Table 4-3: Mean (SD) for the significant interaction effect between age group and time on dizziness severity and Sensory Organization Test (SOT) scores

Outcome Measure	Children		Adults	
	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment
Dizziness Severity (41 children, 23 adults)	26 (22)	7 (11)	21 (20)	20 (25)
SOT Condition 1 (13 children, 8 adults)	79 (14)	92 (3)	91 (3)	91 (6)
SOT Condition 2 (13 children, 8 adults)	72 (21)	89 (5)	83 (11)	83 (13)

4.4 DISCUSSION

The primary finding of this study is that people who had persistent dizziness and balance dysfunction after having a concussion appear to have improved after vestibular rehabilitation.

Although many post-concussive symptoms, including dizziness and imbalance, may resolve within the first few weeks after the concussion,[65, 296] it is less likely that the participants in our sample fell in this category. Only 8/114 (7%) of the participants in our sample had an initial evaluation within 3 weeks of the concussion, and the median number of 61 days (range 6-2566) between the most recent concussion and their referral to vestibular rehabilitation suggests that the symptoms did not resolve spontaneously, and consequently required intervention. Five participants in our sample had BPPV. Although BPPV has been shown to be common after concussion, it did not appear that way in our sample, perhaps because the extended length of time between the concussion and initial evaluation for vestibular rehabilitation.

The intervention spanned a median of 4 visits and 33 days. The number of visits is comparable with other open-ended trials of vestibular rehabilitation for both peripheral and central causes of dizziness reported from the same clinic.[300-301] However, the duration of care in this report was less than in other studies. It is not clear if the shorter duration of care represented truly faster recovery rates, or rather a change in frequency of treatment visits that enabled the therapists to progress the exercise program more quickly. However, this improvement in outcomes in the same number of visits over a shorter time period may indicate that patients referred to vestibular rehabilitation post-concussion may benefit from a higher frequency of visits at the beginning of care.

The patient recovery occurred across multiple domains, i.e. self- reports of dizziness severity, dizziness handicap (DHI), and balance confidence (ABC), as well as functional balance performance. The magnitude of improvement compares well with other types of vestibular disorders.[269, 300-302] Furthermore, the average magnitude of change was greater than the Minimal Clinically Important Difference (MCID) established for the DHI (18 pts),[299] gait speed[303] (0.1 m/s) and SOT composite score (10 pts).[304] Although statistically-derived MCIDs have not been established for the other outcome measures, in our clinical experience, mean improvements of 20 for the ABC, 3 for the DGI, 6 for the FGA, suggest clinically significant changes. Without a control group, it is not possible to know the relative contributions of the vestibular rehabilitation program, concurrent medical management, and natural recovery toward the improved outcome measures. Furthermore, we were not able to determine how impaired the participants were immediately post-concussion, and therefore are unable to know how much improvement in outcomes may have already occurred prior to treatment. However, the finding is consistent with previous studies that have shown that vestibular rehabilitation may reduce dizziness and improve overall balance for individuals with concussion.[34, 44, 234-235]

The scores of dizziness severity and DHI at initial evaluation were similar to several other reports of persons with vestibular disorders, including central and peripheral dysfunction.[300-301] However, our participant sample had qualitatively better scores in several of the functional gait and balance measures, including the DGI, TUG, and FTSTS, as well as the self reported ABC. It is possible that the better gait and balance scores in the current study reflect the younger age distribution of this group. An age difference was found for several of the gait and balance measures, including FTSTS and FGA, so this explanation is plausible, but not definitive since normative data for these measures are lacking in children. In contrast, across all conditions, the SOT scores obtained from children during the initial evaluation (data not shown) were worse than scores obtained from adults with vestibular disorders,[228, 264, 305] and healthy children,[297, 306] providing additional evidence of dysfunctional sensory integration with concussion in children.[295, 307]

In order to assess if age affected the amount of improvement, the interaction between time and age was examined. Only 3 of the measures demonstrated significant interactions: dizziness rating and SOT Conditions 1 and 2. The significant interaction for the dizziness severity revealed that children had a greater improvement in symptom severity despite having slightly worse ratings at the initial evaluation. Closer inspection of the dizziness severity data for the adult group showed that despite the improvement of dizziness in many participants, the large variability in the scores, especially post-treatment scores may attribute to the overall lack of time effect on dizziness for the adults. The significant interaction effect in SOT Conditions 1 and 2 indicates greater improvement in scores in children compared with adults. The adults had a narrow range of scores that were within normal limits for SOT Condition 1 whereas the distribution of the scores for SOT Condition 1 were more dispersed in children, which allowed for greater recovery. In SOT Condition 2, children again had greater room for improvement because of lower initial scores, but it is also surprising that the adults' scores did not increase to normal values. Overall, the results of posturography analyses should be interpreted cautiously, as they were limited by the low number of participants (13 children / 8 adults). However, the lack of interaction between time and age in other outcome measures of DGI, FGA, gait speed, FTSTS, and SOT suggests that these gait and balance measures could be used to track the recovery after vestibular rehabilitation for both adult and children populations. It would be of a great interest if future studies investigate the responsiveness of gait and balance measures in patients with mTBI.

Another aim of the study was to examine if age impacted the overall level of symptoms and the amount of recovery. There were age-related differences in DHI, FGA, and FTSTS scores. The significantly lower scores on the DHI in children compared with adults may support the notion that the perception of dizziness handicap is different between children and adults.[243, 293] However, at the time of initial evaluation, the dizziness severity was not different between the 2 groups. This apparent contradiction may be explained by items in the DHI that are not applicable to children (e.g. Does your problem interfere with your job or household responsibilities) and by lack of items that relate dizziness to the functional difficulties that the children are experiencing.[293] Although the DHI has not been validated for use with children, we used it because there were no other alternatives that assess the impact of dizziness on the functional activities of children, and we felt that most of the items would respond to changes that occurred during vestibular rehabilitation. The lower FTSTS scores in children (by 4 s) are probably not related to any concussion-related factors, but rather explained by greater physical fitness and agility. In addition, significantly higher FGA scores in children (by 2 points) may reflect abilities that are not related to the concussion severity. Furthermore, a difference of two points between groups may not be clinically meaningful.

4.5 LIMITATIONS AND FUTURE DIRECTIONS

Although we believe that this study added to our understanding of the effects of vestibular rehabilitation after concussion, the results of this study were limited by the retrospective nature of the data and the lack of control group. Owing to the retrospective nature of the study, many limitations were identified; first, we were not able to reliably report the immediate markers of concussion severity such as loss of consciousness (LOC), amnesia and confusion, and we were not able to investigate if the presence of these markers could predict poorer outcomes. Second, although acknowledged by athletic trainers as an essential tool in concussion assessment,[125, 308-311] symptom checklist was not implemented as a part of vestibular assessment. Therefore, we were not able to examine the symptoms severity and symptoms recovery in our sample. Third, since there were no complete vestibular battery test, we were not able to place our participants in one of the dizziness groups previously described by Hoffer et al.[34] Fourth, the study was also limited by some missing data and a low number of participants who completed pre- and post-testing, especially the SOT.

We strongly recommend the use of the symptom checklist as a part of vestibular evaluation as it allows the therapist do document the symptomatic severity of the participants and allow the therapist to track the symptoms recovery by examining the difference in symptom severity between the initial sideline symptom checklist, which is commonly used in the field of athletic training and subsequent checklists.

We also recommend a multidisciplinary approach in which neuropsychologist, physical therapist, athletic trainer can bring their expertise and work together to comprehensively mange the concussion. Knowing that there are modifiers for concussion management,[70] we recommend having a profile for the concussion patient in which all the tests for the different domains (Symptoms, neurocognitive and balance) at all evaluation points (baseline, immediately post concussion, and throughout recovery) are documented in a systematic manner and kept accessible to any member of the team.

Future directions for research should include replication of this study in a well controlled prospective design with a control group.

