An active approach in the treatment of post-concussion syndrome - Evidence-based practice in a collective case study

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Abstract

Rational, Aims and Objectives: Prolonged symptoms after a mTBI, known as Post-Concussion Syndrome (PCS), remains a challenging area of rehabilitation. Evidence shows that an active approach can improve prognosis, however PCS is a multifaceted condition with many comorbidities and large variety in patient response. This study investigated the use of submaximal aerobic exercise and body awareness therapy, and the influence on symptoms in PCS cases, viewed through the lens of evidence-based practice (EBP). Method: Four cases were separated into two case studies. Cases in Study A received an aerobic exercise protocol consisting of 8 individual sessions distributed twice a week over 4 weeks, with additional cervical endurance training. Cases in Study B received a body awareness therapy protocol consisting of 6 guided practices distributed twice a week over 3 weeks. Using method triangulation, both quantitative and qualitative data were gathered through the use of the Rivermead Post-Concussion Questionnaire (RPQ) and semi-structured interviews, as well as the Craniocervical Flexion Test (CCFT) in Study A, and the Short Form-36v2 (SF-36) questionnaire in study B. Lastly, research evidence on PCS was included to contextualize cases. Results: Both cases in Study A showed marked improvements in their RPQ scores, but only one showed improvement in the CCFT. In Study B, one case improved in RPQ score and in the mental component of SF-36v2, while the other case did not experience any significant change. All cases expressed positive associations with the interventions during the interviews. Conclusion: These results illustrate how an active and individualized approach can represent important qualities that can be applied to further and larger studies. Based on the results and discussion of this paper, relevant findings and suggestions are summarized in a modified EBP model, which may be of help to practitioners in dealing with PCS patients in the clinical practice.

Keywords

Mind Body Therapy, Mild Traumatic Brain Injury, Aerobic Exercise, Autonomic Nervous System, Physical Therapy Modalities, Neck

1. Introduction

In Denmark approximately 25.000 cases of mTBI are diagnosed each year[1] with an additional estimated 25% undiagnosed,[2] bringing the national incidence rate up to 545 pr. 100.000. This is in line with the international rate where incidents of mTBI, including diagnosed and undiagnosed, are estimated to be about 600 per 100.000 worldwide, or around 45 million a year.[3] Of these, roughly 75-90% experience gradual remission of symptoms within 14 days, whereas 10-25% continue having symptoms, which may then devolve into Post-Concussion Syndrome (PCS).[4,5] While no consensus on the timeframe exists, PCS can be defined as experiencing persistent symptoms of a mTBI for longer than 3 months, as by the DSM-5 criteria, with additional psychosocial sequelae.[6,7] Patients often experience difficulties in maintaining their social, professional and physical levels of activity, and may be at risk of not participating in and contributing to the financial state of society. A Danish survey found that 19% of all mTBI patients were on sick leave for more than a month and that 2% had still not returned a year after the initial trauma.[8] In the U.S., a report from the Agency for Health Research and Quality found that TBI patients across all levels of severity had a higher prevalence of long term depression at 30%, which is more than three times the national average at 8-10%, as well as higher rates of anxiety and PTSD.[9]

An increasing amount of evidence shows that an active approach, contrary to earlier beliefs about a "wait and see approach", can improve outcomes and long term prognosis.[10–12] The international consensus statement on Concussion in Sports from 2016 in Berlin recommends a period of 24-48 hours of physical and cognitive rest after the initial trauma, followed by a progressively active rehabilitation.[13] It is well established that PCS patients can experience barriers towards physical and cognitive activity, with higher levels of cognitive exertion associated with longer duration of symptoms in some,[14] and that adequate management between rest and activity is a central yet complex part of the recovery process.[15–17] These barriers often manifest as exercise intolerance, cervicogenic headaches, rapid eye exhaustion, dizziness, nausea, excessive fatigue, and a low threshold for managing sensory input.[18–22] Therefore, it is important to clarify the parameters of an active approach to treatment in a rehabilitation setting. In this context, an active approach can be both an up or downregulation of physical and mental stimulation, as well as providing education and tools to promote patient self-efficacy.

One of the major challenges in dealing with PCS is categorizing the underlying pathologies and understanding their effect on the symptomatology, to which the evidence suggests a multitude of neurophysiological and psychosomatic mechanisms. These mechanisms include disruptions in cerebral blood flow (CBF),[23,24]changes in brain metabolism,[25] axon damage,[26] changes in autonomic and neuroendocrine function,[27–30] cervical injury and postural weakness,[31] disturbances in the vestibular and oculomotor system,[32,33] and neuropsychological dysfunctions.[34,35] These myriad of components and overlapping comorbidities adds to the complexity of PCS, and highlights the difficulties of having a single treatment regimen. It may also explain the varying responses to clinical assessment.[36]

A useful tool in organizing and providing the most relevant care is the evidence-based practice (EBP) model originally coined by Sackett[37] and further developed through Straus[38] and Howick.[39] While different iterations exists, the model formulates three dimensions of best practice: Best Research Evidence which is the highest graded and most appropriate evidence in the scientific literature, Clinical Expertise which is the clinical experience and knowledge, and Patient Preferences which is the individual patient preferences, their values or larger group characteristics. Using the EBP model practitioners can more easily stratify the individual variables and formulate a cohesive plan of action to target the multifaceted nature of PCS.

By applying two distinct interventions, this paper will examine how an active and individualized approach can be used in the treatment of PCS. The empirical data will be derived from two case studies, each consisting of two cases with separate protocols, highlighting the aspects of overcoming symptoms of PCS with insight from the cases, as well as an inclusion of the relevant literature. This will be viewed through the lens of a modified EBP model and ultimately summarized in a visual presentation, to more appropriately transfer knowledge to the clinical practice.

