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An Exploration of the Impact of Initial Timing of Physical Therapy on Safety and Outcomes After Concussion in Adolescents

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Abstract

Background and Purpose—Physical therapy (PT) is a management strategy increasingly recognized to facilitate recovery after concussion. The purpose of this study was to investigate the safety and outcomes of multimodal impairment-based PT at varying time points after injury in youth diagnosed with concussion.

Methods—Data were extracted retrospectively from medical records for patients who received PT for concussion-related impairments. Patient records were categorized into three cohorts based on the timing of PT implementation: 0–20 days following injury (early intervention), 21–41 days following injury (middle intervention), and 42 or more days following injury (late intervention). The primary outcome measure was Post-Concussion Symptom Inventory (PCSI) score from the beginning to end of the PT episode of care. Additional outcome measures included: number of PT sessions, duration of PT episode of care (days), and occurrence of unplanned visits to a healthcare provider.

Results—A total of 120 patient records (mean age of 14.77 years) were analyzed. Thirty-three, 39, and 48 individuals were categorized into the early, middle, and late intervention cohorts, respectively. There were no significant differences between intervention cohorts with regard to

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symptom change on the PCSI from the beginning to end of the PT episode of care, unplanned healthcare visits, number of PT sessions, or duration of PT episode of care.

Discussion and Conclusion—Early initiation of PT may be safe and tolerable. Future prospective studies are needed to explore the efficacy of PT services administered early following injury to help characterize an optimal care plan for youth following concussion. Video Abstract [available](#) for more insights from the authors (see Supplemental Digital Content 1).

Introduction

Medical management following concussion in children and adolescents has commanded the attention of healthcare providers and researchers alike. The majority of individuals recover spontaneously after concussion, requiring minimal medical evaluation and intervention to safely return to functional activities. However, there is a considerable and concerning subset who report persistent symptoms past the expected timeline of symptom recovery.^{1–4} In these individuals, symptoms are often manifested within somatic, cognitive, and behavioral domains with symptoms ranging from mild to severe in nature and can persist for months to years after injury.^{2, 4, 5} Prolonged symptoms in children and adolescents can significantly impact functioning and participation in activities, such as school and physical activities.⁶ Strategic management plays a crucial role in the resolution of symptoms in these individuals, helping to encourage increased daily function, promote re-integration into physical and cognitive activities, and improve the patients' and families' quality of life.^{6–9}

A commonly prescribed component of concussion management, specifically during the acute phase of injury, is physical and cognitive rest.^{6–11} Although transient rest in the initial hours following injury may be advantageous in expediting recovery, limited and inconclusive evidence exists regarding the efficacy of physical and cognitive rest outside of 24–48 hours after concussion.^{6–9} In the recently published *Consensus Statement on Concussion in Sport – the 5th International Conference on Concussion in Sport*,¹² a panel of expert scientists and clinicians noted limitations in current research with regard to rest and associated recovery in patients diagnosed with sport-related concussion. McCrory et al. concluded, “The exact amount and duration of rest is not yet well defined in the literature and requires further study.”¹³

Physical therapy (PT) has emerged as a potentially effective rehabilitation strategy to help patients re-engage in pre-injury activities after concussion.^{12, 14–18} A systematic review of physical rehabilitation published in 2016 indicated that PT interventions, including manual therapy, vestibular and oculomotor training, and progressive exercise training, may be appropriate and effective in addressing injury-related impairments for individuals diagnosed with concussion.¹⁶ However, many of these therapeutic strategies were evaluated in isolation or with study designs with relatively strict inclusion and exclusion criteria. Study designs of this nature often contrast with clinical scenarios because many patients present with multiple symptoms and impairments that require individualized rehabilitation strategies. Therefore, the pragmatics of leveraging PT interventions effectively may necessitate multiple types of interventions that target specific impairments (i.e., a multimodal impairment-based approach).