4.6 CONCLUSION

Vestibular rehabilitation therapy may reduce dizziness severity and improve gait and balance performance after concussion in both children and adults who have persistent symptoms that do not resolve with rest. Future directions may include replication of this study in a prospective and controlled design.

5.0 THIRD AIM

5.1 INTRODUCTION

Reports of dizziness and imbalance are prevalent in individuals who have had a concussion.

Twenty-three to eighty-one percent of persons post concussion report dizziness in the first days post concussion. Estimates of the prevalence of persistent dizziness after mTBI varies widely from 16-18% at three months,[170, 181] 1.2% at 6 months[182] to 32.5% at five years.[183]

Persistent balance problems have also been reported three weeks after concussion.[18, 171]

Vestibular rehabilitation is a key component to the management of dizziness and balance disorders resulting from vestibular system dysfunction, either peripherally or centrally.[226-231]

Despite the high incidence of dizziness and balance dysfunction in people who have had a concussion, reports of vestibular and balance rehabilitation in management of concussion are sparse.[33-34, 39, 44] Previous studies have shown that vestibular rehabilitation reduces dizziness and improves overall balance for individuals with head injury.[33-34, 39, 44, 249]

The accepted standard of care for vestibular rehabilitation is to use a problem-oriented approach in which impairments and functional limitations are identified during the initial evaluation, and customized exercises are prescribed to address the individual's specific problems, while accounting for the pathology and other co-morbidities.[244] General guidelines for exercise prescription and progression are available in Herdman et al, [244] and more specific programs have been documented for prospective clinical trials.[244] Outside of these descriptions of authoritative practice guidelines, there have been no reports of how vestibular rehabilitation therapists actually use these principles in practice. An understanding of what exercises have been prescribed for individuals with dizziness and imbalance after concussion may be useful for several reasons. Assuming that the physical therapists adhered to the problem-oriented approach described above, the study can provide a detailed picture of the specific impairments and functional limitations encountered by the individuals with concussion and the path by which they returned to their pre-morbid status. Moreover, by understanding the prescription and progression patterns provided by expert clinicians, physical therapists new to prescribing vestibular rehabilitation exercises for patients with concussion can use this information to better understand how to start and then make the exercises more challenging. Additionally, therapists can use the framework of exercise categories, exercise groups and exercise modifiers to better document the detailed prescription pattern of vestibular rehabilitation exercises. Consequently, the purpose of this study is to describe exercise prescription patterns in patients treated with vestibular rehabilitation exercises.

5.2 METHODS

5.2.1 Participants

A retrospective chart review of the 114 participants referred to a tertiary vestibular rehabilitation clinic for vestibular rehabilitation after being diagnosed with concussion. Five patients did not have an indication for vestibular rehabilitation therapy, four patients were diagnosed with Benign

Positional Paroxysmal Vertigo (BPPV) and were successfully treated using the modified Epley Canalith Repositioning Maneuver[312] without need for home exercises. One patient did not return for subsequent visit. A total of 104 participants (66 F/38 M, mean age 24 y, SD 19 y) received a computer-generated home exercise program (HEP) of vestibular rehabilitation exercises after being diagnosed with concussion. Results of the intervention were previously reported.[249]

Participants were referred for a median of 58 (6 – 1,149) days after the concussion episode. The duration of the vestibular rehabilitation intervention was a median of 33 (range 7-181) days, encompassing a median of 4 (range 2-13) visits. The HEP was designed by eight physical therapists with at least three years experience in vestibular physical therapy.

5.2.2 Procedure

Each of the computer-generated exercise handouts (Visual Health Information (VHI), WA, U.S.A) that was placed in the chart was reviewed by one of the authors (PS) and each exercise was classified according to general exercise categories that address common areas of dysfunction in individuals with vestibular and balance disorders. VHI software has a pre-determined set of exercises that allows therapists to make modifications for the initial exercise prescription. The software also allows therapists to create new exercises and to make changes to progress the different exercise prescriptions.

There are five main exercise categories: 1) Eye–Head Coordination 2) Sitting balance 3) Standing Static balance (i.e. feet-in-place), 4) Standing Dynamic balance (feet moving, but not walking), and 5) Ambulation. Each one of these categories consisted of different exercise types.

A brief description of the exercise categories and types is included below.

1) Eye-Head Coordination exercises: This exercise category contains many exercise types that involve movement of head and/or eyes for the purpose of vestibulo–ocular reflex (VOR) gain adaptation, symptom habituation, or oculomotor re-education. The exercises include: VORx1, VORx2, VOR cancellation, convergence, smooth pursuits, anticipatory gaze shifts, imagined target, and saccades.[250]

2) Sitting balance exercises: The patient maintains balance while sitting upright, weight shifting from side to side, or bouncing.

3) Standing Static balance exercises: The patient stands with feet in place while upright or weight shifting. The patient can be asked to stand on one leg, stand on a rocker board or stand with one foot on a step. This category also includes the sit-to-stand exercise.

4) Standing Dynamic balance exercises: The patient stands and moves without walking.

The patient might march in place, step forward or backward, step to the side, step up or down, or turn around.

5) Ambulation exercises: The patient walks forward, backward, on stairs, with turns and practice braiding (i.e. side stepping in an over and under pattern), skipping, jogging and running.

For each type of exercise, a universal set of 10 modifiers was used to describe other characteristics of the exercise (Table 5-1): (1) the posture in which the exercise is performed, (2) the type of support surface, (3) the size of the base of support, (4) the positioning of the trunk and (5) arms, (6) the direction of head movements, (7) the direction of whole body movements, (8) the visual input, (9) the presence or absence of the dual cognitive task and (10) any other special circumstances, such as target distance (near or far) when performing VORx1 exercise.

The frequency and duration of time prescribed per exercise were also recorded. Frequency is recorded in terms of the number of times it is performed per day, and the duration

5.3.1 Preferred Prescription Patterns

Even though the number of potential exercises is large due to the combination of modifiers that could be used, the physical therapists demonstrated preferred prescription patterns that contained a small subset of the potential combinations. For example, examination of these patterns revealed that the VORx1 exercise was usually prescribed in both the yaw and pitch planes. For each patient, it was further customized by changing the posture, size of base of support and visual input. Therefore, the therapists usually did not alter the following modifiers during the VORx1 exercise: surface, trunk position, arm position, direction of whole body movement or involvement of cognitive dual task. The specific patterns for the VORx1 exercise will be presented in more detail in the section on progression.

The VOR cancellation exercise was customized primarily by changing the posture and/or the base of support (BOS). As with the VORx1, VOR cancellation was prescribed in both yaw and pitch planes. In 38% of the participants who received a HEP, VOR cancellation was prescribed in the standing position on a level surface (most with feet apart). While in the standing position, the target was either held in one hand while the arm was moving (e.g. a playing card) or tossed between hands (e.g. a ball). This exercise was also performed while walking (37% of participants), also with targets that were tossed or held in the hand. VOR cancellation was prescribed in the sitting position for 18% of participants, always while having the target held in hand.

For the Standing Static balance exercise category, the standing upright exercise was customized and/or progressed by changing the surface, BOS, direction of head movement and the visual input modifiers. The most common surface was a level one, which was prescribed in 74% of the participants receiving a HEP. Participants were instructed to stand with feet together

(46%), followed by standing tandem and semi-tandem (34% and 31% respectively). Across these three BOS's, the exercise was most commonly prescribed with head still and eyes closed. When the exercise was given with head movement in the yaw direction (n=45), the eyes were open in most cases (n=41). When performed on a foam surface (37%), the standing upright exercise was most commonly prescribed with feet apart followed by feet together (27% and 8% respectively).

When performed with feet apart, it was most commonly performed with head still and eyes closed.

The most common modifiers of the Ambulation exercises were the BOS and direction of head movement. Forward ambulation was the most common prescribed exercise in 73% of the participants. The majority of the participants performed the exercise with feet apart (68%).