2. Methodology

In both case studies method triangulation was used as the foundation of the study designs, including a quantifying positivistic approach to measure changes in clinical symptoms as a result of the interventions, combined with a qualitative humanistic approach used to gain an understanding of the cases' subjective experiences of the interventions. The quantitative data was gathered through clinical examination and questionnaires, and the qualitative understanding was gathered through the use of semi-structured interviews. Because of the volatile symptoms of PCS, the interventions were designed as a cyclical process with the intention of including cases by listening to their feedback and adjusting protocols, if necessary, based on any potentially adverse reactions. This design was inspired by Malterud's research spiral which is based on a continuous evaluation and defining of the problem and intervention, thus preparing researchers to be adaptable and increase transferability to the rehabilitation.[40,41]

2.1 Ethical Foundation

Permission for initiating the study was granted from The Danish National Committee on Health Research Ethics prior to the beginning of the project, concluding that cases were not at risk of harm, and the ethical aspects of the project were assessed according to the Helsinki Declaration.[42] Cases were given oral and written information about the protocols and signed an informed consent form with the right to withdraw at any time. All cases were anonymized, and qualitative data collection was handled with discretion with no sharing of personal information.

2.2 Case and Study Descriptions

Case characteristics are presented in Table 1 and 2. The four cases were recruited through a collaboration with a center of rehabilitation in the capital region of Denmark and separated into two different case studies, Study A and Study B, examining two different intervention protocols. Cases in Study A participated in a submaximal graded aerobic exercise intervention supplemented by postural correction of the cervical spine and cases in Study B participated in a modified body awareness intervention with additional group feedback sessions.

TABLE 1

Study A Inclusion criteria; Persistent symptoms of mTBI for more than 12 months following initial trauma, above the age of 18 and able to sit on a stationary bike without referred pain.

Study B inclusion criteria; Persistent symptoms of mTBI for more than 12 months following initial trauma, above the age of 18, able to stand for a duration up to 20 minutes, able to lie flat on their backs.

Excluding criteria; Unable to communicate in Danish, unable to attend twice a week and contraindicated disorders making the planned interventions impossible.

TABLE 2

2.3 Data and Analysis

All four cases underwent a clinical examination before the interventions covering relevant injury history, current and previous work history, social participation, daily activities and bodily functions in relation to the International Classification of Functioning Disability and Health (ICF) model.[43] All cases were scored on the Rivermead-Post Concussion Questionnaire (RPQ), a standardized post-concussion questionnaire with two subscores,[44]pre- and post-intervention, as well as a semi-structured qualitative interview post intervention. Additionally, cases in Study A underwent a Craniocervical Flexion Test (CCFT)[45] pre and post intervention, and cases in Study B were scored on the SF-36v2 Quality of Life (QOL) questionnaire[46] pre and post intervention. RPQ, SF-36 and CFFT have shown to be valid testing tools in measuring prolonged symptoms of mTBI, QOL and cervical function in different population groups with moderate to high construct validity and reliability.[47–50] Questionnaires followed the guidelines for analysis of RPQ[47] and SF-36v2[51,52] using simple comparative statistics in calculating averages and the semi-structured interviews were recorded, transcribed and analysed by identifying codes and sub-codes, which were clustered ad modum Kvale.[53] The CFFT was administered as per standardized guidelines.[45]

2.4 Interventions

Study A

Submaximal Graded Aerobic Exercise

The aerobic exercise was done on a stationary bike to reduce exposure of cervical compression and impact forces, minimizing symptom exacerbation due to something other than the exercise itself. During the initial session, cases were instructed to reach a baseline heart rate (HR) above 100 BPM if possible, while being monitored for any increase in symptoms which would terminate the test. In each of the following sessions cases then attempted to increase their HR by 10 BPM, on the condition that symptoms were not aggravated. HR thresholds were noted during the first and last session. The intervention consisted of 8 individual consultations distributed twice a week over 4 weeks, with the exercise lasting 15 minutes each session.

Correction of malalignment

Cases were given home exercises based on findings in the CCFT test and posture analysis following Panjabi.[54] These consisted of low intensity endurance training of the deep cervical flexors with a focus on muscle control and close attention not to activate any superficial muscles, as well as additional static stretching. Exercises were done daily in 1-3 sets of 10 repetitions and stretches were held for 45 seconds up to 3 times a day.

Study B

Body Awareness Therapy

The series of movements were inspired by Basic Body Awareness Therapy (BBAT) and designed in cooperation with a physical therapist specialized in BBAT. Large cervical rotations and strenuous movements were removed to minimize possible symptom exacerbation. Cases were guided in the key principles, which emphasize that all movements should be performed with a physical and cognitive presence, allowing them to stay grounded, breathe freely and move energy-economically, in order to make the series flow relaxed and naturally.[55,56] All sessions were concluded with patients doing a brief body scan lying supine on the floor, followed by a short group feedback session. The intervention consisted of 6 guided practices distributed twice a week over 3 weeks, with each session lasting 45 minutes.

3. Results

3.1 Study A

Rivermead Post-Concussion Questionnaire

As shown in Fig. 1 and 2, Case 1 had a reduction from 12 to 8 (33%) in RPQ-3 score and 44 to 25 (43%) in RPQ-13 score, pre- to post-intervention. Case 2 had a similar reduction in both scores, going from 5 to 3 (40%) in RPQ-3 score and 22 to 13 (41%) in RPQ-13 pre- to post-intervention.

FIGURE 1

FIGURE 2

CCFT and Aerobic Threshold

Case 1 remained a positive grade 3 in the CCFT throughout the study. Case 2 was initially scored as a positive grade 1 in the CCFT, managing the requirements with shaky and uneven movements, but improved to a positive grade 3 post intervention.

As shown in Fig. 3, Case 1 managed a working HR of 100 during the first session and 126 in the last session. The exercise intensity, as a percentage of a calculated maximum HR, went from 55% in the first session to 70% in the last session. Case 2 managed a working HR of 119 during the first session and 138 in the last session. The exercise intensity went from 73% in the first session to 85% in the last session. Both cases experienced no aggravation of symptoms during the exercise.

FIGURE 3

Semi-Structured Interview

As shown in Table 3, emerging from these codes were themes of protection against overstimulation and the importance of being in a comfortable setting. Cases explained how this was helpful in preventing them from reaching their mental or physical symptom thresholds. Considering their reduced tolerance to sensory input, controlling the surroundings lowered unwanted stimuli and allowed cases to devote their energy to the intervention itself, without dealing with unnecessary triggers. Both cases described an initial feeling of a lifeless body and how they had avoided exercise for a long time before the intervention. Strenuous physical activity can lead to symptom exacerbation in many PCS patients causing a negative feedback loop further reducing physical activity, making their bodies less resilient long term. After the intervention however, both cases expressed feelings of physical success and improved physical confidence which enabled them to continue to exercise on their own.

