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Case report

Reduced exertion high-intensity interval training (REHIT) in an adult with Cystic Fibrosis: A mixed-methods case study

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ABSTRACT

Although aerobic capacity has been identified as an important predictor of mortality in Cystic Fibrosis (CF) individuals, many remain insufficiently active. As a '*lack of time*' is a commonly cited barrier to exercise, reduced-exertion high-intensity interval training (REHIT) may provide a truly time-effective method to increase aerobic capacity. Six-weeks of REHIT in a CF individual was assessed by a cardiopulmonary exercise test (CPET) and individual perceptions described using a self-report narrative. Peak oxygen uptake ($\dot{V}$ O_2peak) increased by 6% whilst pulmonary function remained unchanged. Qualitative data indicated social support and low-time commitment positively influenced adherence with fatigue and lack of enjoyment noted as a significant barriers. REHIT was demonstrated as a viable, manageable option for a CF individual with moderate-severe pulmonary limitation. Further research is needed to determine the efficacy of REHIT in a large representative sample to ascertain whether it represents an alternative treatment strategy.

1. Introduction

Cystic Fibrosis (CF) is one of the most common, life threatening genetic disorders, affecting more than 10,400 people, in the UK [1]. Due to a defect in the CF trans membrane conductance regulator (CFTR), CF is associated with a range of systemic disorders but is primarily characterised by a build-up of abnormally thick mucus in the gastrointestinal tract and lungs leading to nutritional deficiencies, exercise intolerance, recurrent and chronic respiratory infections, and finally, respiratory failure [1]. Peak aerobic capacity (peak $\dot{V}$ O_2) is one of the strongest predictors of prognosis and mortality in individuals with CF [2]. The growing body of evidence suggesting that exercise interventions can elicit improvements in aerobic capacity, as well as strength, quality of life and pulmonary function [3] is therefore of major clinical importance.

Despite the benefits associated with exercise, there is a tendency for individuals with CF to accumulate less moderate-to-vigorous physical activity (MVPA) than their healthy peers, with significantly fewer females achieving more than 30minutes of daily MVPA [4]. As individuals with CF have to accommodate extensive daily treatment regimes alongside professional and personal commitments, many report a *lack of time* as a significant barrier to exercise [5]. As such, high-intensity interval training (HIIT) has been proposed as a time-efficient alternative to traditional moderate-intensity continuous exercise. Although research investigating the potential efficacy of HIIT in a CF population is limited, it appears that HIIT is able to elicit increases in peak oxygen uptake ($\dot{V}$ O_2peak) across a range of disease severities [6]. However, the time efficiency of these HIIT protocols is highly questionable, with a total time commitment exceeding 30-min per session towards the end of the training programme [7]. As such, total time commitment over a weekly period may ultimately fail to overcome barriers to exercise associated with a lack of time, leaving a need to identify whether current HIIT protocols can be modified to elicit positive exercise adaptations with a lower time commitment.

In healthy adults, Metcalfe et al. [8] demonstrated that reduced-exertion high-intensity interval training (REHIT), involving two 20s Wingate sprints within a 10 minute exercise session, three times a week for six weeks, provides a sufficient stimulus to elicit a 14% increase in $\dot{V}$ O_2peak. These findings suggest that the efficacy of HIIT may not be related to the number of sprints *per se*, but rather the intensity associated with these sprints. Furthermore, although there is debate as to whether such intense exercise programmes are appropriate for use by the general population [9] REHIT only becomes associated with more negative affect, compared to moderate intensity continuous training

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(MICT), when sprint repetitions are increased [10]. Given the substantially reduced time-commitment of the REHIT protocol, overall exposure to negative affect is brief when compared to a longer duration MICT protocol. Taken together with the suggestion that HIIT may elicit favourable physiological adaptations whilst placing a lower toll on the respiratory system [11], REHIT may therefore represent a more preferable, and sustainable, exercise option for those with CF.