Tandem ambulation was the second most common forward ambulation (34%). Across the different BOS's the exercise was prescribed with yaw head movement most frequently (62%), then with pitch head movement and no head movement (28% and 12% respectively).

5.3.2 Progression

The VORx1 exercise can be used as an example of how exercises were progressed (Table 5-3).

The initial exercise prescription was given most commonly in standing with feet apart (40 participants), followed by s tanding with feet together (29 participants) and sitting (21 participants). For the participants who were prescribed VORx1 in sitting, 11 participants were progressed to standing with feet apart, 6 participants to standing with feet together, 2 to walking and 4 participants did not progress any further. During the final prescription of VORx1, 31, 30 and 19 participants were instructed to perform the exercise during walking, standing with feet together and standing with feet apart, respectively. Fewer numbers of participants were given their last VORx1 progression in the semi-tandem and tandem position (6 and 2 participants respectively).

Table 5-3: Progression patterns for the VORx1 exercise†

	Posture				
	Sitting	**Standing Feet Apart**	**Standing Feet Together**	**Standing Tandem/ST**	**Walking**
Initial prescription	**21**	**40**	**29**	**1**	**1**
Progression(s)					
Sitting		-	1	-	-
Standing Feet Apart	11		-	-	-
Standing Feet Together	6	19		-	-
Standing Tandem/ST	-	2	7		2
Walking	2	10	17	3	
Standing Other	-	2	2	-	-
Walking Other	-	-	-	-	2
Final prescription	**4**	**19**	**30**	**8**	**31**

† The total number of participants who received the exercise is 92. The categories are not mutually exclusive, in that some participants may have been performing the Vestibulo-Ocular reflex times 1 (VORx1) in more than 1 posture.ST: Semi-Tandem.

5.4 DISCUSSION

Based on the exercises that were prescribed, we can infer that most of the impairments in these individuals with concussion were in three domains; Eye-Head Coordination, Standing Static balance, and Ambulation. The exercises that were given to the participants in this study are consistent with those prescribed in other research studies involving vestibular rehabilitation.[228-229, 313-314] Moreover, although the previous studies of vestibular rehabilitation in patients with post concussion symptoms did not provide a detailed description about their vestibular rehabilitation program, the use of VORx1 and "positional exercises" has been reported.[34]

Impairments in the Eye-Head Coordination have been reported after brain injury, and may result from disruption in the vestibulo–ocular reflex (VOR)[45] or reflect increased symptoms with head and eye movement.[315] Vestibular adaptation exercises that improve VOR gain will consequently improve gaze stabilization during head movement.[244, 313] Eye–Head Coordination exercises can also be prescribed for habituation purposes if the patient is found to have symptom provocation independently of any reduction in VOR gain. In the current sample of participants, 95% were found to have impairments in Eye-Head Coordination. Because most of the participants did not have formal vestibular function testing, it is not certain how many participants had reduced VOR gain. However, most of the participants had symptom provocation with eye and head movements.

Several studies have reported different balance and ambulation impairments in patients with post-concussion symptoms. Despite the evidence that impairments in the static balance spontaneously resolve within the first 3-5 days after concussion,[30-31] 88% of the current participants were found to have impairments in Standing Static exercises at least 6 days after the concussion. In addition, patients may exhibit slower gait velocity,[15, 28, 152] shorter stride length,[150] and wider step width.[29] In the current sample of participants, Ambulation impairments were found in 76% of the participants.

Ninety percent of participants who had difficulties in the domain of Eye–Head Coordination received a HEP to address gaze stabilization during their first visit (Table 5- 2). Of the participants who had standing static balance difficulties, 75% received a HEP in the Standing Static balance category during the first visit. However, only 54% of the participants who had difficulties during walking were given ambulation exercises during their first visit. These results suggest that the Eye-Head Coordination category is the domain that is usually addressed first by the expert clinicians during vestibular rehabilitation for patients post concussion. Several factors may account for why Ambulation exercises were not emphasized during the first visit. First, it is common for persons with vestibular disorders to become symptomatic before the Ambulation evaluation is complete.[250] Second, the therapist may have identified gait impairments but decided to address the Eye–Head Coordination and Standing Static balance problems first to instill confidence and make sure the participant performed the exercises safely before addressing the more dynamic balance deficits (i.e. during ambulation). Others have suggested using a less aggressive pattern of progression for patients with post concussion symptoms during vestibular rehabilitation.[45] Although the reasons for prescription patterns have not been verified through the current data, these above mentioned issues are frequently seen in the management of patients with vestibular disorders and warrant a frequent re-evaluation for patient's status in order to determine the current impairments and functional limitations throughout the course of vestibular rehabilitation.[250]

The analysis revealed important observations about the exercise prescription and progression patterns. For Eye-Head Coordination exercises, the most important modifiers were the posture and base of support. A typical pattern of progression for the VORx1 exercise would be from sitting to standing with feet apart, to standing with feet together, to walking. By varying the combinations of posture and the size of base of support, the patient must learn to adjust for natural body movements that occur while coordinating the eye and head movements during typical daily activities. VOR cancellation is needed to follow moving objects while the head is synchronously moving in the same direction. Posture was the most important modifier to be changed during VOR cancellation prescription. The exercise was mainly performed in postures that match the scenarios in which the suppression of VOR is needed in real life (i.e. standing and walking). For participants who were more symptomatic, the exercise was prescribed while sitting and progressed to standing and walking after the symptoms improved (data not shown).

Participants received the VORx2 exercise as part of the progression less frequently (9%) than is typically prescribed for people with unilateral vestibular hypo-function. Several reasons may exist to explain this. The participants may not have returned for enough visits to begin this exercise, because their symptoms improved and they were discharged. In other cases, the participants may still have been highly symptomatic with the VORx1 exercise.

Because of the retrospective study design, we were not able to record the explicit rationale for the therapists' prescription. All of the therapists who prescribed the exercises were trained in the customized problem-oriented approach that is considered to be the standard intervention for vestibular rehabilitation.[244] Therefore, we can assume that the general rationale for the exercise prescription in each case w as developed using the same framework of 1) identifying the impairments during the evaluation, 2) prescribing a specific initial exercise to address that impairment safely, and 3) progressing the exercise by increasing difficulty so that the activity can be done in a functional manner. Although the current design cannot specifically address "why" the exercises were given, we believe knowing "what" was prescribed by expert therapists is an important step in understanding the management of these individuals. Given the extreme shortcomings in the published literature about the vestibular rehabilitation exercises for individuals post concussion, we believe that this manuscript is useful for clinicians who are starting vestibular rehabilitation exercises because the exercise prescription and progression patterns included in this manuscript is more detailed from previous studies that have commented on the vestibular rehabilitation exercises post concussion.[33-34, 44] Consequently, if a therapist has a basic understanding of the general principles of vestibular rehabilitation, they can now see how other therapists initially began the program and then progressed the participants. For example, the results of this study suggest that during the initial visit, a therapist may want to concentrate on assessing Eye-Head Coordination exercises and Standing Static balance activities, and when indicated, prescribe exercises in these domains. Initially, the VORx1 exercise was prescribed most frequently in standing with feet apart. In later visits, the participants progressed to perform additional Eye-Head Coordination exercises, in more destabilizing postures, and also perform more Ambulation exercises. Future studies should incorporate a prospective design and determine both elements of prescription pattern (i.e. the "what" and "why").

Additionally, we were not able to report the intensity of the prescribed exercises; this is attributed in part to the retrospective nature of our study in which the intensity was not specified in the software that was used to generate the home exercise program sheets. In the case of Eye-Head Coordination exercises, participants were generally instructed to move their head at a speed that caused their symptoms to increase slightly. Nonetheless, we believe intensity should be more formally quantified in the prescription of vestibular rehabilitation exercises, in cases where it applies. For instance, in the case of Eye-Head Coordination exercises, the speed of head movements (or eye movements) is not well described, and is difficult to monitor. Perhaps wearable sensors could be developed to assist in this area in which the speed of head movement is recorded. Another potential way to prescribe the intensity, especially in the case of symptom provocation, is by having the participant perform the exercise until they reach a certain level of symptom severity on a visual or verbal analog scale. For standing dynamic exercises, the intensity could be prescribed as the number of repetitions per minute, and increased to a higher intensity during the progression. For Ambulation exercises, intensity could be prescribed as the gait speed, or speed of head movements performed during gait.