TABLE 3

3.2 Study B

Rivermead Post-Concussion Questionnaire

As shown in Fig. 4 and 5, RPQ-3 score remained unchanged for Case 3 from pre- to post-intervention, however there was an increase from 28 to 33 (15%) in RPQ-13 score. Case 4 had a reduction in both scores, from 5 to 4 (20%) in RPQ-3 score and 28 to 19 (32%) in RPQ-13 score, pre- to post intervention.

FIGURE 4

FIGURE 5

Short Form-36

As shown in Fig. 6, Case 3 had an increase in the physical component from 30 to 32 (7%) and the mental component from 37 to 40 (8%) from pre to post intervention.

Case 4 had a decline from 40 to 39 (3%) in the physical component, while the mental component increased, going from 32 to 50 (56%) with a notable improvement on questions regarding levels of concentration and fatigue.

FIGURE 6

Semi-Structured interview

As shown in Table 4, emerging from these codes were the meaningfulness of engaging in an acknowledging social space with others, and the positive experience in meeting peers with the same condition and similar challenges. Cases explained how they had withdrawn from social activities due to symptoms and had experienced a loss in the ability to nurture social relationships. Both cases highlighted that attending the intervention had given them a sense of purpose and something to look forward to during the week, which they emphasized was of great importance. Here cases expressed their views on body awareness therapy as a treatment tool, and the pros and cons of this type of activity compared to other more familiar types, like aerobic exercise. Both cases experienced some difficulty conceptualizing the idea initially, which Case 3 continuously had issues with throughout the intervention. They also expressed an improved ability to detect their bodily sensations and Case 4 especially considered this a tool to help reduce unwanted tension and improve self-efficacy. The final codes revolved around reflecting on the intervention and improving ideas to apply to other protocols in the future, as expressed by the cases. The cases underscored the importance of the weekly group feedback session and conversations after each session, which was done with a focus on progression and daily strategies, and how this had helped create a constructive environment. Lastly, the cases expressed that a longer intervention duration would be needed for participants to feel fully comfortable in each other's presence, and to improve one's own presence of body and mind during the movements.

TABLE 4

4. Discussion

PCS patients are characterized by their heterogeneity and the syndrome is in many ways used as an umbrella-term for several complex and overlapping physiological and psychological pathologies. When examining the cases we found that, while having had similar experiences, they had different primary symptoms, different concerns and varying degrees of emotional and physical debilitation. Some researchers have argued that dividing PCS into various subcategories, or so called 'post-concussion disorders', could be used to improve outcomes and better treat underlying causes.[28,57–59] Others have suggested the use of the RPQ, with additional questionnaires, as a possible classification system.[60] While categorizing the cause and effect relationships remains important in advancing the treatment of PCS, the exact mechanisms between symptomatology and pathology is still unclear. Bearing this in mind, there is a need for a rehabilitation that is multifaceted, explorative and tailored to the individual.[4] To further reflect on this process, the following section will examine the nature of PCS pathology and rehabilitation through the lens of the EBD model, while contextualizing our cases.

4.1 Best Research Evidence

Dysfunction of the ANS, or dysautonomia, acutely following a mTBI has been linked to symptoms of exercise intolerance, lowered tolerance to mental and physical stimuli, decreased cognitive ability, increased stress response and emotional dysfunction.[28,61,62]Prolonged dysautonomia is prevalent in the PCS group, with a recent review finding at least one form of autonomic dysregulation in the majority of patients.[27] Evidence shows that the ANS plays a central role in psychological well-being[63–65]and that declining mental health after a mTBI is unfortunately a common occurrence,[35,66] with PCS patients demonstrating higher incidence rates of both depression and anxiety compared to controls.[67,68] Our cases reported an inability to deal with large crowds and various degrees of anxiety, frustration, worry or depression as well as reduced tolerance to external stimuli contributing to social isolation. This is in line with what is often observed in the clinical practice where many PCS patients will abstain from social activities to prevent symptom exacerbation. This abstinence functions as a negative feedback loop creating further withdrawal and worsening symptoms. Considering that prolonged social isolation is linked to poor mental health outcomes in the general population,[69,70]it is not entirely clear to what extent the relationship with PCS is causal or correlated. Furthermore, depression and anxiety might be risk factors for initially developing PCS.[71,72] Yet, studies on rodents have found evidence of causality, in which induced mTBI disrupts limbic system function, subsequently leading to long lasting depressive, fearful and anxious behavior.[73–75] Whatever the case, the neuropsychological nature of PCS makes providing psychosocial coping strategies a viable part of the multidisciplinary approach, and some reviews have supported the use of cognitive behavioral therapy in improving psychosocial outcomes[76]; however, more research is needed.

Meditation and mindfulness,[77–80] body awareness therapy,[81–83] breathing exercises and stretching,[84,85] have shown to be effective ways of modulating the ANS, lower sympathetic activity and improve biomarkers of stress in various populations. Little evidence exists on treatments specifically addressing dysautonomia as a result of mTBI, although one pilot study did show improvements in QOL and self-efficacy on a group of PCS patients after undergoing a mindfulness-based intervention.[86] Moreover, studies show that meditation can improve cognition and regulate CBF,[77,87] making it an area of interest considering that CBF disruptions are linked to mTBI and PCS symptomatology.[24,88] The efficacy of meditation techniques and body awareness strategies can vary between individuals[89] and some techniques can be harder to conceptualize than others, which was illustrated by Case 3 who expressed difficulty in this regard. Our modified BBAT intervention in Study B was directed at addressing the high arousal and stimuli intolerant state of our cases, hopefully modulating the ANS and reducing PCS symptoms. While both cases reported positive associations with the sessions, only Case 4 experienced symptom relief and significant improved QOL. Considering that the intervention lasted 3 weeks, a longer duration of exposure may have been required to more accurately assess the protocol, as a duration of up to 8 weeks has been necessary before experiencing the full benefits of similar methods.[90]

