27	13,93	49,77
Did return-to-sport	Median	24,46	13,32 (21,52)	33,26 (40,61)
	Std deviation	3,75	6,14	13,61
	Minimum	17	8,00	14,96
	Maximum	30	29,52	55,57

Chapter 5 Discussion:

This study aimed to determine whether an intervention, namely Neurofeedback can shorten the recovery period following sport related concussion. Especially, when considering the advances that has been made in the field and its effect on post-concussion syndrome. This study also utilised and explored different outcome measures to describe postural control in collegiate athletes following concussion injury as it is proposed that assessment of dynamic balance and gait should be included in the assessment of the readiness to return-to-play (Parker et al. 2008, Howell et al. 2015). Functional Gait Assessment (FGA) and Tandem Gait (TG) (with and without cognitive loading) were used to track recovery of gait and balance. From the results it seems that neurofeedback can affect gait and balance function and contribute to recovery.

How the above additional measures compared to the SCAT 5 (BESS) scores was also investigated. Although no correlation between SCAT 5 (and BESS) scores, FGA and TG (with and without loading) was found, it was evident that when comparing FGA scores with number of symptoms reported as well as severity of symptoms reported, males significantly under- reported when compared to females.

This chapter will discuss the sample and findings in more detail and report on the challenges experienced during the study periods. The chapter ends with a description of the limitations of this study

5.1 Sample demographics

In our initial sample size calculation it was determined that 80 participants would be needed (40 in each group) to explore the effect of neurofeedback on selected gait measures (refer to chapter 3 p31). However other placebo-controlled neurofeedback studies used smaller sample sizes and were able to detect significant change (May et al. 2013). It was therefore deemed appropriate to use a similar sample size and our study aimed to recruit 30 participants. Preliminary analysis would be conducted after these participants completed the study period and if results indicated the intervention may have an effect, recruitment of additional participants would be considered, if time allowed.

Unfortunately field sport matches were cancelled or postponed due to a severe draught experienced in the Western Cape which resulted in a decline in the number of concussions seen at the Campus Health. Recruitment started at the start of the 2018 academic year and was stopped when the student's final exams started (which coincided with the proposed end of data collection). Only 18 participants had completed the study at this point in time. Two student were lost to follow-up, one student left to return home only to return to his study in the following year and the other left for reasons unknown. The final sample size was 16 who were randomly assigned to one of two groups- nine ended up in the placebo/controlled group and seven in the intervention/ neurofeedback group.

According to Harmon et al (2013) concussion occurs in all sport but the highest incidence of sport related concussion is found in football, rugby, hockey, soccer and then basketball. Despite rugby matches being postponed, 50% of the sample came from this sport, which also included one female player. Both groups were fairly equally represented in terms of sporting code, general demographics and baseline characteristics and history of previous concussions (refer to Table 2 Chapter 4).

History of a previous concussion was also investigated and six of the current participants reported one previous concussion. Despite the knowledge that repeated concussion may have an accumulative effect (Saigal et al. 2014), the effect of this on the outcomes of the measures used in this study were not further explored due to the small sample size.

Even though the sample size was small, it is not clear how representative the current sample is of the general collegiate population at Stellenbosch University or even wider. Although randomisation into intervention and placebo groups showed that the two groups were not different regarding baseline measurements, the sample was not randomly selected from a larger database. All new cases arriving at Campus Health were invited to join the study. The baseline measurements were are not normally distributed suggesting large variation within the small group. Confidence intervals may have assisted in determining level of generalisability but this was not done due to the small sample size.

5.2: The Effect of concussion on postural control (FGA and TG)

Guskiewicz et al. (2011) and Willer et al. (2016) both reported that testing postural control provides an ideal model to assess the effect of concussion. The results of our study support this recommendation. None of the participants scored within the norms for the measures used suggesting gait and balance are affected following concussion. Oldham et al (2018) suggest that static balance like it is measured using the BESS part of the SCAT 5 is not sensitive enough to detect impairments in dynamic balance. Buckley et al. (2016) found that BESS sensitivity was unacceptable low and with was unable to detect recovery even with repeat measures. It is important to remember that most sport require dynamic balance with head turns, avoiding obstacles and complex gait at an increase speed. As such researchers such as Murray et al (2016) propose that postural control in sport should rather be measured not by static postural stability, but rather using functional measures of postural control utilising dual task performance. Alalaheen et al. (2016) also found that a change of more than 0.21m/s in gait speed is indicative of balance problems in athletes with concussion. It was therefore for these reasons that the current study selected the FGA and the TG outcome measures.