While the progression of aerobic and resistance exercises is typically based on increasing the intensity or volume of the same exercise type, vestibular rehabilitation exercises are often based on subtle variations of the exercise types that are not able to be classified using the F.I.T.T (frequency, intensity, time and type) principle of the American College of Sports Medicine (ACSM). The current system was designed to facilitate the reporting of exercises commonly used during vestibular rehabilitation.[244, 316] The 5 main exercise categories and exercise types within each category were loosely based on general exercise categories that address common areas of dysfunction in individuals with vestibular and balance disorders. It is important to note that the patients with dizziness and balance disorders also may have been given range of motion and strengthening exercises as a part of their home exercise program. However, the prescription frequency of these exercise types was much lower than the vestibular rehabilitation exercises.

One of the limitations encountered in the study was having missing home exercise programs. The group with missing data did not differ from the group with complete data in age, gender, and time since concussion; therefore, systematic bias is less likely to have had occurred in prescriptions that may have been based according to age and gender. The group difference in treatment duration may indicate that there was greater opportunity to have data missing, or support the notion that the therapist may have asked the more impaired participants (i.e. longer treatment duration) to continue the same HEP without documenting that in the chart.

5.5 CONCLUSION

Individuals with dizziness and imbalance post concussion may exhibit impairments in Eye-Head Coordination, Standing Static balance and Ambulation. The exercises prescribed by expert clinicians are comparable to the exercises prescribed for individuals with unilateral vestibular hypo-function. Even though the number of potential exercises is nearly limitless due to the number of modifiers, the physical therapists demonstrated preferred prescription patterns that limited the number of modifiers used. By knowing the preferred prescription and progression pattern of exercises employed by expert physical therapists, other clinicians initiating a vestibular rehabilitation treatment program for individuals post-concussion may have a foundation to guide their intervention.

6.0 FOURTH AIM

6.1 INTRODUCTION

Mild traumatic brain injury, or concussion, can result in a variety of symptoms and physical and cognitive impairments. Post- traumatic headache is the most common symptom after concussion.[171, 174-175] Prevalence of initial headache after concussion has been reported to range between 43% to 86% of patients.[18, 171, 176] Persistent headache is also reported in a period up to three months after concussion.[170, 172]

Dizziness is also a frequent symptom after concussion, with 23% to 81% of persons reporting dizziness in the first days following concussion.[18, 181] Of the 61% who reported dizziness in the initial days after concussion in one study, 41% reported mild dizziness, 16% reported moderate dizziness, and 4% reported severe dizziness.[18] Dizziness at the time of concussion was associated with a 6.34 odds ratio (95% CI = 1.34 -29.91, χ^2 = 5.44, P = .02) of a protracted recovery (i.e >21 days) from concussion in a sample of high school football players.[191]

Estimates of the prevalence of persistent dizziness after mTBI varies widely from 16-18% at three months,[170, 181] 1.2% at 6 months[182] to 32.5% at five years.[183] Self- reported balance problems have been reported by as many as 60% of persons post- concussion.[171] Although some studies have suggested that self- reported balance problems usually resolve in the first days after concussion,[31, 144, 146] patients may exhibit poor balance despite not reporting balance problems.[184]

In examining the recovery process after concussion, clinicians and researchers assess a variety of signs, symptoms, and physiological functions (e.g. sensory, cognitive, and motor).[21, 62, 80, 124, 141] The diversity in measurements used to assess individuals with concussion ha ve enhanced our understanding of the multi-faceted nature of the effects after concussion, and improved the sensitivity of the assessment battery available to record functioning in individuals with concussion.[20] A few studies have concluded that cognitive and motor effects of concussion resolve differently after concussion.[16, 216] Parker et al. have found a differential rate of recovery by comparing the recovery pattern in ImPACT composite scores and different dynamic motor tasks.[216]

The lack of correlation between recovery of measures of different domains has been a subject of debate. [14, 20-21, 48, 104] For instance, while some view the lack of perfect correlation between performance measures and self- report symptoms as an indication for the lack of sensitivity in performance measures[48] or an indication for the inaccuracy of self- report symptoms,[21] others speculate that they may represent fundamentally different neurobehavioral processes, or exhibit different recovery trajectories, and therefore they should not be expected to correlate in all cases.[14, 20, 104] Lovell et al. has concluded that post-concussion symptoms are a result of combinations of neurocognitive deficits and other factors (e.g. vestibular dysfunction), and therefore, the correlation (or lack thereof) between symptoms and neurocognitive testing is expected to be less than perfect.[104]

Despite the conceptual debate about the reasons behind the correlation (or lack thereof) between measurements from different domains, examining the relationship between measurements may enhance our understanding about the multi-faceted nature of concussion effects and recovery. Collins et al. revealed a correlation between the neurocognitive testing scores and the severity of headache post concussion.[140] Preliminary evidence from a study that examined self-report symptoms revealed that "balance problems" were significantly correlated with "feeling mentally foggy", "difficulty remembering", and "difficulty concentrating".[21] In addition, these symptoms were also associated with decreased cognitive performance (i.e. ImPACT composite scores). In the same study Broglio et al. examined the relationship between self- report "dizziness" and "balance problems" and Sensory Organization Test (SOT). The study found a significant correlation between change in the total score of SOT to balance problems.[21]

The purpose of this study is to examine the relationship between self-reported symptoms, neurocognitive performance and balance performance in individuals referred to vestibular physical therapy after concussion, and to examine the relationship between recovery in gait and balance measures and neuropsychological recovery made over the course of vestibular physical therapy.

6.2 METHODS

6.2.1 Participants

A retrospective case series was performed of 114 consecutive participants who were referred between 2006 and 2008 to a tertiary balance center for vestibular physical therapy after being diagnosed with a concussion. The study was approved by the institutional review board (IRB).

6.2.2 Outcome measures

Self-report and performance gait/ balance measures were administered during the first physical therapy visit as well as at weekly and monthly intervals. The time points considered for this report include the initial evaluation and discharge scores. If a measure was not recorded at the time of initial evaluation or discharge, the assessment at the time point closest to the initial evaluation or discharge was used.

6.2.2.1 Self report balance measures

Participants were asked to rate their current dizziness severity on a verbal scale from 0-100, where 0 means no dizziness and 100 means maximum dizziness. Verbal anchors relating to severity of dizziness (e.g. slight, mild, moderate, severe) were provided for the scale.

The Activities-specific Balance Confidence scale (ABC) is a questionnaire used to assess the respondent's level of confidence that they would not lose their balance while performing 16 functional activities. The highest possible score of 100 suggests maximum confidence and a score of 0 suggests no confidence.[255]

The Dizziness Handicap Inventory (DHI) is an instrument used to assess the individual's handicap due to their dizziness in 25 items relating to physical, emotional, and functional domains. The highest overall score on the test is 100 and higher scores indicate greater handicap resulting from dizziness.[299]

6.2.2.2 Balance performance measures

The Dynamic Gait Index (DGI) is an eight item instrument that assesses the ability to walk with head turns, changes of speed, and around obstacles. The scale for each item ranges from 0-3, where 0 means severe impairment and 3 means normal. The highest possible score is 24.[256]

The Functional Gait Assessment (FGA) is a 10-item test based on the DGI. The maximum score is 30. Higher scores indicate better performance.[263]

While participants were asked to walk at their comfortable speed, gait speed was timed over 4 meters course using stopwatch.