Exercise intolerance is a common phenomenon in PCS patients and all of our cases reported having experienced symptom exacerbation during physical activity. Studies have found increased blood pressure (BP), HR and arterial CO2 in PCS patients compared to healthy controls during exercise, which may be linked to the changes in CBF and a reduced ability of the ANS to regulate orthostatic BP.[22,91,92]This exercise intolerance occurs at different ranges of HR and while finding the appropriate range for the individual can be challenging, abstaining from exercise and physical activity entirely is not recommended.[92] Both cases in Study A showed a significant decrease in their PCS symptoms post-intervention and were ultimately able to increase their HR intensity, relative to their maximum HR, during exercise by 15% and 12%, for Case 1 and 2 respectively, without symptom exacerbation. However, as the cases simultaneously underwent cervical treatment, it is not possible to isolate the results of the exercise intervention completely. Yet our findings are in line with other studies showing improvements in physiological exercise biomarkers and PCS symptoms using similar protocols.[59,91,93] This may be partly due to changes in CBF, as a pilot study, using fMRI, found that PCS patients had a normalization of brain activity and CBF after the implementation of a submaximal aerobic intervention.[94] An important aspect of the protocol is keeping intensity levels below symptom threshold, before gradually increasing the intensity while assessing individual response. Early initiation of aerobic exercise has been associated with a faster recovery[95]; however, overexertion at different stages post-mTBI can be detrimental[15,96–98]and some evidence suggests that the appropriate intensity is timing-based.[99] It is therefore recommended that practitioners monitor progress under controlled conditions and with the proper testing tools. A high quality and specifically developed method for testing this is the Buffalo Concussion Treadmill Test,[100] but other testing methods with comparable protocols could be similarly applied.

Whiplash is commonly associated with PCS and exists both as part of the symptomatology, as well as a comorbidity. It has similar injury biomechanics to mTBI, such as the abrupt acceleration and deceleration of the cervical spine and head, and shares a majority of symptoms.[101] One of the underlying mechanisms behind this may be cranial nerve trauma, including the vagus nerve which regulates the ANS,[102,103] either as a direct result of impact, or as a secondary effect based on changes in arthrokinematics and joint degeneration.[104,105] Cervical trauma has been linked to oculomotor deficiencies[32,106,107] and whether as a result of whiplash or otherwise, issues with convergence, accommodation and saccades occur regularly after mTBI and often lingers in patients with PCS.[19,108] Screening for this, and possibly referring to neuro-ophthalmologic treatment, is recommended.[109]

All our cases reported cervical stiffness and pain, and evidence shows that a high prevalence of various cervical and periarticular impairments are common after a mTBI. These include postural imbalances, myofascial triggers, muscle weakness, decreased joint mobility and weakness of cervical flexors associated with cervicogenic headaches.[110,111] Considering this, and that up to 50% of whiplash patients still report symptoms a year after injury,[112] cervical pathology is a critical consideration in the PCS rehabilitation.[113–115] Both cases in Study A reported reductions in cervical associated symptoms such as dizziness, nausea, and headaches, although only Case 2 improved in CCFT grading. These findings are inconclusive, but other studies have suggested that deep flexor strengthening can have a positive effect on neck-related issues in some PCS patients[114] and that cervical and vestibular rehabilitation may reduce cervicogenic symptoms.[116,117] A variety of manual treatments may also improve outcomes, however, efficacy seems highly individual and more research is needed.[113,118] Clinically, some PCS patients are sensitive to cervical treatment and may respond with symptom exacerbation to mobilizations, manipulations, strengthening exercises and even stretching.

4.2 Clinical Expertise

When initiating the PCS rehabilitation, identifying potential physical and mental barriers to activity, and acknowledging these limitations, is an important part of the planning. The process requires submaximal testing and treatment, and a deliberate slow progression as symptom thresholds are often low in the early stages. By taking inspiration from other chronic pain protocols, a proper pacing strategy can be useful in building tolerance to the treatment,[119] and using positive reinforcement and education on the nature of PCS can help demystify the condition. This includes focusing on solutions and brain plasticity instead of limitations when communicating with the patient, after the initial explanation on pathology, and may help avoid the unwanted nocebo effects that many chronic pain patients can be susceptible to.[120,121] Setbacks and symptom volatility are to be expected even with thoughtful consideration to programming, which is why the practitioner benefits from listening to the patient and adjusting volume and intensity accordingly, as well as including an appropriate frequency of examination and re-testing. Working on acceptance of current disability may help improve emotional outcomes and patient self-efficacy,[122] and celebrating short term goals helps improve patient motivation and long term compliance.[123,124] Lastly, a key part of administering the rehabilitation is knowing when a referral is indicated and if treatment is outside the bounds of expertise of the practitioner.

4.3 Patient preferences

PCS is in many ways a "hidden condition" not easily visible and with no current standardized biomarkers for diagnosis,[125]and the path towards rehabilitation is often confusing, and uncertain, for patients and practitioners alike. Most general practitioners are not well equipped to treat PCS patients, which is highlighted by the lack of standardized care, and rest is often the only offered treatment strategy. Our cases expressed dissatisfaction with their healthcare providers and felt neglected, as well as not having been taken seriously. One of the emerging themes derived from the cases was the importance of meeting other patients in similar circumstances who could relate to them and inhabit an acknowledging space to freely share experiences and discuss daily obstacles. This acknowledgement and social exchange was seen as a central part of coping with the condition, and should be viewed by practitioners as a legitimate consideration for rehabilitation in the clinical practice. The use of deliberate framing and the facilitation of a constructive and accommodating environment in our studies were beneficial in dealing with the psychosocial challenges. Cases further highlighted that being in a safe environment, and adjusting for unwanted mental and physical overstimulation, resulted in less exacerbation of symptoms. Besides the benefits of rehabilitation on their mood, stamina and cognitive function, our cases expressed a sense of meaning in their daily lives when having something to attend, especially considering that three of the cases were on sick leave, with none regularly engaging in scheduled social events. The interventions themselves were seen as motivating factors, regardless of any improvement in symptoms, suggesting that an active approach has an inherent advantage compared to a passive or non-active approach even before considering outcomes. Through the gathering of the qualitative data, including the group feedback sessions, our cases helped clarify valuable areas of concern illuminating patient preferences and individual perspectives on the intervention protocols which would not have been possible otherwise.

4.4 Model of Conclusion

By taking advantage of the three dimensions of the EBP model as a methodological approach to the PCS cases, this paper incorporated the: Best Research Evidence, Clinical Expertise and Patient Preferences, through an examination of the benefits of two distinct intervention protocols. These results illustrate how an active and individualized approach can represent important qualities that can be applied into further and larger studies, and we recommend additional studies regarding exposure to active, individualized and graded treatments to patients dealing with PCS. Based on the results and discussion in this paper, we have summarized relevant findings and suggestions in the following modified EBP model (Fig. 7), which may be of help to practitioners in the clinical practice.