As individuals' perceptions of exercise are influenced by their baseline fitness levels and physical activity status [12], it could be suggested that many within the CF population may feel physically 'incapable' and insufficiently motivated to adhere to the intense REHIT protocol, especially those who are largely sedentary. Moreover, in addition to capability and motivation, enjoyment plays a key role in exercise adherence. Whilst there is growing evidence to suggest that REHIT may be more enjoyable when compared to MICT in inactive individuals [8], there remains a need for a better understanding of individual's phenomenological experience of high-intensity exercise. Although quantitative measures may provide an indicative value of 'enjoyment', this gives limited information regarding how the exercise experience can be manipulated to improve positive affect, enjoyment and long-term adherence. Given that the barriers to exercise within a CF population are multi-faceted, there is a need for researchers to adopt qualitative methods in order to explore in greater detail, whether high-intensity exercise can be suitable for a CF population.

If the results of the REHIT protocol in sedentary individuals can be replicated within a CF population, it may offer a novel, and truly time-effective exercise modality that can help improve markers of cardiorespiratory health. Therefore, the aim of this case study was to understand the potential efficacy and sustainability of REHIT within a CF population. Qualitative methods were used to identify CF-specific exercise enablers and barriers that may need to be taken into account before the protocol can be delivered to a larger population.

2. Case report

2.1. Participant

A 25-year old male, diagnosed with Cystic Fibrosis (homozygous F508del) at the age of two years, and currently being treated at the Manchester Adults Cystic Fibrosis Centre at the University Hospital of South Manchester (UHSM), was recruited for this case study in September 2018. His disease was characterised by pancreatic insufficiency and chronic infections with Pseudomonas aeruginosa, non-tuberculous mycobacterium abscesses (NTM) and allergic bronchopulmonary aspergillosis (ABPA) for over five years. Since January 2018, his FEV_1 had remained stable at around 2.34 L and he has had no inpatient admissions or intravenous antibiotics since June 2016. He is currently physically active and participates in Olympic weightlifting 3–4 times per week. As the participant experienced an acute exacerbation in December 2018, he was required to complete two-weeks of oral antibiotics and, subsequently, was unable to complete the intended six-week follow-up.

3. Experimental design

A mixed-methods case study design was adopted to address the aims of the study, where conclusions were drawn from the collection and analysis of both quantitative and qualitative data. The participant underwent pre- and post-intervention testing for $\dot{V}O_2$peak and pulmonary function. Measures of pulmonary function were completed at UHSM, during clinic appointments booked in line with the study requirements. All other measurements, along with the training protocol, were completed at Swansea University. Ethical approval for data collection was approved by the College of Engineering Research Ethics Committee at Swansea University (July 2018, No: 2018-071).

3.1. Pulmonary function

Forced expiratory volume in 1 second (FEV_1) and forced vital capacity (FVC) were measured at rest using a spirometer (EasyOne, ndd Medizintechnik AC, Zurich), following the British Thoracic Society guidelines [13]. The highest FEV_1 and FVC values were chosen from at least three efforts.

3.2. Cardiopulmonary exercise test (CPET)

Peak $\dot{V}O_2$ was determined by an incremental ramp test on an electronically braked cycle ergometer (Lode excalibur sport, Lode, The Netherlands). The participant completed a warm-up, pedaling at between 60 and 80 revolutions per minute (rpm) against a 20 W load for 3 minutes. The workload was subsequently increased by 20 $W \cdot min^{-1}$ until volitional exhaustion at which point a cadence of 60–80 rpm could no longer be maintained, despite strong verbal encouragement. To validate that it was a true maximal effort, the participant completed a supramaximal verification test to exhaustion (S_{max}), following at least 15 minutes of recovery. Specifically, a 3 minute warm-up at 20 W was followed by a 'step transition' to 110% of the peak power achieved during the incremental test, which the participant was asked to maintain for as long as tolerable. During both the incremental test and S_{max} test, the participant breathed through a low-dead space facemask and breath-by-breath gas exchange was measured (Vyntus CPX metabolic cart, Vyaire Medical, Illinois, USA). $\dot{V}O_2$peak, peak carbon dioxide output ($\dot{V}CO_2$) and peak minute ventilation ($\dot{V}E$) were determined using the highest value from a 15 second moving average. The gas exchange threshold (GET) was identified using the V-slope method and the oxygen uptake efficiency slope (OUES) was determined according to the following equation:

$$\dot{V}O_2 = a(\log \dot{V}E) + b$$

where the constant a is defined as the OUES and b is the intercept with the y-axis. OUES was calculated using data up to and including three different thresholds (50%, 75%, 100% of $\dot{V}O_2$peak).