The FGA measure incorporates head turns, stepping over obstacles, walking with eyes closed, pivot turns and tandem gait, with and without cognitive loading while walking 6m on a level surface. Normative values for gait speed as described by Power et al. (2013) suggest that males walk a self-selected speed of 1.35m/s and females 1.24m/s which means that males take 4.4s to complete a 6m track while females will take an average of 4,8s. In the current study males posted a mean time of 4.1s over the 6 m track and the female students a mean time of 5.83s. These findings are very similar to those reported in Alalaheen et al. (2016)'s study which suggested that gait speed was more affected in females than in males with concussion.

This difference found between males and females was similar on the SCAT 5 in which females reported symptoms and severity of symptoms significantly more than their male counterparts. Although the males in the current study walked faster than predicted, they still slowed down in order to compensate for poor balance of the improvement in their TG time over 4 sessions is considered. A significant correlation was still found between symptoms and severity of symptoms for the group and their time taken to complete the FGA 6m track. This confirms that after concussion athletes tend to have to slow down to compensate for problems related to complex gait i.e. balance demands.

5.2.1 Correlation between SCAT 5 (BESS) and FGA

All of the participants first SCAT 5 was recorded within 1 day of the concussion injury. Unfortunately, it was not possible to record the gait and balance performance on the same day as the SCAT 5 was recorded. The average time between these measurements was 5.5 days, ranging between 1 and 11 days. Because of the small sample size all participant data was included in these analyses although spontaneous resolution could have occurred in this period. Despite this we continued to explore relationships between these variables and measurements.

The first analysis we conducted was to see whether any correlation exist between the BESS scores and the rest of the SCAT 5 scores, namely number of symptoms and severity of symptoms reported. No significant correlation was found. Similarly no literature to suggest that with more reported symptoms and higher severity rating that BESS scores increase. This was unexpected as several studies have shown that the BESS is sensitive to detect balance problems within 3 days of sustaining concussion (Valovich 2006; Change 2014; Murray 2014; Mcdevitt 2016). The SCAT 5 was recorded 1 day after the athlete sustained a concussion. Innes (2018) studied the correlation between self-report symptoms and the BESS. In all of the cases the SCAT was recorded between 1-2 days after the concussion except in one case. Although the SCAT protocol was adhere to the BESS did not pick up postural deficits. This could be because it is a static balance test and not dynamic test and that postural deficits manifest itself in gait more than in static balance. It however, raises concern about the sensitivity of the BESS to identify postural deficits even within 1-2 days after concussion. Buckley et al. (2016) argues that static balance measurements limit the assessment of the sensory part of postural control and ignores the motor and cognitive (dynamic and dual task) part of postural control.

The second analysis was between the BESS scores and the FGA. The BESS records the number of errors out of 30 and a person with perfect balance should have 0/30. On the FGA however, a perfect score is 30/30. A negative correlation was therefore expected because the more errors the participants have on the BESS the lower the FGA score should have been. This was not the case though in the current study. A significant positive correlation was found between the errors scored on the BESS and the FGA (p=.034). One reason we propose for this is that the BESS measures static balance whereas the FGA measure dynamic balance which include stepping over obstacles, changing speed, head turns, walking with eyes closed and tandem gait.

Given that balance may be affected as a result of concussion injury, these results confirm the literature recommendations that recovery of postural control in sport related concussion could be measured using dynamic and complex gait measurements.

5.2.2 Correlation between SCAT 5 (no. of symptoms and the severity of symptoms reported) and FGA

Most of the current available literature investigated the reliability of FGA in detecting postural decline in patients with vestibular disorders (Wrisley et al. 2014, Yang et al 2016) as well as FGA as a measurement of recovery after concussion (Schneider et al 2016) None of these studies however explored whether any relationships exist between the number of reported symptoms, or the severity of symptoms, and the FGA. Inness (2018) compared the self-report balance disturbance (as determined on the SCAT 3) with performance based balance. The author used a static balance assessment (BESS and centre of pressure on force plate) and found no clear relationship between static balance and self-reported symptoms.

In the current study a weak correlation was found between reported symptoms and the FGA scores but due to the small sample size this was not significant. As expected, the relationship was negative suggesting that as the number of symptoms increase the FGA scores decrease suggesting that this relationship is worth exploring further. It is also important to take into consideration that the FGA was measure between 7-10 day after the concussion and therefore one would expect that some spontaneous recovery would have taken place. If testing of the FGA was done on the same day as the SCAT 5 a stronger relationship might have been shown.

Lovell et al. (2006) also tried to determine whether differences exist between males and females when self-reporting symptoms following concussion. The authors collated data from 1391 male athletes and 355 female athletes using the Post-Concussion Scale (PCS). The PCS is a 22 item scale that measures symptoms as well as their severity in the acute phase after concussion. It also utilise self-report scale. The study confirmed the findings of the current study in that female athletes tend to report more symptoms than males after a sustaining a concussion. Although no significant correlation between self-reported number of symptoms and FGA scores was found in the current study, when exploring this relationship, in females a negative correlation was found, albeit it again not significant. Post-hoc analysis however does indicate that this trend would reach a level of significance ($p<0.05$) should the sample have been larger.