In a retrospective analysis published in 2017, investigators reported on the safety and feasibility of a multimodal, impairment-based physical therapy program consisting of aerobic exercise, vestibular/oculomotor training, and cervical spine interventions for patients ages 12–20 years who experienced persistent post-concussion symptoms for three weeks or more after injury.¹² Patients were treated with a specific PT intervention, or combination of PT interventions, based on their unique impairments. The results indicated that patients' symptoms and impairments improved, with only minor symptom exacerbation and no adverse events. However, the study focused on the inclusion of patients who began therapy three or more weeks post-injury (range of 21–228 days, median of 41 days) and had a relatively small sample size ($n = 25$). Therefore, how the timing of initiation of PT may affect safety, tolerability, and recovery trajectories remains unclear.

Issues related to timing and dose of PT interventions are of paramount across all areas of neurologic physical therapist practice. Without concrete evidence to indicate optimal timing of initiation of multi-modal impairment-based PT interventions, large variations in practice can be expected as health care providers must primarily rely on clinical judgment and local practice cultures to guide their decision-making processes. The purpose of the study was to explore symptom recovery, safety, and preliminary outcomes of a multimodal, impairment-based PT approach initiated at varying time points after injury. A primary objective was to pragmatically evaluate the feasibility of earlier initiation of PT services after concussion within the context of a real clinical setting in order to provide insight and assess proof of concept for future clinical trials.

Methods

A retrospective observational study design was conducted using medical records at a large metropolitan children's hospital from June 11, 2014 to January 31, 2016. Upon approval from the Institutional Review Board, medical records of patients who received outpatient, PT services to address concussion-related complaints were identified. To be incorporated into the initial data extraction, the medical record had to include: 1) a physician-verified medical diagnosis of concussion, 2) documentation of a formal referral for outpatient impairment-based PT interventions with the episode of care terminating prior to January 31, 2016, and 3) no history of a medical condition that mimic the signs and symptoms of prolonged concussion symptoms (e.g., history of chronic headaches, depression, cardiovascular conditions). Patients with prior history of concussion were included in the analysis, but previous history and the number of prior concussions were noted to help describe the sample. The initial data pool was screened further using the following exclusion criteria: 1) younger than 12 years of age at the time of the initial PT evaluation, 2) no data available beyond the initial PT visit, 3) incomplete data for the initial visit symptom score or final visit symptom score, and 4) insufficient documentation or evidence of poor adherence with the PT assessment and intervention protocols. Twelve years of age was selected as a cut-off to ensure consistency in the symptom outcome measure used because the protocol at the institution called for younger children to be assessed using a different version of the symptom inventory form.

Patient Profiles

Demographic information obtained from the medical records included date of injury, age at time of evaluation, sex, prior history of concussion, and athlete versus non-athlete status. Patient records were categorized into three cohorts based on the timing of PT implementation: 0–20 days following injury (early intervention), 21–41 days following injury (middle intervention), and 42 or more days following injury (late intervention). The rationale for the timing groups was based off a desire to build upon previous studies that focused on initiation of PT three or more weeks after injury.^{12, 15, 19} This led to the decision to operationalize the definition of PT interventions within the first three weeks as the early cohort. Additionally, it was decided to define the middle intervention cohort as 3–6 weeks post-injury because many studies that incorporate sub-symptom threshold aerobic exercise training have primarily evaluated outcomes in patients who were four or more weeks, post-injury.^{15, 18–20} Current guidelines also suggest that a typical recovery period for children and adolescents is within four weeks, with symptoms that last beyond that period representing patients categorized as experiencing protracted or slow recoveries.²¹ Finally, a number of patients initiate PT later than the 4–6 week period. To address the concern that this later set of patients may represent a different type of subgroup, the study team decided to evaluate a third cohort that began PT later than the 6 week post-injury mark.

Outcome Measures

Total symptom severity score on the Post-Concussion Symptom Inventory (PCSI) was used as the primary outcome measure. The PCSI is a self-reported measure of 21 post-concussion symptoms on a 7-point Likert scale.^{22, 23} The PCSI is used to evaluate the severity and totality of symptoms experienced following concussion. The total symptom severity score is the sum of all 21 self-reported symptoms, with a higher score indicating increased totality and severity of symptoms; a score of zero indicates the absence of all symptoms. The PCSI has adequate psychometric properties among children and adolescents, suggesting accurate interpretation of self-reported symptoms following concussion.²⁰

To evaluate the safety of PT interventions provided, each patient's medical record was evaluated for any occurrences of unplanned visits to a health care provider, urgent care center, or hospital emergency department. An unplanned visit to a health care provider was flagged as a potential adverse event if it was related to an exacerbation of symptoms that had occurred within 7 days of an in-clinic PT session or completion of PT exercises at home. The duration of the PT episode of care was determined from the date of the initial visit to the date of the final visit; the date of the final visit was determined by documentation of discharge from the treating physical therapist or by the visit date after which the patient did not return to PT within one month of the prior visit (categorized as self-discharge).