3.3. Quality of life and fatigue index

During both pre- and post-testing visits, the participant completed a quality of life questionnaire (Cystic Fibrosis Questionnaire – CFK-UK) [14]. This validated questionnaire consists of twelve scales with scores ranging from 0 to 100, where higher scores represent a reduced frequency of symptoms and a higher QoL. The participant also completed the Checklist Individual Strength Questionnaire (CIS). This validated questionnaire has been used in both CF and chronic obstructive pulmonary disease (COPD) to assess fatigue [15]. Higher scores indicate a higher degree of fatigue, greater problems with concentration, reduced motivation and less physical activity. A score of 35 or higher is used to define severe fatigue in adults.

3.4. Training protocol

Akin to Metcalfe et al. [8], the participant completed a modified version of the REHIT protocol (Table 1), three times per-week, with at least 24-h recovery between sessions, for a six-week period. All sessions were completed on a mechanically braked cycle ergometer (Ergomedic 874e, Monark, Vansrbo, Sweden) and lasted 10 minutes in total, including warm-up and cool-down. Prior to each sprint, the participant was asked to increase pedal cadence against no resistance before a breaking force of 7.5% body weight was applied to the cycle ergometer for the specified sprint duration. Rate of perceived exertion (RPE) was collected immediately after each session using the 15-point Borg scale. At the same time-point, a subjective measure of dyspnoea was collected using the modified Borg dyspnoea scale.

Table 1
Example interview questions. Further questions are available upon request from the lead author.

Pre	Post	12-h post
What are your thoughts on today's session?	What were the most enjoyable aspects of the session [if any]?	Are you thinking/feeling differently towards today's session?
	What were the most enjoyable aspects of the session [if any]?	
What are your expectations regarding today's session?	What factors enabled you to complete the session?	Was the exercise easy to fit in with your day?

Pre – Completed before the exercise session, Post – Completed following the exercise session, 12-h post, Completed at least 12-h post completing the exercise session.

3.5. Case study

The case study approach offers an in-depth exploration of the REHIT protocol in an individual with CF. Though generalisability is limited, the case study allows for a detailed understanding of an individuals perception towards the REHIT protocol and identifies enablers and barriers which may encourage and inhibit the implementation of REHIT in future research or as an exercise prescription. Indeed, future research, informed by this case study, should endeavour to proactively promote any exercise enablers, and directly address the negative aspects of REHIT, in order to minimise attrition rates and ultimately gain an understanding of the potential physiological and psycho-social benefits that REHIT can provide the wider CF population.

3.6. Self-report narrative

To explore in detail the personal experience of the training intervention, the participant was asked to complete a self-report narrative over the six-week period. This was conducted pre-, post- and 12-h post-exercise. The participant answered a series of open-ended, 'interview style' questions, relating to their feelings, expectations, motivation and challenges they associated with each specific session. The first and second author developed the series of questions, examples of which are shown in Table 1.

In line with Teddlie & Tashakkori [16], all questions included written probes to remind the participant to elaborate on points where necessary. The participant's narrative was analysed through qualitative content analysis [17]. All forms of recorded communication were transcribed verbatim and read several times to ensure familiarisation. The transcripts were examined and quotations/phrases extracted, providing pertinent examples of the participant's thoughts, feelings, expectations and behaviours before, during and after a REHIT session, in order to assess the suitability of, and challenges presented by, the protocol and how the individual was able to overcome these. All quotations/phrases with a similar meaning were categorised into the main themes, which in turn were collated further into sub-themes to provide a detailed narrative. Authors one and three independently analysed the data and reached a consensus on the themes and sub-themes.