Analysis of scores regarding self-reported severity of symptoms and the FGA also showed a negative moderate negative correlation. Again this was not significant for the group but as expected, as the severity of the symptoms increased the FGA scores decreased. As was seen above, the same trend was found when comparing males and females, with female participants rating the severity higher than males, suggesting again that male athletes might be under reporting symptoms.

5.2.3 Correlation between SCAT 5 (number of symptoms and severity of symptoms reported) and Tandem Gait (without loading)

No literature could be found that explored relationships between these variables. The current study however did find a significant correlation to exist between number of symptoms reported on the SCAT 5 and Tandem Gait without loading ($p=.04$). The same results could be seen when comparing severity of symptoms and Tandem Gait without loading. A moderate correlation ($p=.05$) was found. These findings were expected in that as number of reported symptoms increased and or severity of these symptoms were scored higher, balance would be affected. This study confirms this hypothesis.

The mean time to complete the track during the TG without loading, was similar to the measures reported in Schneider's (2013) study. However unlike Schneider (2013) who did not find any significant difference between male and female athletes, the current study did show that females took significantly longer than males to complete the 6m track. The reasons for this remain unclear at this point but warrant further investigation.

5.2.4 Correlation between SCAT 5 (number of symptoms and severity of symptoms) and Tandem Gait (with cognitive loading)

There was again no literature found comparing symptoms and severity reported on the SCAT 5 and TG with cognitive loading. The current study however found no significant correlation between the number of symptoms and TG with loading. When gender differences however were explored, a significant correlation between the number of symptoms and TG with loading was found in males ($p<0.5$). The correlation was negative indicating that as the number of symptoms increase the Tandem gait time decrease. This was unexpected and suggest that the male athletes under report symptoms. Lovell et al (2006) reported the same trend that female athletes tend to report more symptoms and severity than male students. Barsky, Peekna,& Borus (2001) that women report more symptoms more frequent and more intense than men that visit physicians. This can be contributed to a difference in threshold for judging and describing symptoms.

One male participant in the placebo group recorded only 2 symptoms with a very low severity but took 60s to complete the track with cognitive loading. Howell (2017) reported that concussed athletes mean time for tandem gait with loading was 16,4s. The authors used the same type of cognitive loading as was employed in this study by counting backwards in increments of 7 or 6 from 100. Although female participants did not have a significant correlation there was a positive trend, meaning that as their symptoms and severity increased their time to complete the track with cognitive loading, increased.

The same trend was seen for SCAT 5 severity of symptoms and TG with loading - there was no significant correlation but when gender differences were explored, male participants showed a significant negative correlation ($p<0.05$), showing again that males are most likely under reporting their symptoms and suggests that balance measures should be included when assessing readiness to return-to-play. These findings were further corroborated by one of the male participants who during the study suffered a second concussion after returning to sport within two weeks after his first incident. His second concussion was worse than the first because he suffered from total amnesia for 3min. He returned to play at the point where his TG with cognitive loading was 35,67s despite no reported symptoms related to concussion.

In summary:

The FGA showed a moderate negative correlation to the SCAT 5 number of symptom and severity of symptoms reported indicating that as the number of and severity symptoms increases, the FGA scores decreased. Similar findings were found for TG without loading, however when gender differences were compared male participants had a negative trend meaning that as their number and severity of symptom increase so their TG score decreased. One would have expect them to respond in the same manner as demonstrated by the female participants who, as number of and severity increased so did the time to complete the track in TG.

5.3 The Effect of neurofeedback on recovery of postural control

The effect neurofeedback had on postural control as determined by the different outcome measures is discussed in more detail below.

5.3.1 The effect of neurofeedback as determined by the FGA

In the current study both groups improved significantly from pre to post intervention period as determined by the FGA. No significant differences were found between the two groups however post hoc analysis suggest a trend does exist favouring the experimental/neurofeedback group. Had the sample been bigger differences could have been detected. Although anecdotal, the placebo group showed in some cases a decline before showing improvement, while in the treatment group all participants showed a steady improvement from session one to session four.

One contributing factor to the lack of significant difference between the two groups could also be that participants in the current study received only 4 treatment sessions. Azarpaikan (2014) concluded that 8 session was needed to improve static and dynamic balance in Parkinson’s patients. In another study in stoke population, 40 sessions were given (Lee et al 2013). In the current study treatment was limited to 4 sessions due to time constraints. At first it was decided that 8 session would be given , in line with Azarpaikan (2014)’s study but none of the student were willing to commit to so many sessions. It was therefore decide to limit the sessions to four. Another reason for limiting sessions to four was that persons with Parkinson’s disease and stroke may have greater potential for improving postural control, causality of these deficits are due to permanent (and degenerative) impairments affecting the nervous system, requiring longer exposure in order to have a significant effect. Whereas concussion has a shorter recovery time.