Physical Therapy Evaluation and Interventions

Patients were evaluated and treated by one of 32 licensed physical therapists who were trained to treat patients with concussion via an initial comprehensive training session with bi-annual refresher trainings conducted by a sports certified physical therapy specialist with extensive experience working with children and adolescents with concussions. Clinicians were given the opportunity to receive additional individualized training to ensure high

comfort level and consistent practice patterns across the treating physical therapists. All of the evaluation strategies and intervention strategies provided in the training sessions were pre-approved by internal and external physician and physical therapy brain injury specialists and aligned well with strategies previously proposed by Hugentobler et al.,¹⁷ Ellis et al.,^{24, 25} Alsalaheen et al.,^{26, 27} and Schneider et al.²⁸ Each physical therapist was given the latitude to determine which tests and interventions were clinically appropriate and safe to be administered with each patient but were encouraged to follow a general set of care guidelines (Figure 1). As no guidelines specific to PT interventions were available at the time, the therapists were encouraged to utilize related guidelines to further guide their treatment strategies (e.g., neck pain guidelines,²⁹ cervicogenic headache recommendations³⁰).

Statistical Analysis

Descriptive statistics were computed for the sample as a whole and for each intervention cohort. Chi-square tests for independence were utilized to determine the presence of group differences in sex, athletic status, and prior concussion history. Tests for the assumptions of normality, homogeneity of variance were used to determine the appropriateness of parametric versus non-parametric comparisons between groups for age, initial PCSI visit severity scores, final visit PCSI scores, change in PCSI scores, number of PT sessions, and duration of PT episode of care. One-way Analysis of Variance (ANOVA) was used to compare the groups when the assumptions for parametric testing were met, and a Kruskal-Wallis H Test with post-hoc analyses were used for when there were concerns for a lack of normality or homogeneity of variance. An *a priori* alpha level was set at 0.05 to assess for statistical significance between intervention cohorts.

Results

In the initial chart extraction, 173 records were identified as potential cases for this study. Of the original record set, 120 records (78 females, 42 males) were deemed appropriate relative to the inclusion and exclusion criteria. Of the 120 records identified, all were deemed to have sufficient documentation and appropriate adherence to the concussion management protocols emphasized in staff training sessions. Figure 2 provides the inclusion flow chart relative to each intervention cohort. The mean age for all of the cohorts combined was 14.77 years (SD 1.94), with a range of 12 to 21 years and median of 14. Thirty-three individuals (27.5%) were categorized into the early intervention cohort, while 39 (32.5%) and 48 (40.0%) individuals were categorized into the middle and late intervention cohorts, respectively. Table 1 summarizes the demographic results by cohort. No significant differences were identified between intervention cohorts with regard to sex, age, prior history of concussion, or athlete versus non-athlete status ($p > 0.05$). Of note, the late intervention cohort had a higher rate of previous concussions (54%) compared to the early (36%) and middle (34.1%) cohorts.

Figures 3, 4, and 5 provide plots of the spread of scores for PCSI measures relative to each cohort. Intervention cohorts did not statistically differ with regard to their initial ($p = 0.50$), final ($p = 0.13$), or change in ($p = 0.38$) PCSI scores. Although, the mean and median scores

for the initial and change in PCSI values were slightly lower for the late intervention cohort compared to the early and middle intervention cohorts, a deeper analysis of the cohorts combined did not show any significant correlations among days since injury and initial PCSI score or change in PCSI ($p > 0.05$).