4. Results

The participant characteristics pre- and post-intervention are shown in Table 2. At the end of the six-week intervention, there was no change in body mass or BMI. The adherence to the training programme was good, with an attendance rate of 94% (17/18 sessions). The reason for absence was exhaustion from an unsettled night due to persistent coughing.

Table 2
Participant characteristic data.

	Baseline	Post-Training
Age	25	25
Height (cm)	171.5	171.5
Weight (kg)	66.8	66.9
BMI (kg/m^2)	22.7	22.7
FEV_1 (L)	2.34	2.32
FEV_1 (% predicted)	54	53
FVC (L)	3.46	3.45
FVC (% predicted)	66	66
$\dot{V}O_2$peak ($L \cdot min^{-1}$)	2.54	2.70
$\dot{V}O_2$peak ($ml \cdot kg \cdot min^{-1}$)	38.0	40.4
V_E ($L \cdot min^{-1}$)	122.1	121.4
GET (%$\dot{V}O_2$peak)	55	59
OUES (50% $\dot{V}O_2$peak)	1,249.0	1,229.4
OUES (75% $\dot{V}O_2$peak)	1,909.2	1,953.6
OUES (100% $\dot{V}O_2$peak)	2,592.6	2,655.6

Pre/Post intervention measurements, BMI: *Body mass index*.

4.1. Physiological measures

At the end of the six-week intervention, there was no difference in pulmonary function. In contrast, the REHIT protocol resulted in an increase in $\dot{V}O_2$peak of 6.3% and 6.1% when expressed in absolute terms or relative to body mass. Furthermore, the GET increased by 7% and OUES increased at both 75% and 100% of $\dot{V}O_2$peak.

4.2. Subjective measures (RPE, dyspnoea, HRQoL, CIS)

Overall, the training intervention was well-tolerated by the participant, with a mean six-week RPE score of 14, corresponding to 'somewhat hard'. Mean weekly RPE values peaked in Week 4. The mean dyspnoea score for the 6-week intervention was 4, corresponding to 'somewhat severe'. Mean weekly dyspnoea scores peaked in weeks 4 and 6, with a score of 5, corresponding to 'severe'. Following the six-week intervention, higher scores in the HRQoL questionnaire were found in the Physical (+33%) and Digestive (+13%) domains, whereas decreases were identified in the Emotional (9.08%), Treatment (50%), Body Image (20%) and Respiratory (27%) domains. There were no changes in the remaining domains. All measures from the CIS fatigue index showed decreases following the six-week intervention with the total score decreasing from 70 to 56 (20%). The largest decrease (44%) was the physical activity domain.

4.3. Qualitative findings

Three over-arching dimensions were identified: *motives towards taking part in the protocol; maintaining exercise protocol involvement; and barriers to adhering to the exercise protocol.* Please note that a pseudonym has been used throughout the following narrative.

4.3.1. Motives towards taking part in the protocol

The main motives for taking part in the protocol were: i) history of Physical activity (PA) and exercise for health management; and ii) not being defined by CF.

i) History of PA and exercise for health management

Ben had always been an active individual, with the pre-conceived notion that *"exercise will keep me well"* based on his mother's influence and beliefs. He has (until 2016) been active within martial arts since the age of 10 years, and as an adult was training up to 10 times per-week. After experiencing a significant knee injury, Ben's inactivity over a period of over 12-months led to him becoming underweight and

experiencing a significant decrease in lung function and capacity to complete daily tasks. Therefore, to improve his day-to-day functioning and quality of life, he joined an Olympic weightlifting gym and has been an active member for the last two years, which, "*helped improve my health and helped me gain weight*". As a result, his lung function over the last year has been stable, although significantly lower than the previous few years. Therefore, for Ben, the key motive to exercise and engage within the protocol was to help maintain his overall health and "*make day-to-day life easier*". Specifically, he wished to undertake the protocol to "*test*" himself, see whether he could "*still do what I used to be able to do"* and ascertain if he could improve his health any further.