The Timed "Up& Go" (TUG) is a timed test during which the participant stands from a chair, walks three meters at their normal walking speed, and returns to the chair.[258]

The Five Times Sit To Stand (FTSTS) requires participants to stand-up and sit down from a standard height chair five times as quickly as possible. The participants were asked to complete the task with their hands crossed on their chest.[259]

Dynamic Computerized Posturography: Participants performed the Sensory Organization Test (SOT, Neurocom, Inc.) under six different sensory conditions:1) eyes open, fixed support; 2)eyes closed, fixed support; 3)sway-referenced vision, fixed support; 4) eyes open, sway-referenced support; 5) eyes closed, sway-referenced support; 6) sway-referenced vision and support surface. Three 20 s trials were performed for each condition. The highest theoretical equilibrium score is 100 which indicates no sway; losses of balance were graded as zero.

Average scores for each condition were recorded, and the composite score was calculated using a weighted average of the individual trials.

6.2.2.3 Neurocognitive and symptom measures

During the time participants were seen for vestibular physical therapy, participants received neuropsychological assessments that included repetitive administration of the Immediate Post-concussion Assessment and Cognitive Testing (ImPACT).[24] ImPACT is a co mputer administered software program that consists of a neurocognitive testing battery and post-concussion symptom (PCS) scale.[24] The neurocognitive testing of ImPACT measures different areas of cognitive functioning including attention, processing speed, reaction time, and memory.

The ImPACT neurocognitive battery uses six test modules (Word Memory, Design Memory, X's and O's, Symbol Match, Color Match, and Three Letter Memory) to generate four composite scores. Each testing module may contribute to more than one composite score. A detailed description of individual tests and composite scores are provided elsewhere.[59, 63, 136] The four performance composite scores, consisting of verbal memory, visual memory, visual –motor processing speed and reaction time were used in this manuscript. Additionally, the total PCS score and the individual scores of symptoms were recorded. The PCS includes 22 items and is designed to quantify the severity of symptoms in the acute phase of recovery after concussion, using a 7 point Likert scale. For any particular symptom, the scale ranges from 0 (no symptom) to 6 (severe), and the total PCS score is calculated by adding the scores obtained for the 22 items.

The PCS has been evaluated for its psychometric properties, clinical interpretation and normative scores.[18, 138, 141] The time points considered for this report were the ImPACT tests that were closest to the start of vestibular physical therapy and the closest point to discharge from vestibular physical therapy, both within 30 days of the balance assessment.

6.2.3 Statistical analysis

Descriptive statistics were used to describe the participants' demographic characteristics, time between concussion and ImPACT testing, and time between concussion and the start of vestibular physical therapy. In order to examine if the participants had more prevalent "vestibular/ balance" symptoms, a paired t-test was used to examine if the patients had higher symptom scores in the "vestibular" symptoms (as detailed below) compared to other symptoms around the start of vestibular physical therapy. A paired t-test was also used to examine if there was a difference in change scores between the vestibular symptoms and other symptoms over the course of vestibular physical therapy.

A vestibular/ balance subset of symptoms that included dizziness, nausea, balance problems, headache, sensitivity to light and sensitivity to sound was considered for correlation analysis with measures administered at the vestibular physical therapy.

Correlation analysis was performed to examine the relationship between the measures of dizziness severity rating, ABC, DHI, DGI, FGA, gait speed, TUG, FTSTS and the five composite scores of ImPACT at the starting point of vestibular physical therapy. The normality of the distribution was examined. The ABC, DHI, FGA, GS, TUG, FTSTS, and conditions 2,4,5,6, of SOT were normally distributed. For the variables in ImPACT, all variables were normally distributed except reaction time. The natural log transformation for the reaction time was used throughout the analysis. For the variables that were not normally distributed (dizziness rating, SOT composite score and condition 1 &3 of SOT), Spearman- rho correlation analysis was performed for the original score. A total of 70 correlation analyses were conducted. To account for multiple comparisons, the False Discovery Rate (FDR) method described by

Benjamini and Hochberg was used.[317] False discovery rate is the expected proportion of erroneous rejections among all rejections.

Correlation analysis was also performed to examine the relationship between change in vestibular/ balance measures and change in ImPACT measures over the course of vestibular physical therapy. For the correlation in the change scores, Spearman- rho correlation coefficient was used for all analyses.

6.3 RESULTS

6.3.1 Analysis at rehab start

Ninety-three participants (59 F/34 M) out of 114 had received ImPACT testing around the time when they were initially seen for vestibular physical therapy after concussion. Of the participants included in this analysis, 65% (n = 60) were children (i.e. <18 y.o). Of the 60 children included in this analysis, the concussive injury was sport –related in 29 participants, while another 29 participants endured non-sport related concussion. The cause of concussion was unidentified for two participants. For the adult participants (n = 33), only eight participants suffered a sport-related concussion while the majority of the adult participants (n = 25) endured non- sport related concussion (e.g. fall, motor vehicle accident, assault).

The median age for the participants included in the analysis was 16 years (range: 11 -54).

They were seen at a median of 50 days after concussion (range: 4 -2566) days. The ImPACT testing was administered within 29 days of the start of their vestibular physical therapy (M =2.46 days, SD = 11.2 days, Median = 2, range 58 (29 days before-29 days after).

Participants were more symptomatic in the “vestibular” symptoms (M = 2.6) compared to other symptoms (M = 2.0, t_{92} = -6.0, p<.001).

6.3.1.1 Relationship between clinical balance and neurocogntive measures

Using the FDR method to adjust for multiplicity of analyses, 33 out of 70 correlations were significant (Table 6-1).

Greater total PCS scores were significantly related to greater impairment in all of the self-report measures, worse performance in 3 of the 4 clinical performance measures, and greater sway during only one of the SOT conditions (fixed surface with eyes closed). The strongest correlation for the PCS was with the self-reported dizziness handicap inventory score (r = 0.49).

Of the neurocognitive measures of ImPACT, the visual memory score was correlated most times with the self-report and performance measures. Lower (i.e. worse) visual memory scores were associated with worse impairments in the self-report and balance measures.

Furthermore, lower visual memory scores were associated with greater sway in 5 of the 6 SOT conditions. In particular, visual memory performance was most strongly related to postural sway on a solid surface with eyes closed.

Reaction time, verbal memory, and processing speed were related to the self-report and clinical performance measures to a slightly lesser degree than visual memory. In all cases, worse neurocognitive performance was associated with the expected deficits in self-report measures and balance performance.

Table 6-1: Relationship between ImPACT composite scores and measures administered at the start of vestibular physical therapy

	Visual memory	**Reaction time**	**Verbal memory**	**Processing speed**	**Total PCS score**
Self-Report					
Dizziness rating† (n = 90)	r_{s}= -.15, p = .159	r_{s}= .09, p = .425	r_{s}= -.04, p = .684	r_{s}= -.02, p = .889	**r_{s} = .24*, p = .021**
ABC (n = 90)	***r* =.37*, p = <001**	***r* =-.36*, p = <001**	***r* =.25*, p = .020**	***r* =.27*, p = .010**	***r* = -.39*, p = <001**
DHI (n = 90)	***r* =-.28*, p = .008**	***r* =.27*,p = .011**	*r* =-.22, p = .041	*r* =-.21, p = .048	***r* =.49*, p = <001**
Clinical Performance					
FGA (n = 82)	***r* = .43*, p = <001**	***r* = -.40*, p = <001**	***r* = .40*, p = <001**	***r* = .31*, p = .004**	***r* = -.38*, p = <001**
GS (n = 84)	***r* = .31*, p = .004**	*r* = -.17, p = .114	***r* = .33*, p = .002**	*r* = .20, p = .066	***r* = -.32*, p = .003**
TUG (n = 71)	*r* = -.24, p = .045	***r* = .31*, p =.009**	*r* = -.19, p = .105	*r* = -.21, p = .081	*r* = .14, p = .239
FTSTS (n = 69)	***r* = -.41*, p = <001**	***r* = .45*, p = <001**	***r* = -.38*, p = .001**	***r* = -.29*, p = .014**	***r* = .38*, p = .001**
Sensory Organization Test (SOT)					
SOT composite† (n = 49)	r_{s} = .32, p =.024	r_{s} = -.18, p = .221	r_{s} = .11, p = .437	r_{s} = .20, p =.171	r_{s} = -.26, p = .074
SOT 1† (n = 48)	r_{s} = .23, p = .118	r_{s} = -.11, p = .451	r_{s} = .19, p = .190	r_{s} = .08, p = .585	r_{s} = .004, p = .977
SOT 2 (n = 48)	***r* = .53*, .000**	***r* = -.46*, p = .001**	***r* = .46*, p= .001**	***r* = .37*, p =.011**	***r* = -.36* p = .012**
SOT 3† (n = 48)	**r_{s} = .47*, p = .001**	**r_{s} = -.40*, p = .005**	r_{s} = .30, p = .036	r_{s} = .26, p = .070	r_{s} = -.31, p = .031
SOT 4 (n = 48)	***r* = .40*, p =.005**	*r* = -.26, p = .072	*r* = .30, p = .040	*r* = .30, p = .039	*r* = -.18, p = .222
SOT 5 (n = 48)	***r* = .37*, p = .010**	*r* = -.24, p = .105	*r* = .27, p = .065	*r* = .15, p = .309	*r* = -.23, p = .122
SOT 6 (n = 48)	***r* = .33*, p = .021**	*r* = -.16, p = .266	*r* = .16, p = .288	*r* = .12, p = .405	*r* = -.22, p = .131