All three cohorts demonstrated an overall reduction in PCSI values. Even so, 13 patients (10.8%) reported higher PCSI values (i.e., higher symptom burden) at the final visit compared to the initial visit (Figure 5). Two participants (6%) in the early intervention cohort, who both reported relatively low scores at their first visit (4 and 11 points) noted a slight increase from the first to last visit with very small magnitudes (2 and 7 point increases, respectively). Four participants (10%) in the middle intervention cohort reported increases of varying magnitudes (7, 10, 17, and 22 point increases). Seven participants (14.6%) in the late intervention cohort reported increases with a wide range in magnitude (2, 3, 5, 10, 20, 22, and 58 point increases). Further review of the charts indicated that all of the patients with score increases in the middle and late intervention groups, may have had some concussion-related impairments that may not have been directly addressable with PT interventions (i.e., anxiety, depression, sleep challenges).

There were no statistical differences among the early, middle, or later cohorts identified for either the number of PT sessions ($p = 0.21$) or the duration of PT episode of care ($p = 0.19$). Figures 6 and 7 provide the spread of scores for each cohort and measure. Out of the 120 records included, seven (5.8 %) individuals had an unplanned visit to a health care provider for symptom exacerbation within one week of a PT session. Three unplanned visits occurred in both the early and middle intervention cohorts, while one unplanned visit occurred in the late intervention cohort. Of note, all of the unplanned healthcare visits related to symptom exacerbations occurred at least two days following completion of a PT clinic or home exercise session, suggesting that the symptom exacerbations that led to the unplanned healthcare visits were not likely to be due to the PT exercises. Due to the low rates of adverse events, a statistical comparison between cohorts inappropriate.

Discussion

The purpose of this study was to evaluate the safety and preliminary outcomes of the implementation of PT interventions at varying time points after injury for youth diagnosed with concussion. With the low rate of adverse events, all of which were not likely related to PT interventions, these data indicate that multimodal, impairment-based PT is likely safe, regardless of the timing of initiation. Additionally, the results indicate that patients receiving PT interventions can experience improvements in their symptoms, irrespective of how early or late initiation of PT occurs. Collectively, the results of this study suggest that multimodal PT interventions administered by licensed physical therapists may be feasible and safe even within the first few weeks after injury to help facilitate prompt recovery and mitigate the onset of secondary effects from delayed treatment.

Previous research illustrates the importance and effectiveness of PT interventions in facilitating recovery for patients presenting with concussion-related impairments.^{12, 14, 16, 31} However, it is unclear when the administration of PT services should be initiated, as the

majority of available studies evaluating PT-related interventions illustrate the recovery patterns for participants who are three or more weeks post-injury.^{12, 15–17, 19, 32} Prolonged physical rest may lead to secondary effects such as physical deconditioning, feelings of depression, and social isolation that can confound symptomology.^{6, 24, 33} Moreover, emerging evidence suggests that strict, prolonged rest following concussion may actually lengthen the recovery process.^{10, 31, 34, 35}

As described in the introduction, Grabowski et al.¹² demonstrated that multimodal, impairment-based therapy is safe and associated with decreases in post-concussion symptoms when initiated three or more weeks post-injury. The results of the current study are similar to the findings from a recent case series comparing the timing of initiation of physical therapy services conducted in another hospital system.³⁶ A retrospective evaluation of a sample of 677 children and adolescents with concussion found that use of an exercise-based intervention in children and adolescents was associated with improvements in symptoms regardless if the timing of initiation was less than two weeks or greater than two weeks post-injury.³⁶ Although the specific physical therapy interventions provided differed between Dobney et al.³⁶ and the current study, they both indicate that PT interventions are safe and typically accompanied by improvements in concussion symptoms, regardless of the timing of initiation post-injury.

For the current study, the total number of PT sessions and the duration of PT services were also similar across intervention cohorts. These results, coupled with the similarity in improvements in symptoms across cohorts, suggest that introducing PT earlier in the recovery process may be beneficial in minimizing the potential burden of longer recovery trajectories. If patients can safely participate in PT within three weeks following injury, as the results of the current study suggest, a logical next step is to investigate if earlier initiation of PT interventions can help reduce the risk for prolonged recovery and facilitate earlier return to pre-injury functional levels. Future studies exploring the rate of recovery and return to pre-injury functional participation may provide further insight into the advantages and disadvantages of earlier initiation of PT services.