FIGURE 7

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Conflicts of Interest Statement

The authors declare no conflicts of interest.

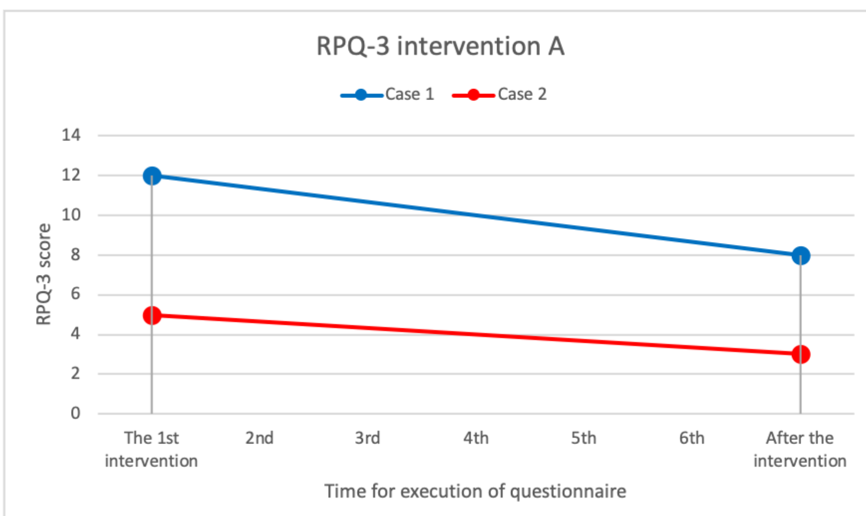


Figure 1 - Results from the Rivermead Post Concussion Questionnaire RPQ-3 score for Study A – Case 1 and 2 - conducted at first intervention and after the intervention. RPQ-3 score includes symptoms of headache, dizziness and nausea. Each symptom is scored from 0 to 4 – 0=not experienced at all, 1=no longer a problem, 2=a mild problem, 3=a moderate problem, 4=a severe problem. RPQ-3 range: 0-12

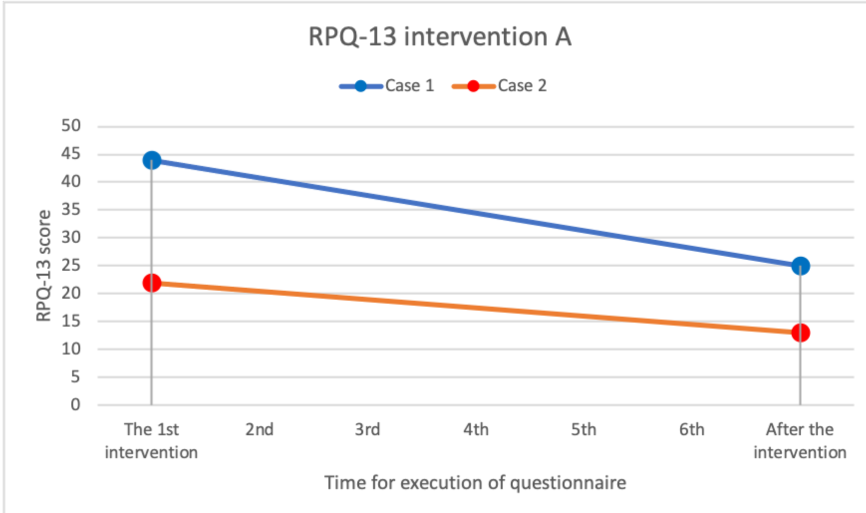


Figure 2 - Results from the Rivermead Post Concussion Questionnaire RPQ-13 score for case Study A – Case 1 and 2 – conducted at first intervention and after the intervention. RPQ-13 score includes symptoms of noise sensitivity, sleep disturbance, fatigue, irritability, depression, frustration, poor memory, difficulty concentrating, reduced cognitive function, blurry vision, light sensitivity, double vision and restlessness. Each symptom is scored from 0 to 4 – 0=not experienced at all, 1=no longer a problem, 2=a mild problem, 3=a moderate problem, 4=a severe problem. RPQ-13 range: 0-52

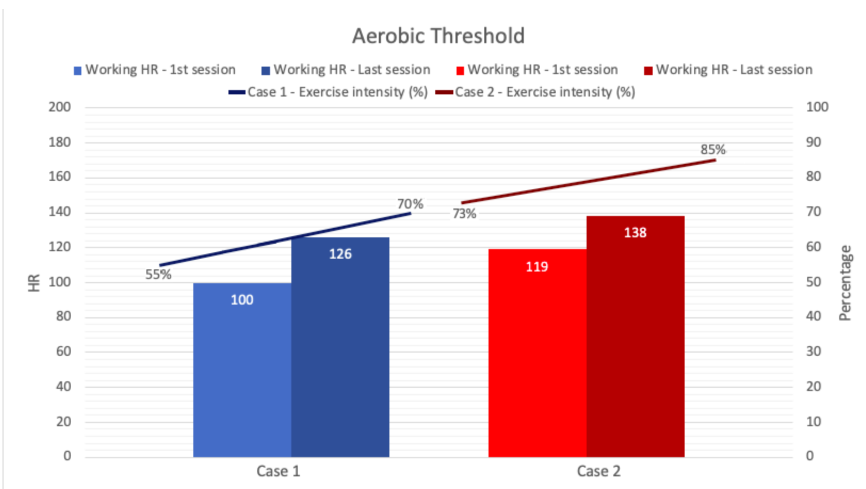


Figure 3 - Graphic illustration showing the absolute HR and the exercise intensity, expressed in percentages, first session and last session for Case 1 and 2 in Study A