n = Number of participants, ABC = Activities-specific Balance Confidence scale, DHI = Dizziness Handicap Inventory, FGA = Functional Gait Assessment, TUG = Timed “Up & Go”, FTSTS = Five Times Sit To Stand, SOT = Sensory Organization Test, *r* = Pearson product-moment correlation coefficient , r_s Spearman's rank correlation coefficient

For the measures where total PCS score was significantly related to self-report and clinical performance measures, a secondary analysis was conducted to examine if the vestibular subset of symptoms related better to these measures than the total symptom score. The results revealed that the total symptom score relates better to the DHI, GS, FTSTS and SOT compared to the "vestibular/ balance "subset that included dizziness, nausea, balance problems, headache, sensitivity to light and sensitivity to sound. However, the "vestibular/ balance "subset better relates to the ABC and dizziness rating compared to the total symptom score (Table 6-2).

Table 6-2: The relationship between outcome measures administered at the start of vestibular rehabilitation, total symptom score and "vestibular/ balance" subset of symptoms

Outcome measure (n)	**Total symptom**	**Vestibular/ balance**
Dizziness rating (90)	r_s = .243, p =.021	r_s =.410, p <001
ABC (91)	*r* = -.393, p <001	*R* = -.453, p <001
DHI (91)	*r* =.494, p <001	*r* =.485, p <001
FGA (82)	*r* = -.382, p <001	*R* = -.368, p= .001
GS (84)	*r* = -.316, p = .003	*R* = -.294, p = .007
FTSTS (69)	*r* =.381, p = .001	*r* =.327, p = .006

n = Number of participants, ABC = Activities-specific Balance Confidence scale, DHI = Dizziness Handicap Inventory, FGA = Functional Gait Assessment, FTSTS = Five Times Sit To Stand, GS = Gait Speed, r = Pearson product-moment correlation coefficient, r_s Spearman's rank correlation coefficient

6.3.2 Analysis of change scores

Of the 93 participants who had received ImPACT testing around the time of initial assessment of vestibular physical therapy, 22 participants did not continue in vestibular therapy after the initial evaluation, and therefore, they were excluded from this analysis. Seventy-one participated in vestibular physical therapy program. However, 29 of the subjects did not have an ImPACT follow up during the time were they were seen for vestibular physical therapy (i.e. no change scores for ImPACT). Therefore, 39 participants (29 F/ 10 M) received two ImPACT tests; one around the start of vestibular physical therapy and one around the time of discharge from vestibular physical therapy, and qualified for the analysis of relationship in change scores.

There was no significant difference between the group that is included in the analysis (n =39) and the group who did not qualify for this analysis (n =54), in time since concussion (Mann- Whitney U =809, p = .144), age (Mann- Whitney U = 937, p = .787), or treatment duration (Mann- Whitney U = 341, p = .096). However, the group included in the analysis of change scores reported higher dizziness severity and exhibited significantly worse performance on the DGI, FGA and SOT recorded at the start of vestibular physical therapy, compared with the group that were not included in this analysis at the time of initial evaluation in vestibular physical therapy (Table 6-3).

Of the 39 participants included in this analysis, 67% (n =26) were children (i.e. <18 y.o). The median age for the participants included in the analysis was 16.1 years (range: 11 - 47).

They were seen after a median of 46 days after concussion (range: 4 -168). The ImPACT testing was administered within 29 days around the start of their vestibular physical therapy (M =2 days, SD = 8.1 days, Median = 1, range (10 before - 23 after). The ImPACT testing closest to the discharge from vestibular physical therapy was administered within 29 days around the discharge from vestibular physical therapy (M = 0 (i.e. ImPACT testing and discharge from therapy were on the same day), SD = 10.9 days, Median = same day, range: (26 before - 25 after).

Table 6-3: Difference in the initial outcome measures between subjects not included in change analysis (n = 54) and subjects included in change analysis (n = 39)

Outcome measure at the time of initial evaluation	Participants not in change analysis		Participants in change analysis		t-test,p value
ImPACT composite					
	mean (SD)	**n**	**mean (SD)**	**N**	
Total PCS score	45 (32)	54	51 (24)	39	t_{91} = -1.1, .26
Verbal memory	79 (14)	54	75 (17)	39	t_{91} = 1.2, .23
Visual memory	66 (16)	54	61 (16)	39	t_{91} = 1.7, .09
Processing speed	30.5 (10.2)	54	30.0 (11.3)	39	t_{91} = .23, .82
Reaction time	.70 (.27)	54	.73 (24)	39	t_{91} = -.6, .51
Vestibular rehab measures					
	mean (SD)	**n**	**mean (SD)**	**n**	
Dizziness rating	14 (18)	53	30 (22)	31	**t_{82} = -3.5, .001***
ABC	71 (28)	52	62 (25)	32	t_{82} = 1.4, .16
DHI	42 (21)	52	49 (18)	38	t_{83} = -1.8, .08
DGI	22 (2)	44	20 (4)	23	**$t_{27.7}$ = 2.8, .009***
FGA	26 (4)	44	23 (6)	23	**$t_{31.3}$ = 2.6, .02***
GS (m/sec)	1.14 (.26)	46	1.03 (.22)	22	t_{66} = 1.7, .06
TUG (sec)	8.3 (1.7)	33	9.4 (2.7)	20	$t_{27.6}$ = -1.6, .11
FTSTS (sec)	9.7 (3.5)	37	10.8 (3.8)	18	t_{54} = -1.1, .28
SOT	65 (12)	24	45 (23)	13	**$t_{15.9}$ = 3.01, .008***

n = Number of participants, SD = Standard Deviation, ABC = Activities-specific Balance Confidence scale, DHI = Dizziness Handicap Inventory, DGI = Dynamic Gait Index, FGA = Functional Gait Assessment, GS = Gait Speed, TUG = Timed "Up & Go", FTSTS = Five Times Sit To Stand, SOT = Sensory Organization Test, *r* = Pearson product-moment correlation coefficient, r_s Spearman's rank correlation coefficient

The change in self-report and clinical performance measures was calculated over an average period of 50 days, (SD = 44 days) and the change in ImPACT was calculated over an average period of 49 days (SD = 43 days). A paired t-test revealed that this group of 39 participants who were included in this analysis exhibited a greater change in the vestibular/ balance symptoms subset (M = -1.5, SD = 1.0) compared to other symptoms (M = -0.9, SD =0.9) = over the course of vestibular physical therapy (t_{38} = -6.1, p <.001).