Several limitations need to be considered prior to applying the evidence of the current study to the treatment of patients diagnosed with concussion. First, the study's design as a retrospective analysis prevents the formation of a definitive conclusion with regard to safety and tolerability following early implementation of PT. Limited patient information was available when reviewing medical records, including confirmation of full completion of recommended episode of care, level of adherence to provider recommendations, and the precise PT intervention protocols each patient received. Likewise, unless the patient was seen directly in the health system, or a patient self-reported and a clinician documented that an unplanned health provider visit occurred, there is potential that unplanned visits to healthcare providers for symptom exacerbations were missed. In addition, there was large variation in physician referral patterns for initiating PT services after concussion, which allowed for the current study to explore timing variables. However, it is possible that there was a selection bias with regard to the timing in which physicians referred patients for PT services after concussion. Physicians may have intentionally or unintentionally screened out

patients, using clinical judgment, who may not be ready to safely engage in progressive, monitored physical activity.

It is also important to acknowledge that licensed physical therapists are all trained to work with patients with a variety of health conditions, and specifically brain injuries across the spectrum of severity. However, it is important to consider that the patients in this study were all being treated by physical therapists who were trained and experienced in managing patients with pediatric concussions. Future research is needed to determine how physical therapists' level of training and experience specific to working with patients with concussions may influence the overall success rates and outcomes. Another limitation to the study is that retrospective design constrained the ability to accurately capture and report on any additional services or interventions patients received (e.g., medication, occupational therapy, psychological interventions) unless the therapists directly asked and documented it within the patient's medical record. Additionally, due to the lack of control group, it cannot be determined if improvements in symptoms that patients experienced were a result of the PT interventions, other interventions they may have received along the way, or natural recovery processes.

A final limitation of note is that the sample size for this study, although larger than previous studies related to this topic, may have had limited the statistical power to capture differences between the cohorts. A post-hoc power analysis using Cohen's *d* of .2 and .5 estimated effect sizes and a 95% confidence level for capturing differences between the cohorts indicated a statistical power ranging between .58 and .98 based on the size of the current sample. However, this represents a large range in power, and some statistical experts do not consider a post-hoc analysis appropriate for representing observed power in a study.³⁷ Therefore, the results of this study should be considered exploratory and descriptive. Future prospective studies are needed to providing confirmatory and explanatory evidence regarding optimal timing for the initiation of PT services after concussion.

Conclusions

The current study provides evidence for the feasibility of incorporation of multimodal impairment-based PT earlier into the concussion plan of care, specifically within three weeks post-injury. The timing of PT services is an important component to consider when determining the most appropriate care for this patient population as there is growing concern regarding the negative effects of prolonged physical and cognitive rest. Future research should aim to validate the results of this exploratory study through prospective clinical trials in order to identify the most optimal and appropriate plan of care for this patient population.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