ii) Not being defined by CF

While Ben stated that he was more symptomatic as he aged (due to multiple chronic infections), he believed that engaging in this exercise protocol and improving his fitness may help him maintain his goal of not being defined by his CF; *"…whilst CF is a part of me; I never want to be defined by it"*. For Ben, exercise represented an "*escape from reality"*, a place where he was able to be *"normal"* and not have to think about treatment or the daily routine that comes with CF: *"I can be a different person [when exercising]…where my only thoughts are to do with the exercise and the social environment that goes with that. At home I have CF. In the gym, I am Ben who lifts weights"*. Accordingly, taking part in the exercise protocol provided Ben with an opportunity to "escape" CF, but also try and maintain control over his condition (rather than vice versa): *"I have CF, but that doesn't mean CF should stop me doing things. It makes things difficult but if I can keep well and keep fighting then I can avoid CF's control for as long as possible"*.

4.3.2. Maintaining exercise protocol involvement (enablers)

The key reasons for sustained protocol involvement were: i) initial positive feedback; ii) short-term exercise commitment; iii) visualization; iv) management and planning of exercise; and v) social support.

i) Initial positive feedback

Ben's performance in the baseline test provided him with reassurance that his fitness was "*better than I thought*", and led to the belief that he was capable of completing the REHIT protocol "*I used to think that I would be less fit as my lung function declined. I have now learned this isn't necessarily the case."* Thus, this initial positive feedback not only enhanced Ben's perceived capability (self-efficacy) to exercise and complete the protocol, but also raised his desire to improve his fitness further: *"I came into this [protocol] happy with my $\dot{V}O_2$ if it was at 20. So, 38 is crazy! But I still want to see if I can improve"* Furthermore, Ben identified that the baseline score had reinforced his belief that the effort directed towards his exercise regime over the last two years had been worthwhile, and it provided further motivation to explore whether the additional cardio-based exercise would continue to improve his fitness capacity.

Of note, the increased self-efficacy gained from the baseline testing, prompted Ben's desire to exert more effort during the exercise protocol: *"…not that I would have gone less than 100%, but these results gave me the knowledge that I can complete this to a decent standard"*.

ii) Low time-commitment

The structure of the REHIT protocol, with its low time-commitment and limited amount of high-intensity work, was a main contributing factor to taking part and then adhering to the exercise programme: "*the whole 10 minutes thing is a massive motivational factor. If the session was 30-45 minutes I would have found it very hard to justify to myself that it would be worth doing when I was so tired"*. Given the large time-commitment to treatment and increased fatigue amongst most individuals with CF, Ben proposed that REHIT may represent a time-efficient strategy that may help implement exercise into their daily lives. He felt it represented a low-volume alternative to "*traditional*" endurance training, which may appeal to those who want to improve their fitness, and/or prefer a low-volume exercise option. Similarly, given that improved health was one of Ben's main motives to begin the protocol, the potential to achieve this goal in such a short space of time was an important driver for adherence, *"I mean it's pretty hard to argue that only 10 minutes of your day is needed to potentially make your life a little easier"*.

iii) Visualization

The use of psychological skills played an important role in continued adherence to the protocol**,** particularly during the tough sessions, and on days where Ben did not want to attend. This mainly included visualization, where he would imagine the consequences of non-compliance and successful completion: "*I visualized how I would feel if I missed a session…then visualizing myself after the session and the good feeling I have of completing a session… and then visualizing the end of the programme when it has all been worth the effort"*. He had learnt this strategy through his treatment programme; *"I do the same with my treatment, as at times when I can't be bothered, I have to sit down and rationalize how I'm going to feel afterwards and how is it going to affect me long-term… normally I feel guilty and end up doing it"*.