The results of analysis of relationship between change in ImPACT composite scores and change in self-report and clinical performance measures revealed that no significant relationship was found after adjusting for multiple comparisons using the FDR method (Table 6-4).

Table 6-4: Relationship between change in Vestibular/ balance measures and change in imPACT composites and the total symptom score

Change score (n)	Verbal memory	Visual memory	Processing speed	Reaction time	Total symptom score
Dizziness rating (31)	r_s = -.153, p = .413	r_s = -.052, p = .781	r_s =.134, p = .473	r_s = -.079, p =.674	r_s = -.074, p = .694
ABC (32)	r_s =.036, p = .847	r_s =.107, p = .559	r_s =.191, . p =296	r_s = -.199, p =.276	r_s = -.333, p = .062
DHI (33)	r_s = -.275, p = .122	r_s = -.222, p = .122	r_s = -.366, p = .036	r_s =.166, p = .356	r_s =.345, p =.049
FGA (23)	r_s =.327, p = .128	r_s =.201, p = .358	r_s =.592, p = .003	r_s = -.335, p = .118	r_s = -.070, p = .750
GS (22)	r_s =.282, p = .204	r_s =.222, p = .321	r_s =.377, p = .084	r_s = -.232, p = .299	r_s =.064, p = .776
TUG (20)	r_s = -.438, p = .053	r_s = -.008, p = .972	r_s = -.366, p = .112	r_s =.059, p = 803	r_s = -.197, p = .406
FTSTS (18)	r_s = -.265, p = .287	r_s = -.232, p =.354	r_s = -.292, p =.240	r_s =.688, p =.002	r_s =.171, p = .499

n = Number of participants, ABC = Activities-specific Balance Confidence scale, DHI = Dizziness Handicap Inventory, FGA = Functional Gait Assessment, GS = Gait Speed, TUG = Timed “Up & Go”, FTSTS = Five Times Sit To Stand. r_s = Spearman's rank correlation coefficient

The analysis of whether a change in the “vestibular” symptoms of PCS relates better to the change in the vestibular measures than total symptom score revealed that no differences were found between the change in vestibular symptoms when compared to the change in the total symptom score. (Table 6-5)

Table 6-5: Relationship between change in symptom scores and change in measures administered over the course of vestibular rehabilitation

Change in outcome measure (n)	Change in total symptom score	Change in vestibular symptoms
Dizziness rating (31)	r_s = -.074, p= .69	r_s =.026, p= .89
ABC (32)	r_s = -.333, p=.06	r_s = -.348, p= .05
DHI (33)	r_s =.345*, p= .049	r_s =.307, p= .08
FGA (23)	r_s = -.070, p= .75	r_s = -.072, p= .75
GS (22)	r_s =.064, p= .77	r_s = -.057, p=.80
TUG (20)	r_s = -.197, p= .41	r_s = -.136, p= .57
FTSTS (18)	r_s =.171, p= .49	r_s =.386, p= .11

n = Number of participants, ABC = Activities-specific Balance Confidence scale, DHI = Dizziness Handicap Inventory, FGA = Functional Gait Assessment, GS = Gait Speed, TUG = Timed “Up & Go”, FTSTS = Five Times Sit To Stand, r_s = Spearman's rank correlation coefficient

6.4 DISCUSSION

A number of significant correlations (33/70) were found between the ImPACT performance scores and measures administered at the time of start of vestibular physical therapy. However, no significant relationships were found between the change in ImPACT composites and the change in gait/ balance measures. Although all performance composite scores in ImPACT exhibited some significant correlations with measures administered at the start of vestibular physical therapy, it was noted that correlations were centered on visual memory compared to reaction time, verbal memory and processing speed evidenced by more number of significant relationships found with visual memory. Additionally, although FGA, FTSTS and Condition 2 of

SOT were significantly correlated to all ImPACT composite scores, the correlation coefficients were higher (i.e. moderate) for visual memory and reaction time compared with correlations exhibited for verbal memory and processing speed. Visual memory is a composite score that is extracted from the Design Memory test and the X's and O's test in ImPACT. The vestibular subset of symptoms seems to relate better to the self report measures of dizziness severity rating and ABC. However, the vestibular subset of symptoms in this manuscript did not exhibit stronger relationship to the clinical balance measures compared to the total symptom score.

The comparison between the results of this manuscript with the results of previous research that studied the correlation between measures after concussion is limited. According to our knowledge, there were no p revious research studies that have examined the relationship between ImPACT composite scores and the balance outcomes used in this study. A previous study suggested a relationship between self- report symptoms related to neurocognition (i.e. difficulty remembering, difficulty concentration, and feeling mentally foggy) and neurocogntive testing performance.[21] Also, a relationship was supported between self- reported symptoms related to balance (i.e. dizziness and balance problems) and balance performance. However, the evidence is less clear when the comparison is made between neurocognitive testing and balance performance. Broglio et al. examined if the symptoms of "feeling mentally foggy", "difficulty concentrating", and "difficulty remembering" are associated with decreased cognitive performance (i.e. ImPACT composite scores). The results revealed a significant correlation between "feeling mentally foggy" and reaction time (r_s = 0.36), between "difficulty concentrating" and verbal memory (r_s = -0.41), and between "difficulty remembering" and change in verbal memory and reaction time (r_s = 0.48 and 0.36, respectively).[21]

The absence of a relationship between the change scores in measures administered during vestibular physical therapy may indicate that the recovery of neurocognitive domains and gait/ balance deficits are different. Moreover, over the period when change scores were calculated, patients received a customized intervention based on the deficits found at the initial vestibular evaluation and they were discharged based on the improvement in vestibular outcomes at the time of discharge. Consequently, this specificity of intervention to vestibular impairments may have contributed to the lack of relationship between the change in ImPACT composite scores and change in vestibular symptoms. The significant difference found between change in "vestibular" symptoms (M = -1.5, SD = 1.0) compared to other symptoms (M = -0.9, SD =0.9), (t_{38} = -6.1, p <.001) may support the notion that the vestibular/ balance symptoms may have changed differently attributed in part to the vestibular physical therapy exercises. Therefore, this may have altered the relationship with total symptom score.

Additionally, the absence of relationships found in this sample may be explained by reasons related to the methodology and analysis used in the current manuscript; the analysis of change relationships may have been underpowered due to the following factors: 1) Small number of participants included in each analysis; although 39 participants qualified for the change analysis, the actual numbers in each analysis ranged between 18 and 33, 2). Since we have also used the FDR to control for the multiplicity of analyses, we may have further limited our ability to find significant results.

Although the composite scores of visual memory and reaction time seem to better relate to the initial measures of vestibular physical therapy, a different pattern is observed when the relationship is closely examined for the change scores. If the relationship in change scores is to be examined without adjustment for multiplicity of analysis (i.e. α = 0.05), the visual-motor processing speed is significantly correlated with the change in DHI and FGA (and SOT composite scores and Conditions 3, 5 and 6 not shown). This change in the trends of relationship may suggest the exercises provided in the vestibular physical therapy may have been beneficial to the cognitive domain of visual-motor processing speed.

The participants in this study were referred to vestibular physical therapy and they reported significantly worse symptoms in “vestibular “symptoms compared to other symptoms suggesting that the referral for vestibular physical therapy clinic was appropriate. Although this group of concussion patients can be labeled as v estibular patients, the deficits reported in neurocognitive performance testing (i.e. ImPACT) emphasize the universal effects of concussion even within this group of individuals with concussion that have complaints of vestibular symptoms beyond the third week after concussion.

The findings of this study re- emphasize the need for a comprehensive approach of concussion management that takes into account the effects of concussion on different areas of brain functioning and allow clinicians to make appropriate recommendations on return to play or work after concussion.[103]

Although this study aimed to examine the relationship between the neurocognitive and balance performance and recovery after concussion, the design of the study was limited; therefore, the results of this study are only preliminary and intended to guide future research directions. The participants included in this study were obtained from a clinical population of patients referred by one practice for vestibular physical therapy were the referral process was solely based on clinical judgment and is often made if the patients are not recovering concussion.