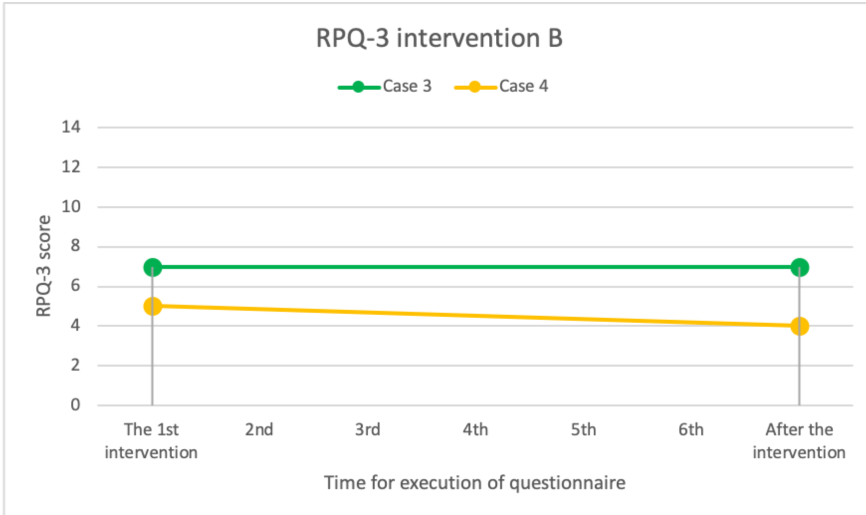


Figure 4 - Results from the Rivermead Post Concussion Questionnaire RPQ-3 score for case Study B – Case 3 and 4 - conducted at first intervention and after the intervention. RPQ-3 score includes symptoms of headache, dizziness and nausea. Each symptom is scored from 0 to 4 – 0=not experienced at all, 1=no longer a problem, 2=a mild problem, 3=a moderate problem, 4=a severe problem. RPQ-3 range: 0-12

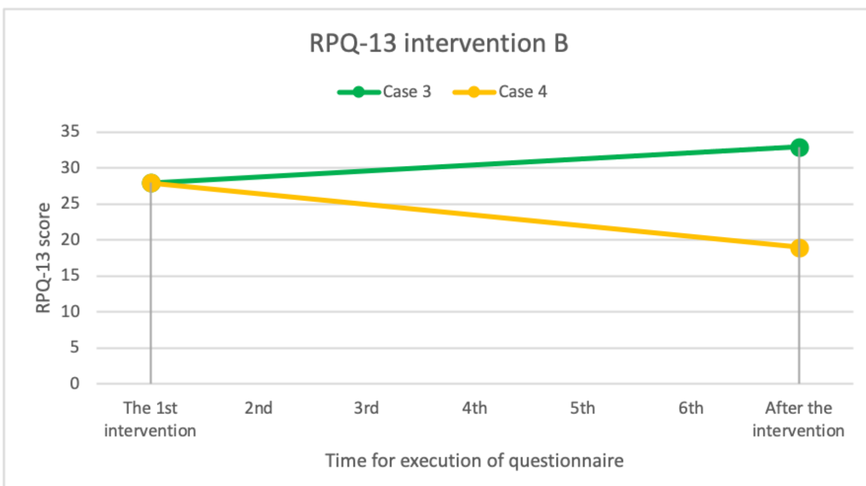


Figure 5 - Results from the Rivermead Post Concussion Questionnaire RPQ-13 score for Study B – Case 3 and 4 - conducted at first intervention and after the intervention. RPQ-13 score includes symptoms of noise sensitivity, sleep disturbance, fatigue, irritability, depression, frustration, poor memory, difficulty concentrating, reduced cognitive function, blurry vision, light sensitivity, double vision and restlessness. Each symptom is scored from 0 to 4 – 0=not experienced at all, 1=no longer a problem, 2=a mild problem, 3=a moderate problem, 4=a severe problem. RPQ-13 range: 0-52

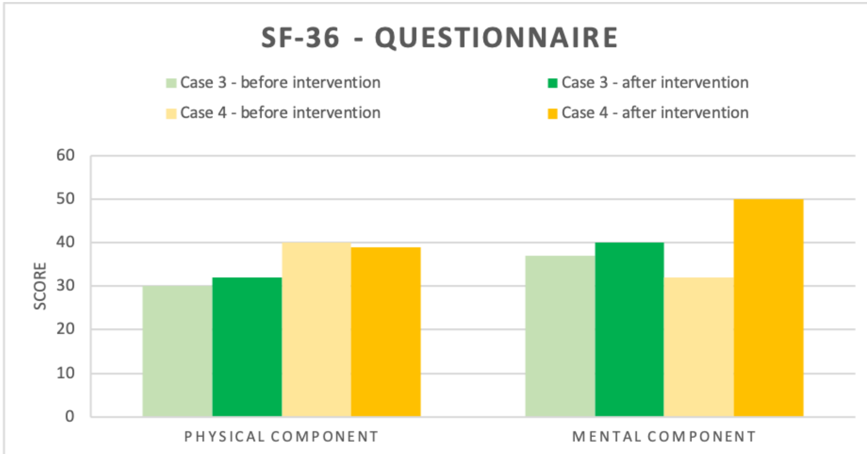


Figure 6 - Results from the SF-36 questionnaire for Study B – Case 3 and 4 – conducted before the first intervention and after the last intervention. The questionnaire is separated into mental and physical health, with higher scores signifying better quality of life