When looking closely at the data the treatment group displayed less variability and almost all participants scored 30/30 with the lowest score at 27/30. More participants in the placebo group did not reach 30/30 and the lowest score was 21/30. These suggest the intervention may be affective for improving gait and as such warrant further investigation and a bigger sample group.

5.3.2: The effect of neurofeedback as determined by Tandem Gait (without loading)

As described in the methods section, we used the FGA track for this outcome, because it is the same length as used by Schneider et al. (2013) . A pilot trial to establish norms for non-concussed athletes was deemed appropriate. The results from the current study compare favourably with those reported in Schneider (2013) who also amended the standard TG test.

Although both groups improved significantly from pre to post on this measure, the intervention group scored significantly better than the placebo group. On closer inspection (refer to Table 17, Chapter 4), the improvement in the treatment group is very apparent. The rate of change was much slower in the placebo group. As with the FGA the placebo group shown a decline in performance after session 1 and again after session 3 and ended with a slower time as they started with.

Neurofeedback group had a significant effect on postural control as measured by Tandem Gait (without loading) compared to a placebo group. This is consistent with literature even though fewer sessions was given (Haggard et al 2000).

5.3.3 The effect of neurofeedback on Tandem Gait (with loading)

For this measure, the treatment group showed a significant improvement from pre-to post intervention. Despite this, the difference between the two group was not (refer to Table 18). By the 4th measurement the treatment group was scoring close to the normative values reported in the pilot trial although huge variation within the group was found. With one participant still scoring 22.35s - double the norm - after 4 sessions. Again post hoc analysis suggest that a trend for significance exists. The treatment group showed a consistent improvement and less variability whereas the placebo group first declined in performance before improving.

At this point it can only be postulated that the small sample size and shorter duration than recommended in literature, are reasons for the variation seen in our sample. Due to time constraint it was chosen to limit the number of sessions which is different from what was found in literature. The aim of TG with loading is for the participants to be able to maintain a reasonable speed while assigning capacity to a cognitive task. It was clear that the placebo group still struggled even after four sessions, they still had an increase in body sway and had to stop to be able to think of the next subtraction. Whereas the treatment group showed a steady improvement from session 2 until session 4. Although, the effect is not significant, the difference in the two group shows a positive impact that neurofeedback had on the ability of the treatment group to dual task which was not clear in the placebo group. All participants completed their four sessions within two weeks of starting the study with two sessions per week. Student started the study 5,5 days on average after their concussion and completed it within two weeks.

5.4 Relationships between the FGA and Tandem Time (with and without loading)

Dessy et al. (2017) found that the SCAT 5 is sensitive enough to detect the presence of concussion but recommend that it not be used as a stand-alone assessment to determine recovery and therefore readiness to return-to-play (RTP). Despite the very small sample size, it was deemed appropriate to look at participants return to sport and their data on the FGA, TG with and without loading. While results should be interpreted with caution, this preliminary investigation does suggest that including postural control measures such as the FGA and TG with loading should be considered when deciding readiness to RTP.

At the time the data collection period for the current study was terminated, 13 of the 16 participants had returned to sport. One suffered another concussion within two weeks of the first. Despite returning to sport, some athletes still reported some symptoms on their final SCAT 5 assessment. This was also the finding of Notebaerd (2005) who found that only a small percentage of coaches follow the guidelines. He also recommended that different measures should be used to assess the recovery before athletes start with their graded program.

At each of the sessions, the participants were asked if they have returned to their sport. If they have then the date was noted. The scores on the FGA, TG time with and without loading were also noted. None of them followed a graded return to play.

Theoretically, if the decision to return-to-play were done based on the FGA, Tandem Gait with and without loading none of the sample's athletes would have been considered ready to return. None of the athletes scored 30 on the FGA, Tandem Gait without loading of equal or lower than 11,08s, nor Tandem Time with loading of equal or lower than 17,68s. If one compared the Tandem gait time without loading to the non-concussed students then one would expect that athletes would reached at least the same time or better, than the normative group. The same could be said for TG time with loading. As it has been pointed out in literature, concussed athletes slow down especially under dual tasking and complex gait and that these deficits continue past the acute phase. One would therefore need to look at these measures in order to ascertain if an athletes has recovered fully in order to return- to-play. Many of these students assessment for readiness to return-to-play rest only on the BESS that has been shown not to be sensitive enough after 3-5 days after concussed incident.