iv) Management and planning of exercise

Ben did find that the intensity required for each session of the protocol was difficult, and after experiencing fatigue at the end of week 2, he chose to re-structure his current physical activity and daily schedule: "*…managing your week is very important to avoid both mental and physical exhaustion"*. For him, this planning enabled him to recover and feel physically *"less exhausted"*, thereby giving him the opportunity to sustain involvement. Ben stated that *"…once I planned things properly, I knew I could manage the workload and my worries went away. It gave me the boost to know that I could still do this despite going through a tough period"*.

v) Social support

Ben consistently referenced the support of a peer (i.e., researcher overseeing each exercise session) as a critical factor in enabling him to sustain involvement in the protocol. He believed that this person was, "*in it with me",* and so was invested in his successful completion of the protocol. Ben was also able to discuss his experiences and feelings (whether positive or negative) with a researcher, and such a sounding board helped rationalize his own feelings. Moreover, feedback from someone who was witnessing the exercise first-hand was considered highly motivating: "*My training partner today though said my sprints were much faster and my recovery was a lot better than Friday. This feedback is great, I think even if you feel you have had a bad session it may look a lot easier on the eye, and that changes your perception of the training session all together… having someone with you does give you that extra 1% you need just to going out the last few seconds"*. Accordingly, social support (informational and emotional) enabled Ben to perceive a bad session more positively and notice the fitness improvements that were occurring through the testing: *"It [social* support*] helps because it [the protocol] never…feels easier, and I didn't notice I was getting better. So the feedback helped me know that I am getting fitter…and knowing that kept me coming back"*.

Ben emphasised that the support provided by the peer/researcher also helped his motivation during each session, by offering encouragement and the exercise goal of counting down the remaining time: *"…we went with a 10 second count down so I knew how long I needed to keep pushing for"*. He also stated that this strategy was only effective during the last part of the sprints, and when the supporting peer verbalized the countdown: *"I have tried things like this in the past and if I watch the clock*

myself everything seems to go so much slower and then I slow down before the end because I know I am almost done. So, if you have someone helping you get through that last 10 seconds it keeps you going". Overall, Ben concluded: *"…this protocol definitely needs someone to oversee it… because without them, and their encouragement, and their investment, it would have been very easy to slack off when it got tough"*.

4.3.3. Barriers to adhering to the exercise protocol

The following barriers to exercise protocol adherence were identified and overcome by Ben: i) aggravating symptoms; ii) lack of enjoyment; and iii) fatigue.

i) Aggravating symptoms

Prior to the exercise protocol, Ben discussed how adverse physical reactions had prevented him participating in certain types of exercise and had created concerns regarding the current protocol: "*…obviously physical symptoms after doing cardio are never nice. Being sick, breathless, wheezing and a tight chest is something people with CF know is going to be part of their day-to-day life anyway. So why exacerbate it further with this exercise?"*.

Indeed, due to past negative experience of aerobic activity, in a period when his health was declining, Ben had chosen to undertake exercise that did not exacerbate his symptoms. Thus, given his understanding of this particular type of protocol, Ben hoped it would present an opportunity to overcome the perceived barriers associated with exertion (i.e., breathlessness): *"If this was a long duration, continuous exercise protocol I would have 100% avoided it. I know I cough doing stuff like that so what's the point"*. Moreover, as it was completed in an environment where his condition was understood, his symptoms could have been managed without any explanation, which was considered important.

Thus, Ben reinforced the importance of experiencing a positive physical response, and gaining confidence, early in the exercise programme: *"Once I got the first few sessions out the way and realized, you know what, I'm not actually coughing, then my confidence just doubled… it was nice to be able to push myself again without coughing or throwing up"*. Moreover, by the time Ben had experienced any symptoms (Week 3), the fact that he was able to continue, gave him further belief in being able to overcome such barriers; *"Today I actually had a little cough during the rest after the first sprint. Nothing major but I am sure in the past that would have put me off doing another sprint just in case it got worse…I think the fact that it passed so quickly and I recovered in time to give 100% in the second sprint; just helped me believe I can do this"*.

ii) Lack of enjoyment

Though the sessions were perceived as manageable and Ben overcame many of the barriers to partaking in PA, he stated that he didn't particularly enjoy the protocol due to its level of intensity: *"On paper, two 20's sprints looks easy, but the resistance is so much that it completely alters how the session feels!"* Ben noted that whilst he eventually got used to the intensity of each session, when time increases were implemented, these were the sessions he least looked forward to: *"You spend weeks getting used to 15s sprints and can just about manage them, then they increase and it feels like two steps back…20s almost seems impossible before you do it"*.