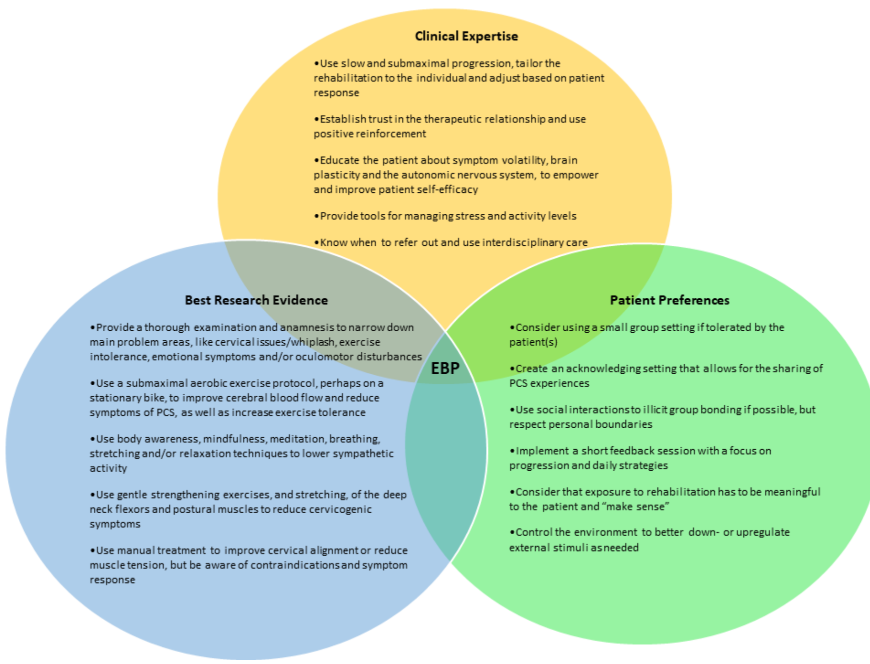
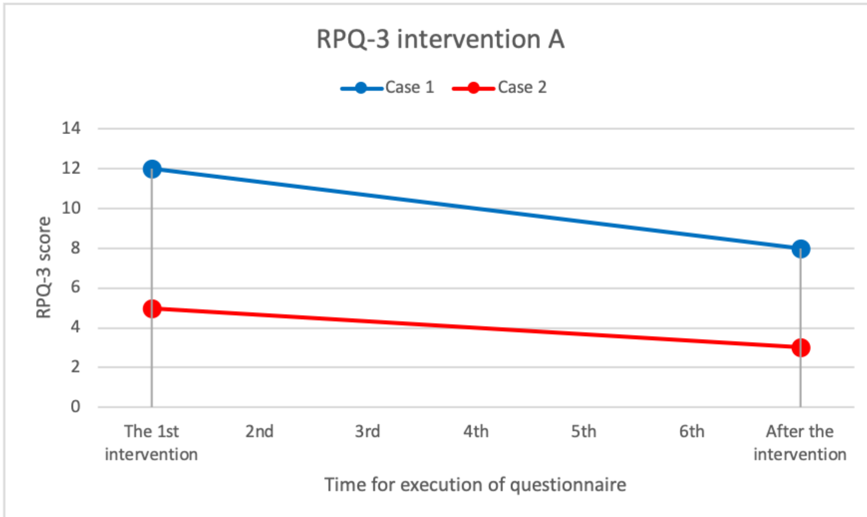
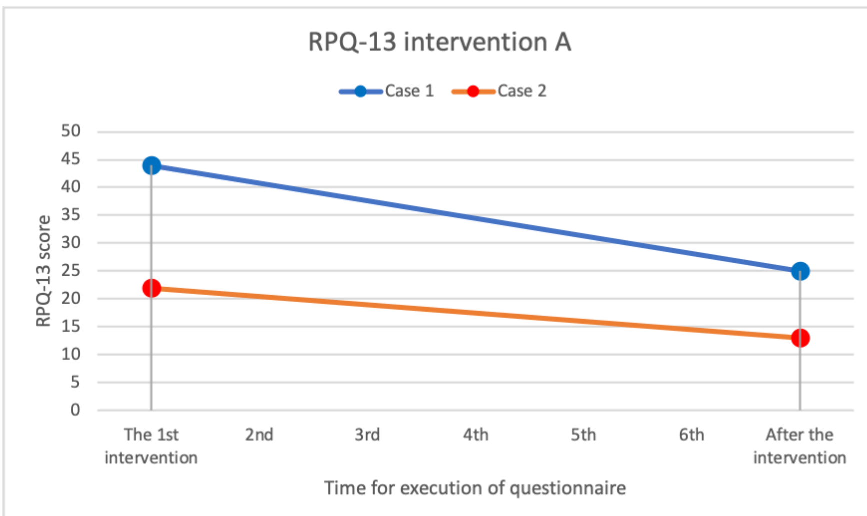
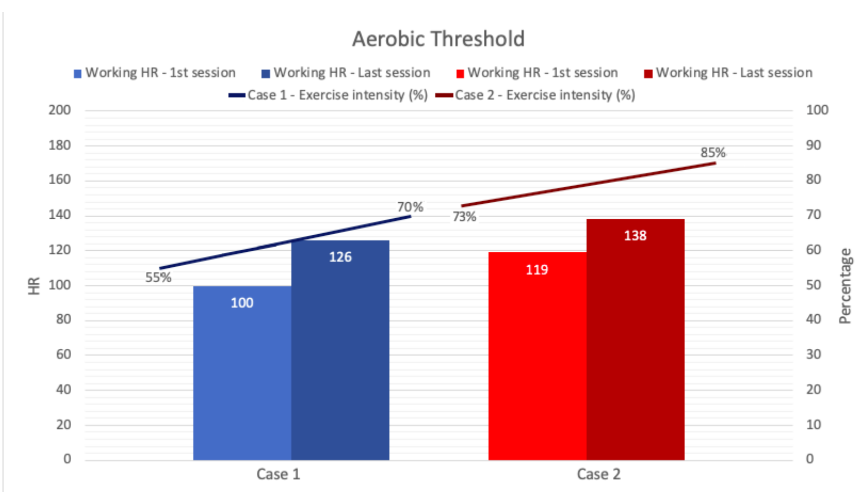
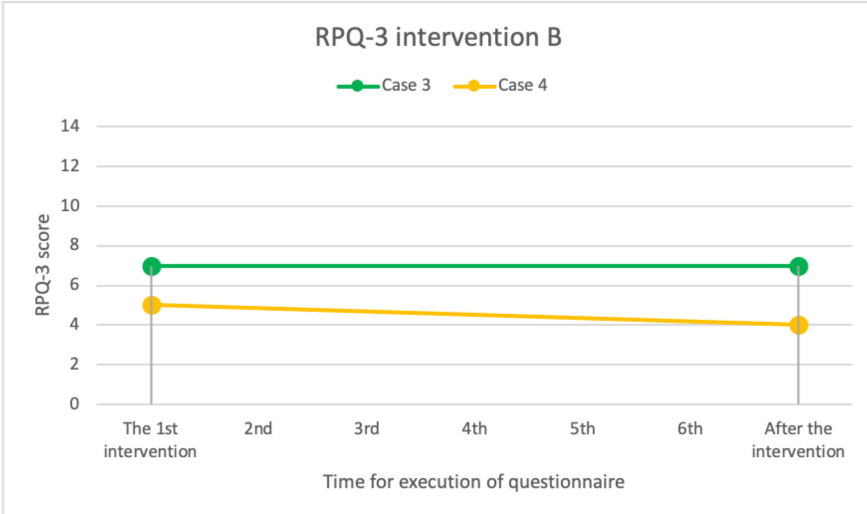