Chapter 6: Conclusion and Recommendations

6.1 Conclusion

This study aimed to determine whether neurofeedback can shorten the time to postural recovery, as determined using the Functional Gait Assessment (FGA), Tandem Gait speed (TG) without loading and TG with loading, after a sport related concussion. Despite a small sample size, this double blinded randomised controlled trial corroborated findings from the literature that postural control is affected in persons who have sustained a concussion during participation in sport and that neurofeedback may be indicated to speed up recovery following concussion injury.

The effect of neurofeedback on recovery of postural control after concussion was most evident in the recovery of TG without loading, however the trend is evident in the FGA and TG with loading and warrant further investigation. Neurofeedback enabled the athletes to steadily improve with each session which was not the same for the placebo group who showed a decline between sessions.

When exploring relationships between the SCAT 5 and the selected postural control measurements, several correlations were found. Weak correlation between the SCAT 5 (number of symptoms as well as self-reported severity of symptoms) and the FGA was found, although this was not significant. There was a significant correlation found between SCAT 5 (the number of symptoms and the severity of symptoms) and Tandem Gait without loading. As the no of reported symptoms increased, the time taken to complete the TG test also increased. However when participants in the current study were asked to walk while counting backwards (i.e. with cognitive loading), no correlation was found.

For the latter, differences between males and females were found in that a significant negative correlation was found in males between no of symptoms reported and their score on the TG (with loading) test. No relationship was seen in females. A similar significant negative correlation was found in males for self-reported symptoms and their scores on the TG (with loading) but again this relationship was not seen in females. In males instead of the time taken to complete the TG test increasing as the number and severity of symptoms increased, the opposite was found. As their symptoms increased their TG time decreased. It is suggested in literature that the more severe the concussion the more athletes compensate for their balance problems by slowing down. In this study we found that the male students that posted the slowest time on the TG had the least symptoms. This was a concern, suggesting than males are less likely to honestly report/under report their symptoms following concussion injury compared to females.

The current study further explored the relationships between the above measures at the time participants returned to play and the results suggest that when measuring dynamic balance, in this case using the FGA and TG with and without loading, none of the current participants would have been declared fit to return to sport. Unfortunately no baseline measurements before concussion injury were available and as such this hypothesis should be further explored. All of the above participants scored no errors on the BESS (a static measure of balance) which forms part of the SCAT 5 also supporting the recommendation that it should not be used as a standalone measure for RTP.

It is important to remember the variability among the Tandem Gait with and without loading in this group. One of the major limitation in this analysis, is that without baseline measures before concussion, it remains speculative whether this combination will suffice to monitor recovery and determine readiness to RTP.

6.2 Limitations

One major limitation of this study is the small sample size. Adverse weather conditions, a severe draught, made recruitment very difficult. Despite this some significant differences were seen between the intervention and control group. Post hoc analysis confirms that a larger sample size would have been more effective for demonstrating the effect of neurofeedback on recovery. The time constraint (being a master's study) further contributed to the small sample size.

The small sample size therefore affects generalisability, but although the findings cannot be extrapolated to the broader concussion population, it is deemed that this sample is representative of collegiate athletes at Stellenbosch University and as such data will be shared with Campus Health.

Another limitation of this study is the lack of pre-concussion measurements for each of the participants. Although 30/30 on the FGA can be expected of an uninjured athlete and that the average gait speed of 11,24s for males and ….. for females should have been the case, without these prior to the injury, drawing conclusions as to RTP is difficult and results should be interpreted with caution.

A third limitation in this study concerns the time of the assessments. The time between the first SCAT 5 (BESS) and the dynamic balance assessments were not consistently recorded between participants, which have led to under-scoring in some cases. The sample was also too small for sub group analysis to see what impact this could have had on the results.

6.3 Recommendations:

6.3.1 For clinicians

Neurofeedback may be effective in aiding recovery post-concussion. At this stage four treatment sessions seems too few and similarly to literature eight sessions is recommended

Assessment immediately following concussion should include dynamic balance assessment and especially Tandem Gait with and without loading. Recovery from concussion should include TG with and without loading rather than relying on self-report symptoms. Especially since male athletes tend to inaccurately report symptoms and this should be brought to the coaches attention.

Assessment for monitoring progress and RTP should not only rely on the SCAT 5 but should include more objective measurement of postural control like the TG with and without loading. It would also be recommended that teams have a baseline score that could be used to determine recovery for TG with and without loading. This could then determine the readiness to start the graded return to play program, it can also aid health professionals to ascertain if there is a recurrence of symptoms.

Although not part of the current study, it was observed that athletes are not aware of the risks associated with too early RTP and impact of additional concussions. It is therefore recommended that more time is spent on education of athletes and coaches on the risk and possible long-term consequences of early return-to-play.