1. Sigurdardottir S, Andelic N, Roe C, Jerstad T, Schanke AK. Post-concussion symptoms after traumatic brain injury at 3 and 12 months post-injury: a prospective study. *Brain Inj.* Jun; 2009 23(6):489–497. [PubMed: 19484622]
2. Barlow KM, Crawford S, Stevenson A, Sandhu SS, Belanger F, Dewey D. Epidemiology of postconcussion syndrome in pediatric mild traumatic brain injury. *Pediatrics.* Aug; 2010 126(2):e374–381. [PubMed: 20660554]
3. Yeates KO. Mild traumatic brain injury and postconcussive symptoms in children and adolescents. *J Int Neuropsychol Soc.* Nov; 2010 16(6):953–960. [PubMed: 20735890]
4. Barlow KM, Crawford S, Brooks BL, Turley B, Mikrogianakis A. The Incidence of Postconcussion Syndrome Remains Stable Following Mild Traumatic Brain Injury in Children. *Pediatr Neurol.* Dec; 2015 53(6):491–497. [PubMed: 26421987]
5. McCarthy MT, Kosofsky BE. Clinical features and biomarkers of concussion and mild traumatic brain injury in pediatric patients. *Ann N Y Acad Sci.* May; 2015 1345:89–98. [PubMed: 25809391]
6. Stein CJ, MacDougall R, Quatman-Yates CC, et al. Young Athletes' Concerns About Sport-Related Concussion: The Patient's Perspective. *Clin J Sport Med.* Sep; 2016 26(5):386–390. [PubMed: 26540601]
7. Harmon KG, Drezner JA, Gammons M, et al. American Medical Society for Sports Medicine position statement: concussion in sport. *Br J Sports Med.* Jan; 2013 47(1):15–26. [PubMed: 23243113]
8. McCrory P, Meeuwisse WH, Aubry M, et al. Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012. *Br J Sports Med.* Apr; 2013 47(5):250–258. [PubMed: 23479479]
9. Giza CC, Kutcher JS, Ashwal S, et al. Summary of evidence-based guideline update: evaluation and management of concussion in sports: report of the Guideline Development Subcommittee of the American Academy of Neurology. *Neurology.* Jun 11; 2013 80(24):2250–2257. [PubMed: 23508730]
10. Thomas DG, Apps JN, Hoffmann RG, McCrea M, Hammeke T. Benefits of strict rest after acute concussion: a randomized controlled trial. *Pediatrics.* Feb; 2015 135(2):213–223. [PubMed: 25560444]
11. Schneider KJ, Iverson GL, Emery CA, McCrory P, Herring SA, Meeuwisse WH. The effects of rest and treatment following sport-related concussion: a systematic review of the literature. *Br J Sports Med.* Apr; 2013 47(5):304–307. [PubMed: 23479489]
12. Grabowski P, Wilson J, Walker A, Enz D, Wang S. Multimodal impairment-based physical therapy for the treatment of patients with post-concussion syndrome: A retrospective analysis on safety and feasibility. *Phys Ther Sport.* Jun 07; 2016 23:22–30. [PubMed: 27665247]
13. McCrory P, Meeuwisse W, Dvorak J, et al. Consensus statement on concussion in sport-the 5th international conference on concussion in sport held in Berlin, October 2016. *Br J Sports Med.* Apr 26; 2017
14. Schneider KJ, Meeuwisse WH, Nettel-Aguirre A, et al. Cervicovestibular rehabilitation in sport-related concussion: a randomised controlled trial. *Br J Sports Med.* Sep; 2014 48(17):1294–1298. [PubMed: 24855132]
15. Gagnon I, Grilli L, Friedman D, Iverson GL. A pilot study of active rehabilitation for adolescents who are slow to recover from sport-related concussion. *Scand J Med Sci Sports.* Mar; 2016 26(3): 299–306. [PubMed: 25735821]
16. Quatman-Yates C, Cupp A, Gunsch C, Haley T, Vaculik S, Kujawa D. Physical Rehabilitation Interventions for Post-mTBI Symptoms Lasting Greater Than 2 Weeks: Systematic Review. *Phys Ther.* Nov; 2016 96(11):1753–1763. [PubMed: 27197826]