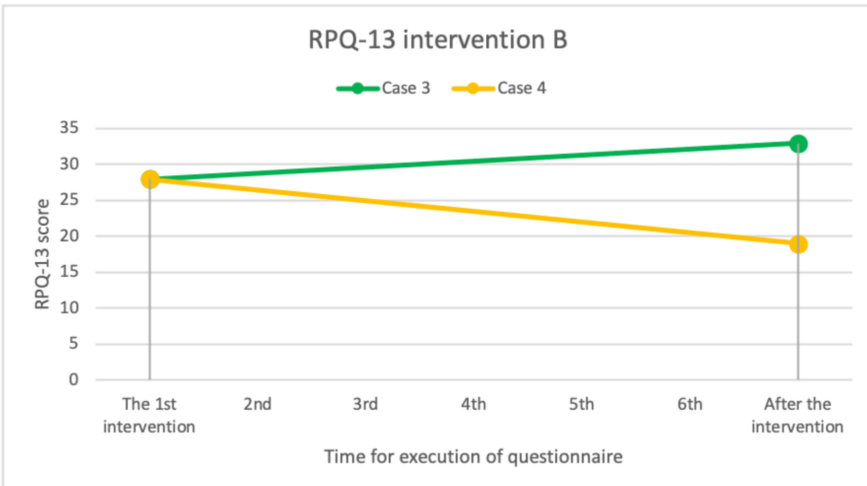
Figure 7 - The modified EBP model directed at treating PCS in the clinical practice, with bullet point suggestions encompassing the three dimensions of Best Research Evidence, Clinical Expertise and Patient Preferences

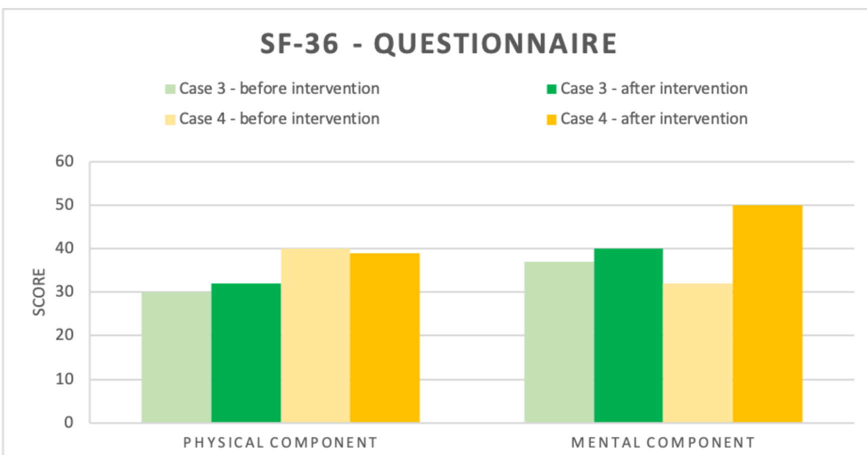

RPQ-3 intervention A
Case 1
Case 2
14
12
10
8
6
4
2
0
RPQ-3 score
The 1st intervention
2nd
3rd
4th
5th
6th
After the intervention
Time for execution of questionnaire

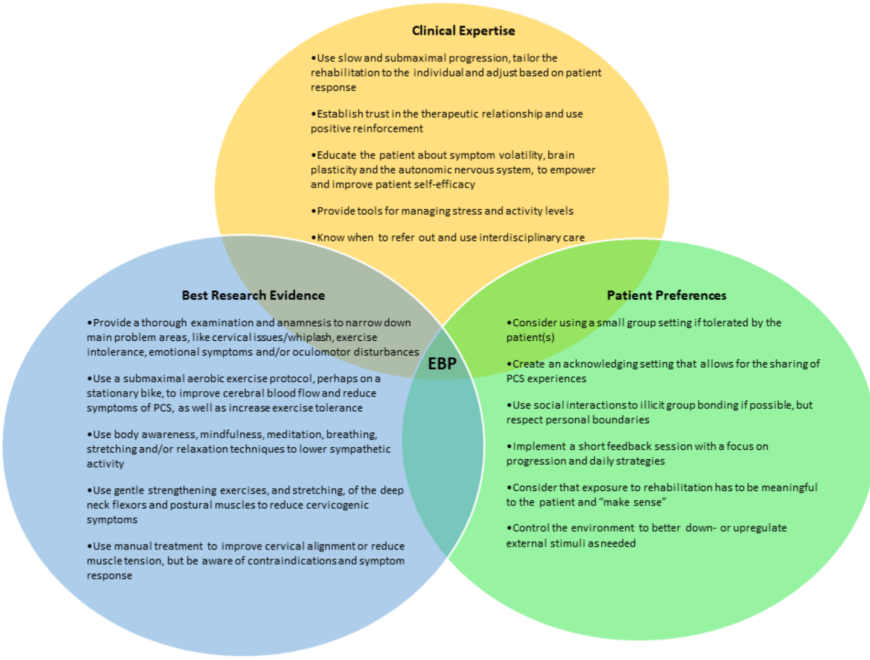

RPQ-13 intervention A
Case 1
Case 2
50
45
40
35
30
25
20
15
10
5
0
RPQ-13 score
The 1st intervention
2nd
3rd
4th
5th
6th
After the intervention
Time for execution of questionnaire


Aerobic Threshold
Working HR - 1st session
Working HR - Last session
Working HR - 1st session
Working HR - Last session
Case 1 - Exercise intensity (%)
Case 2 - Exercise intensity (%)
HR
Percentage
55%
70%
73%
85%
100
126
119
138
Case 1
Case 2


RPQ-3 intervention B
Case 3
Case 4
RPQ-3 score
14
12
10
8
6
4
2
0
The 1st intervention
2nd
3rd
4th
5th
6th
After the intervention
Time for execution of questionnaire


RPQ-13 intervention B
Case 3
Case 4
RPQ-13 score
35
30
25
20
15
10
5
0
The 1st intervention
2nd
3rd
4th
5th
6th
After the intervention
Time for execution of questionnaire


SF-36 - QUESTIONNAIRE
Case 3 - before intervention
Case 3 - after intervention
Case 4 - before intervention
Case 4 - after intervention
SCORE
60
50
40
30
20
10
0
PHYSICAL COMPONENT
MENTAL COMPONENT



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