6.3.2 For further research

Despite the small sample size and limited treatment sessions, neurofeedback did impact recovery in some of the participants and as such warrant further investigation:

- team doctors should record baseline measurements at the start of the season to assist with interpreting results following concussion

- studies comparing the effected of increased intervention exposure is recommended. It is hypothesised that up to 8 treatment sessions may yield optimum outcome in cases with poor balance measurement scores following concussion……

- the FGA and TG were selected for measuring postural control. Force plate data and/or 3D motion analysis (currently the gold standard for movement analysis) may assist in validating these as appropriate measures of postural control in this population

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Appendix A: Ethics Approval

UNIVERSITEIT•STELLENBOSCH•UNIVERSITY
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Ethics Letter

29-Nov-2017

Ethics Reference #: S16/10/228

Title: The effect of neurofeedback on post-concussion syndrome

Dear Mrs Catherina E Lamprecht,

Your request for extension/annual renewal of ethics approval dated 24 October 2017 refers.

The Health Research Ethics Committee reviewed and approved the annual progress report through an expedited review process.

The approval of the research project is extended for a further year.

Approval Date: 29 November 2017

Expiry Date: 28 November 2018

Kindly be reminded to submit progress reports two (2) months before expiry date.

Where to submit any documentation

Kindly submit **ONE HARD COPY** to Elvira Rohland, RDSD, Room 5007, Teaching Building, and **ONE ELECTRONIC COPY** to ethics@sun.ac.za .

Please remember to use your **protocol number (S16/10/228)** on any documents or correspondence with the HREC concerning your research protocol.

Federal Wide Assurance Number: 00001372
Institutional Review Board (IRB) Number: IRB0005240 for HREC1
Institutional Review Board (IRB) Number: IRB0005239 for HREC2

Fakulteit Geneeskunde en Gesondheidswetenskappe
Faculty of Medicine and Health Sciences

Afdeling Navorsingsontwikkeling en -Steun • Research Development and Support Division

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The Health Research Ethics Committee complies with the SA National Health Act No. 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 Part 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki and the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles, Structures and Processes 2015 (Departement of Health).

Yours sincerely,

[redacted]

HREC Coordinator,
Health Research Ethics Committee 2

STELLENBOSCH UNIVERSITY
Health Research Ethics Committee
29 NOV 2017
STELLENBOSCH UNIVERSITEIT
Gesondheidsnavorsing Etiekkomittee

Fakulteit Geneeskunde en Gesondheidswetenskappe
•
Faculty of Medicine and Health Sciences

Afdeling Navorsingsontwikkeling en -Steun • Research Development and Support Division

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Appendix B: Information leaflet

PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM

TITLE OF THE RESEARCH PROJECT:
The Effect of Neurofeedback on Post-Concussion syndrome:

REFERENCE NUMBER:

PRINCIPAL INVESTIGATOR: Catherina Elizabeth Lamprecht contact 0[redacted]

Supervisor: Dr M Unger contact number 0[redacted]

Prof W Derman Contact number [redacted]

ADDRESS:

CONTACT NUMBER:[redacted]

You are being invited to take part in a research project. Please take some time to read the information presented here, which will explain the details of this project. Please ask the study staff or doctor any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how you could be involved. Also, your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

This study has been approved by the **Health Research Ethics Committee at Stellenbosch University** and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research.

What is this research study all about?

- *The study will be conducted at Campus health and a total of 82 participants will be recruited to participate.*
- *We are trying to find out if Neurofeedback is a better treatment option than the current rest without activity after a concussion injury sustained during a sporting event. We want to see if Neurofeedback can shorten the time to full recovery which in this case will be measured as the participants being symptom free as well as having no deficit on their balance assessment. It is imperative that a person that sustained a concussion does not return to sport until fully recovered since it could increase their chances of another injury which in turn increase the likelihood of long term disorders and possible early onset of dementia. At the same time it is very important to any athletes to be able to return to sport as soon as it is safe.*
- *Neurofeedback training can also be called brainwave biofeedback. Training consist of placing a couple of electrodes on the skull, the electrodes measures the brain's EEG signals or the brainwaves (electrical activity) produced by the brain. The equipment then gives real time audio and visual feedback to you about your brain's activity. No electrical current is relayed to the brain, the brain's electrical activity is relayed to the computer. We cannot reliably influence our own brain activity because we lack awareness of its electrical activity. The feedback enables us to be more aware of our brains activity which enables us to learn to influence and change it. This enables us to retrain and recondition our brain's activity to a point where the changes becomes enduring. The theory is that once the brain's electrical activity or EEG has normalised most of the symptoms of the sustained concussion will also disappear.*
- *After suffering a concussion and during your assessment at the Campus health it was found that you still persistent symptoms and there was an error registered on your balance assessment. Concussion is an injury to the brain and therefore retraining its own electrical activity might enable it to recover faster and ensure a quick and full recovery.*
- *Furthermore, a more extensive balance assessment will be performed, looking not only at your dynamic balance but also at your ability to be able to multitask. Multitasking is part of our everyday lives (walking and talking or texting) but is also vital in your performance on the sports field. During the neurofeedback we will pay special attention to enhancing your brain's influence on balance as well as to balance while you are performing a cognitive task.*