17. Hugentobler JA, Vegh M, Janiszewski B, Quatman-Yates C. Physical Therapy Intervention Strategies for Patients with Prolonged Mild Traumatic Brain Injury Symptoms: A Case Series. *Int J Sports Phys Ther.* Oct; 2015 10(5):676–689. [PubMed: 26491618]
18. Leddy JJ, Kozlowski K, Donnelly JP, Pendergast DR, Epstein LH, Willer B. A preliminary study of subsymptom threshold exercise training for refractory post-concussion syndrome. *Clin J Sport Med.* Jan; 2010 20(1):21–27. [PubMed: 20051730]
19. Kurowski BG, Hugentobler J, Quatman-Yates C, et al. Aerobic Exercise for Adolescents With Prolonged Symptoms After Mild Traumatic Brain Injury: An Exploratory Randomized Clinical Trial. *J Head Trauma Rehabil.* Mar-Apr;2017 32(2):79–89. [PubMed: 27120294]
20. Leddy JJ, Cox JL, Baker JG, et al. Exercise treatment for postconcussion syndrome: a pilot study of changes in functional magnetic resonance imaging activation, physiology, and symptoms. *J Head Trauma Rehabil.* Jul-Aug;2013 28(4):241–249. [PubMed: 23249769]
21. McCrory P, Meeuwisse W, Dvorak J, et al. Consensus statement on concussion in sport-the 5(th) international conference on concussion in sport held in Berlin, October 2016. *Br J Sports Med.* Jun; 2017 51(11):838–847. [PubMed: 28446457]
22. Sady MD, Vaughan CG, Gioia GA. Psychometric characteristics of the postconcussion symptom inventory in children and adolescents. *Arch Clin Neuropsychol.* Jun; 2014 29(4):348–363. [PubMed: 24739735]
23. Gioia GA, Schneider JC, Vaughan CG, Isquith PK. Which symptom assessments and approaches are uniquely appropriate for paediatric concussion? *Br J Sports Med.* May; 2009 43(Suppl 1):i13–22. [PubMed: 19433419]
24. Ellis MJ, Leddy J, Willer B. Multi-Disciplinary Management of Athletes with Post-Concussion Syndrome: An Evolving Pathophysiological Approach. *Front Neurol.* 2016; 7:136. [PubMed: 27605923]
25. Ellis MJ, Leddy JJ, Willer B. Physiological, vestibulo-ocular and cervicogenic post-concussion disorders: an evidence-based classification system with directions for treatment. *Brain Inj.* 2015; 29(2):238–248. [PubMed: 25314613]
26. Alsalaheen BA, Mucha A, Morris LO, et al. Vestibular rehabilitation for dizziness and balance disorders after concussion. *J Neurol Phys Ther.* Jun; 2010 34(2):87–93. [PubMed: 20588094]
27. Alsalaheen BA, Whitney SL, Mucha A, Morris LO, Furman JM, Sparto PJ. Exercise prescription patterns in patients treated with vestibular rehabilitation after concussion. *Physiother Res Int.* Jun; 2013 18(2):100–108. [PubMed: 22786783]
28. Schneider KJ, Meeuwisse WH, Barlow KM, Emery CA. Cervicovestibular rehabilitation following sport-related concussion. *Br J Sports Med.* Nov 10.2017
29. Childs JD, Cleland JA, Elliott JM, et al. Neck pain: Clinical practice guidelines linked to the International Classification of Functioning, Disability, and Health from the Orthopedic Section of the American Physical Therapy Association. *J Orthop Sports Phys Ther.* Sep; 2008 38(9):A1–A34.
30. Page P. Cervicogenic headaches: an evidence-led approach to clinical management. *Int J Sports Phys Ther.* Sep; 2011 6(3):254–266. [PubMed: 22034615]
31. Schneider KJ, Leddy JJ, Guskiewicz KM, et al. Rest and treatment/rehabilitation following sport-related concussion: a systematic review. *Br J Sports Med.* Jun; 2017 51(12):930–934. [PubMed: 28341726]
32. Gagnon I, Galli C, Friedman D, Grilli L, Iverson GL. Active rehabilitation for children who are slow to recover following sport-related concussion. *Brain Inj.* Nov; 2009 23(12):956–964. [PubMed: 19831492]
33. Gibson S, Nigrovic LE, O'Brien M, Meehan WP 3rd. The effect of recommending cognitive rest on recovery from sport-related concussion. *Brain Inj.* 2013; 27(7–8):839–842. [PubMed: 23758286]
34. DiFazio M, Silverberg ND, Kirkwood MW, Bernier R, Iverson GL. Prolonged Activity Restriction After Concussion: Are We Worsening Outcomes? *Clin Pediatr (Phila).* May; 2016 55(5):443–451. [PubMed: 26130391]
35. Grool AM, Aglipay M, Momoli F, et al. Association Between Early Participation in Physical Activity Following Acute Concussion and Persistent Postconcussive Symptoms in Children and Adolescents. *JAMA.* Dec 20; 2016 316(23):2504–2514. [PubMed: 27997652]

36. Dobney DM, Grilli L, Kocilowicz H, et al. Is There an Optimal Time to Initiate an Active Rehabilitation Protocol for Concussion Management in Children? A Case Series. *J Head Trauma Rehabil.* Sep 18.2017
37. Hoenig J, DMH. The Abuse of Power: The Pervasive Fallacy of Power Calculations for Data Analysis. *The American Statistician.* 2001; 55(1):19–24.