The majority of participants [n = 85 (91 %)] were referred after three weeks of concussion, and therefore this sample does not represent the wide spectrum of individuals with concussion who will make full recovery by the third week post- concussion. The relationship between neurocognitive functioning and balance functioning may have been different if examined in the acute (i.e. < 3 weeks) vs. chronic phase after concussion. Furthermore, the participants of this study are clearly experiencing “vestibular” symptoms compared to other symptoms, suggesting the referral to vestibular physical therapy was a sound clinical decision.

However, there might have been individuals with prolonged recovery that are managed in other adjacent interventions and were not referred to vestibular physical therapy. Consequently, the relationships found in this study could be different if examined in a larger group of individuals with prolonged recovery after concussion (with and without vestibular deficit).

In summary, the participants of this study represent a small percentage of individuals with concussion who are thought to benefit from vestibular physical therapy after balance/dizziness related symptoms that lasted beyond the normal window of recovery. Therefore, this sample does not represent the majority of individuals with concussion who achieve full recovery before the third week after injury.

Furthermore, due to the retrospective design of this manuscript, the time points considered for the correlation analyses were highly variable between participants and may have influenced the findings of this study. Although the time between vestibular measures and ImPACT testing was not significantly related to any of the measures; it may have affected the strength of correlation coefficients. A prospective design that allows concurrent neurocognitive and gait/ balance evaluation may provide a better estimation about the relationship between neurocogntive and gait/ balance functioning after concussion.

The results obtained from the analysis of relationship between change scores have additional limitations; the participants included in this analysis tend to be more impaired in the gait/ balance measures at the start of vestibular physical therapy and therefore, they may represent even a smaller group of individuals with prolonged balance deficits after concussion and does not represent the whole spectrum of individuals with prolonged balance deficits after concussion.

Furthermore, while being treated with vestibular physical therapy, some participants were treated with other interventions such as medications, an exertional physical therapy program, or had restricted work or school access in order to minimize mental and physical exertion and to expedite recovery. It is unclear if the different adjacent interventions may have affected the results found in this group. Without a control group, the role of adjacent interventions on the relationship between the recovery of different domains cannot be ruled out. However, the adjacent interventions provided for some participants in this study were reported in clinicians' notes, and were not systematically recorded in the medical charts making the examination of its role in the recovery process unattainable. A future prospective study design should consider the uniformity of interventions for all participants, and should allow examining the effects of adjacent interventions on the interrelationships between recovery of neurogognitive and gait/ balance outcomes after concussion.

The participants in this study endured sport-related and non-sport related concussions.

While the majority of concussion injuries in the adult participants were caused by non-sport injuries, the sport related concussions represent almost 50% of concussions in children participants (i.e. < 18y.o). Due to power related issues, we did not examine if the relationship would be different between sport-related and non-sport related injuries and we did not examine if the relationship is different between children and adults.

Although we acknowledge the limitations in this study, we believe that this study can serve as a starting point to direct future research to examine the interrelationships between the recovery of different domains. Despite the limitations of this study, the results demonstrated that the relationships between gait/ balance measures appear to be centered on the visual memory and reaction time at referral. However, the change obtained in vestibular measures may appear to be centered on the visual-motor processing speed, and therefore future research should consider these domains when examining the relationship between neurocognitive functioning and gait/ functional balance testing for further research.

6.5 CONCLUSION

The significant relationships between the ImPACT neurocognitive performance scores and balance measures at the start of vestibular rehabilitation may reflect that similar levels of functioning exist across domains. Future areas of exploration will include assessment of changes in neurocognitive and balance function during vestibular rehabilitation to see if recovery of these measures have similar trajectories.

7.0 FUTURE CONSIDERATIONS AND FUTURE DIRECTIONS

7.1 FUTURE CONSIDERATIONS

Based on the limitations we have encountered in the current dissertation, I have the following suggestions for future considerations. In the first aim, we aimed to provide normative data and to examine the reliability for clinical gait/ balance measures for healthy high school aged children.

We chose the participants from two private parochial schools in an urban location (one female only, and one male only) and the other school was a public co-educational school in a suburban school district. However, for future considerations, the schools should represent a wider spectrum of socioeconomic status of rural and public schools. A future study should include equal representation of students at all ages within our age range. Additionally we did not collect race/ ethnicity data. However, race/ ethnicity should be reported to provide an indication of how well participants match to the overall high school demographics of the USA. The participants in aim one included athletes and non athletes, a future study can examine if the normative reference scores are different between athletes and non athletes. For the reliability analysis, we should examine the inter rater reliability of the BESS test as it is being scored clinically vs. videotaping.

When we examined the outcome of vestibular rehabilitation exercises, the majority of our samples were referred for vestibular physical therapy while being managed with other interventions. Unfortunately, there was no systematic reporting of other interventions and therefore, the relative contribution of vestibular rehabilitation was not determined. A future prospective study can examine the relative contribution of vestibular physical therapy and ensure the uniformity of interventions. Furthermore, the majority of our participants were referred for therapy beyond three weeks after concussion. A future study may consider if early referral affects the outcomes of vestibular rehabilitation vs. later referrals for vestibular therapy.

When we recorded the exercise prescription patterns, we were not able to determine the rationale for the exercise prescription; a future prospective study should examine the therapist rationale for the exercise prescription and the rational for exercise progression. A prospective design will also allow for less missing data.

Another suggestion for aim four is to design a prospective study in which the neurocognitive testing and the balance testing are being concurrently examined. A prospective study can also examine if the relationship between neurocognitive and balance recovery is different between individuals treated with vestibular physical therapy vs. individuals who are not being treated with vestibular physical therapy.

7.2 FUTURE DIRECTIONS

In order to provide a higher quality of evidence, I suggest the following design. Individuals with concussion who are being seen by a neuropsychologist within the first three days of concussion should be examined for both neurocognitive and balance deficits **Time 1(t1).** The results of this testing will place the patients into one of three categories 1) Individuals with no neurocogntive deficits and no ba lance deficits, 2) Individuals with neurocogntive deficits but no balance deficits, and 3) Individuals with balance deficits (compared to reference scores) or high balance symptom score (based on the “vestibular “subset of symptoms).

The individuals who did not have neuropsychological or balance impairments will not be eligible whereas the individuals in the other two categories could be recruited for the study, after the participants were enrolled in the study, the individuals who presented with neurocognitive but not a balance deficit can be managed with traditional concussion management for five weeks.

The individuals who presented with balance deficits and/ or balance symptoms can be allocated to one of the two study groups; the experimental group that includes a customized physical therapy program that is provided for the individuals two visits every week for 5 weeks (based on the median number of treatment duration found in the second aim of the dissertation).

The control group will be managed by conventional concussion management approach for five weeks. After the fifth week, all participants will be examined for neurocognitive and balance testing.

An independent t- test is conducted to examine if the individuals with balance deficits (category 3) also exhibited worse neuropsychological performance compared with individuals with no balance deficits (category 2) immediately post concussion.

After the five weeks, the change scores in neuropsychological and balance measures is calculated (t2 – t1), an independent t- test is conducted to examine if the presence of the balance deficits is associated with worse neuropsychological recovery by examining if the recovery in ImPACT composite scores is different between the individuals with balance deficits (the control group of category 3) and the individuals with only neurocogntive deficits (category 2).

For individuals in category three (balance deficits), an independent t- test can be conducted to ensure the participants were not significantly different on any of the outcome measures at the time of group allocation. An independent t- test is conducted to examine if the change scores are significantly different between the groups treated with vestibular PT when compared with the group of conventional concussion management (effect of vestibular PT).

After the change scores in neurocognitive measures and balance measures is calculated for all participants, a co rrelation analysis is conducted. T he Fisher's *z* test is conducted to examine if the correlation between neuropsychological and balance recovery is different between individuals treated with vestibular rehabilitation vs. individuals treated with conventional management.

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