- *After the balance assessment you will be entered into a computer as a number only and then the computer will randomly assign you to the treatment group or placebo group. This means that you have an equal chance to be assigned to a group that receive neurofeedback or the group that will receive a placebo. A placebo means the computer will not react to your brain's electrical activity but will give random visual and auditory feedback. Since this is a double blind study it means that neither you nor the investigator will have any idea who receives feedback and who receives the placebo.*
- *During the intervention four electrodes will be placed on your head and you will watch an animation and listen to music for 10 minutes. Then the electrodes will be moved to a different area on your head and you will continue to watch the same animation and listen to music for another 10 minutes. You will be asked to have this intervention twice a week for2 weeks or until your balance assessment is cleared or hundred percent.*
- *This is a double blind study which means that only the computer knows which participants received feedback based on their EEG signal and which participants only receive a random animation. Even the investigator will not be able to guess which animation is based on the EEG signal.*
- *No medication will be used, except if you experience persistent headaches that does not want to clear with rest, then you will be referred back to the campus Doctor for treatment.*
- *It is current treatment protocol that no person may return to sport until all symptoms have been cleared. The reason being that your chances for another injury are higher than before. Therefore, since you have a deficit as well as persistent symptoms you would not have been able to return to your sport even if you do not participate in this study.*
- *Once you are symptom free and your balance have returned you will be send back to the campus doctor for a final clearance to return to your sport. You will exit the study when you have completed 4 neurofeedback sessions. If you have completed 4 sessions but your balance has not returned to normal then you will be send back to the campus doctor to be assessed for possible return to sport*

Why have you been invited to participate?

- *You have been chosen because you sustained a concussion during your last sporting event and were diagnosed by the campus health team to have a deficit on your balance scoring.*

What will your responsibilities be?

- *You will be asked to visit the High-Performance centre situated in the Gymnasium at Coetzenburg twice a week in order to have the intervention for 2 weeks.*

Will you benefit from taking part in this research?

- *The fact that you receive an extensive balance assessment will decrease your chances of returning to sport too soon and that will decrease your chances of sustaining another concussion. In the long term if this intervention proof to be successful by shortening the recovery time it could mean that athletes that sustain concussion can be returned to their sport safely in a shorter period.*

Are there any risks involved in your taking part in this research?

There are no risks involved except the possibility of having a headache. If the headaches does not clear after rest you will be referred back to the campus health for treatment. The researchers in this study will not participate in any additional management other than the intervention.

If you do not agree to take part, what alternatives do you have?

- *Currently the treatment option after a concussion is rest. If you do not want to participate or are unable then you will still be assessed by campus health every two weeks until all your symptoms have cleared.*

Who will have access to your medical records?

- Once you have given written consent then the primary investigator will get the information of your SCAT 3 report as performed by the Campus health doctor. If you are not willing to participate then your information as captured in your SCAT 5 assessment will remain confidential.
- *All the information will be treated as confidential and will be kept in a safe. The results of this trial will not use any individual's data or name in such a way that the person can be identified, therefore each participant will remain anonymous. Only the principal investigator will have access to each individuals name and data.*

Will you be paid to take part in this study and are there any costs involved?

Yes, You will remunerated four hundred R 400.00. That means for every session you will remunerated R100.00. The intervention sessions will be planned around your class schedule to not interfere with your studies and since you will be on campus it should not involve other traveling costs.

Will the placebo group have to opportunity to receive treatment afterwards?

If Neurofeedback proof to be successful all the people in the placebo group will be offered 4 sessions of neurofeedback free of charge at the same venue.

Is there anything else that you should know or do?

- You can contact Catherina Lamprecht at Tel if you have any further queries or encounter any disorders.
- You can contact the Health Research Ethics Committee at 021-938 9207 if you have any concerns or complaints that have not been adequately addressed by your study doctor.
- You will receive a copy of this information and consent form for your own records.

Declaration by participant

By signing below, I …………………………………..………… agree to take part in a research study entitled: The effect of neurofeedback on Post-Concussion syndrome.

I declare that:

- I have read or had read to me this information and consent form and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to take part.

- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.
- I may be asked to leave the study before it has finished, if the study doctor or researcher feels it is in my best interests, or if I do not follow the study plan, as agreed to.

Signed at (*place*) .... on (*date*) .... 2017.

....

Signature of participant

....

Signature of witness

Declaration by investigator

I *(name)* ……………………………………………..……… declare that:

- I explained the information in this document to ………………………………..
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did/did not use an interpreter. (*If an interpreter is used then the interpreter must sign the declaration below.)*

Signed at (*place*) .... on (*date*) .... 2017.