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Figure 1.
Concussion care pathway recommendations for physical therapy evaluation and treatment.
PCSI = Post-Concussion Symptom Inventory

Figure 2.
Flow chart for inclusion in the analysis

Figure 3.

Initial session PCSI scores for each patient by intervention timing group.

Shewart chart for individual measures (sometimes referred to as an I-chart, X chart, or Xmr chart). Each dot represents an individual. The y axis represents PCSI total severity scores, and the x axis is ordered sequentially by PCSI score in order from lowest to highest for each group. The dashed line represents the mean score for each group.

Figure 4.

Final session PCSI scores for each patient by intervention timing group

Shewart chart for individual measures (sometimes referred to as an I-chart, X chart, or Xmr chart). Each dot represents an individual patient. The y axis represents PCSI total severity scores, and the x axis is ordered sequentially by PCSI score in order from lowest to highest for each group. The dashed line represents the mean score for each group.

Figure 5.

Change in PCSI scores from initial visit to final visit for each patient by intervention timing group. Shewart chart for individual measures (sometimes referred to as an I-chart, X chart, or Xmr chart). Each dot represents an individual patient. The y axis represents PCSI total severity scores, and the x axis is ordered sequentially by PCSI score in order from lowest to highest for each group. The dashed line represents the mean score for each group.

Figure 6.

Number of PT sessions for each patient by intervention timing group. Shewart chart for individual measures (sometimes referred to as an I-chart, X chart, or Xmr chart). Each dot represents an individual patient. The y axis represents number of PT visits scores, and the x axis is ordered sequentially by number of PT visits in order from lowest to highest for each group. The dashed line represents the mean score for each group.

Figure 7.

Duration of PT episode of care (days) for each patient by intervention timing group. Shewart chart for individual measures (sometimes referred to as an I-chart, X chart, or Xmr chart). Each dot represents an individual patient. The y axis represents days in the PT episode of care, and the x axis is ordered sequentially by number of days in order from lowest to highest for each group. The dashed line represents the median score for each group.

Table 1**Patient Profiles by Intervention Timing Cohort**

	Early Intervention (n = 33)	Middle Intervention (n = 39)	Late Intervention (n = 48)
Age (years)			
range	12 – 19	12 – 19	13 – 21
mean (SD)	14.94 (1.97)	15.08 (1.87)	15.61 (1.69)
median	15	15	16
Days to PT Initiation			
range	1 – 20	21 – 40	42 – 363
mean (SD)	11.63 (4.90)	30.51 (5.83)	97.81 (72.27)
median	15	32	67
Sex	19 F, 14 M	29 F, 10 M	31 F, 17 M
Athlete Status (A, NA)	30 A, 3 NA	34 A, 5 NA	44 A, 5 NA
Prior Concussion (Yes, No)	12 Yes, 21 No	15 Yes, 24 No	26 Yes, 23 No
PCSI Initial Session			
range	0 – 84	0 – 90	0 – 54
mean (SD)	25.14 (15.19)	25.59 (21.09)	17.66 (15.70)
median	19	19	13
PCSI Final Session			
range	0 – 33	0 – 33	0 – 83
mean (SD)	5.27 (8.89)	12.03 (16.14)	14.21 (21.24)
median	1	5	3
Change in PCSI Score			
range	–80 – +7	–86 – +22	–43 – +58
mean (SD)	–19.89 (23.21)	–13.56 (19.55)	–6.45 (17.02)
median	–10	–12	–6.5
Number of PT Sessions			
range	2 – 18	2 – 48	2 – 15
mean (SD)	6.51 (4.13)	8.46 (7.78)	6.89 (3.63)
median	6	7	7
Duration of PT Care (days)			
range	4 – 106	5 – 206	9 – 245
mean (SD)	40.94 (28.85)	54.54 (45.12)	61.53 (46.25)
median	36	42	52
Discharge Status (C, S)	23 C, 10 S	24 C, 15 S	32 C, 17 S

* SD = Standard Deviation. A= Athlete, NA = Non-athlete. Y = Yes, N = No. PCSI refers to the patients' self-reported Post-Concussion Symptom Index total scores for those patients who had scores available for the beginning of their first session and the end of their first session. F = female, M = Male. C = clinician-discharge (discharged by physical therapist), S = Self-discharge.