.... **Signature of investigator**	.... **Signature of witness**

Declaration by interpreter

I *(name)* ……………………………………………..……… declare that:

- I assisted the investigator (*name*) ……………………………………… to explain the information in this document

  to (*name of participant*) ……………..………………………….. using the language medium of Afrikaans/Xhosa.

- We encouraged him/her to ask questions and took adequate time to answer them.
- I conveyed a factually correct version of what was related to me.
- I am satisfied that the participant fully understands the content of this informed consent document and has had all his/her question satisfactorily answered.

Signed at (*place*) ....…........…………. on (*date*) ……………..……………….

Signature of interpreter............................ **Signature of witness…………………………**

Appendix C: FGA and Tandem speed with Loading data capture sheet

Number in Feedback Program **Activity or sport** **Date**	**1= step out of track** **2= lift arms to brace themselves** **3=slowed down** **4= increased body sway** **5= complained of dizziness**		
	Score	**Time**	**Quality**
1.Gait on level surface			
3- Walk 6m in less 5.5sec			
2 Walk between 5.5 and 7sec			
1 Walk slow speed, abnormal gait pattern, deviates outside walkway, walks more than 7sec.			
0 Cannot walk the 6m walkway			
2. Change in gait speed			
3 Ability to change speed without losing balance or deviating gait, or deviating outside the walkway.			
2 Able to change speed but demonstrate gait deviations, deviates outside the walkway(15-25cm) or cannot change velocity			
1 Make only minor adjustments to speed, deviates outside of walkway(25-38cm), change speed but loses balance			
0 Cannot change speed, deviates greater than 38cm out of walkway, loses balance and have to reach for support			
3 Gait with Horizontal head turns			
3 Performs head turns smoothly with no gait change in velocity, do not deviate more than 15cm outside of the walkway			
2 Perform head turns with a slight change in gait velocity, deviates between 15-25cm outside of the walkway			
1 Moderate change in gait velocity, slowdowns, deviates between 25-38cm outside but recover.			
0 Severe impairment with severe disruption of gait, staggers more than 38cm outside of walkway, loses balance, or reach for the wall			
4. Gait with Vertical Head turns			
3 Perform head turns with no change in gait, deviated no more than 15cm outside of walkway.			

2 Perform task with slight gait velocity changes, minor disruption in smooth gait, deviates between 15-25cm outside of walkway			
1 Performs task with moderate changes in gait velocity, slowdowns, deviates between 25-38cm outside of walkway but recover.			
0 performs task with severe disruption of gait velocity, deviates more than 38cm outside walkway, loses balance, have to reach for the wall			
5. Gait and pivot turns			
3 Pivot turns safely within 3 sec and stops quickly without losing balance			
2 Pivot safely in >3 sec , stops without losing balance, stops with mild imbalance, requires small steps to catch balance			
1 Turns slowly, requires several steps to catch balance			
0 cannot turn safely, requires assistance to turn and stop.			
6 Step over obstacles			
3 Is able to step over 2 stacked boxes without changing gait speed , no evidence of imbalance			
2 Is able to step over one box without changing gait speed, no evidence of imbalance			
1Is able to step over 1 shoebox but must slow down and adjust steps to clear box			
0 Cannot perform the task without assistance			
7. Gait with Narrow base of support (Tandem)			
3 Able to ambulate 10 steps without losing footing or staggering			
2.Ambulates 7-9 steps			
1 Ambulates 4-7 steps			
0 Ambulates less than 4 steps or cannot perform without assistance			
8. Gait with eyes Closed:			
3 Walk with eyes closed in less than 7sec, deviates no more than 15cm outside of walkway			
2 Slower speed, deviates between 15-25cm outside of walkway, walk 6m in less than 9 sec but more than 7 sec.			
1 walk slow speed. Abnormal gait pattern. Deviates 25-38cm outside of walkway, requires more than 9 sec			
0 Cannot walk without assistance, severe gait imbalance, deviates more than 38cm outside of walkway.			

9 Ambulating backwards			
3 good speed, normal gait pattern, deviates less than 15cm outside of walkway.			
2 Slow speed, mild gait deviation, deviates between 15-25cm outside of walkway			
1 Walk at slow speed, evidence of imbalance, deviates between 15-38cm outside of walkway			
0 Severe gait deviations or imbalance, deviates greater than 38cm outside of walkway.			
10. Steps			
3 Alternating feet no rail.			
2 alternating feet but use rail			
1 two feet on a step and use rail.			
0 Cannot do safely.			
Modified Stroop	**Time**	**Errors**	**Quality**
Time to walk 6m walkway heel-to-toe while reciting backwards from 100 in increments of 7			
Increments of 6			
Increments of 8			
Increments of 4			