However, Ben believed that his background in high-intensity sports played a significant role in maintaining adherence: *"I have experience in grinding through sessions and looking at the bigger picture, even though at the time things don't feel pleasant…Maybe for those who don't have this experience, they may find things more difficult"*. Ben explained that as not every session was unpleasant, he tried to rationalize afterwards, why that particular session may have been more difficult or less enjoyable. Taking into consideration sleep, nutrition, daily activity and stress, Ben stated that he was able to account for his lack of enjoyment and look to correct that for future sessions. Similarly, Ben identified that he would try to remember why he was taking part in this process, and revisited his belief that this programme would be beneficial in the long-term: *"I know every session can't be enjoyable, that's the case in every sport. But with this, I know it is only short-term and whilst not always enjoyable, I can see my goal at the end and that's what keeps me going. I want to be fitter and one bad session will not deter me from achieving that"*.

iii) Fatigue

Whilst Ben was able to complete the protocol, fatigue was a major barrier to adherence, especially during the first 3 weeks. An inability to manage the programme alongside his own physical activity left Ben, *"mentally and physically exhausted …"* and increasingly amotivated, *"I don't know how I'm going to do six-weeks of this"*. His main concern was that the feeling of exhaustion had the potential to manifest itself as an infection or period of illness: *"as I kid I ran myself into the ground exercising without knowing it and got an infection which I have never got rid of since…Whilst I love to push myself, I am far more aware of my boundaries these days"*. Therefore, Ben reiterated the importance of "*knowing your body*" as a main factor in adhering to the protocol. *"…at the end of the day, this [exercise] is supposed to be beneficial. I think my advice to anyone would be 'if you need a rest, take one'. Having a few days off is going to be more beneficial if you complete the protocol rather than make yourself ill pushing too hard"*. Accordingly, Ben missed one session when he was feeling particularly fatigued and reduced any additional PA until his fatigue was managed. Such management of his training was the key mechanism to overcome this barrier.

Therefore, while the protocol appears to be difficult, with periods in which the participant may need to be monitored, managed and encouraged to continue, Ben concluded that: "*Those with CF go through far worse experiences on a day-to-day basis, and this protocol should be seen as something they can conquer as opposed to something negative…In the grand scheme of things this [the protocol] is easy"*.

5. Discussion

The aim of the present study was to investigate the viability of a low-volume HIIT protocol in an individual with CF and therefore extend the limited literature regarding the potential beneficial effects of HIIT in individuals with CF. Overall, the findings indicate that the number of sprints and overall exercise duration may be reduced substantially when compared to both MICT and traditional HIIT, whilst still retaining the positive physiological effects. The narrative data also provides a holistic insight into the experience of completing REHIT, highlighting specific factors that need to be considered to encourage adherence and enable successful future exercise prescription. Specifically, this case study demonstrates the importance of the low time-commitment, highlights the imperative role that social support plays in enhancing motivation and self-efficacy, and identifies the collective impact that both factors have on sustaining adherence. Hence, REHIT may represent a potentially highly appropriate and effective exercise modality for a variety of CF individuals, if such factors are considered.

Despite the low time-commitment and training volume, the current six-week REHIT protocol was associated with a 6.3% and 7.0% increase in $\dot{V}O_2$peak and GET, respectively. Such increases in aerobic capacity are of considerable clinical significance, given that a higher aerobic capacity is associated with improved HRQoL, a reduced risk of hospitalisation and improved survival [2]. It is interesting to note that the magnitude of change observed in this case study is in accord with those typically reported in those with CF following conventional MICT [18] or HIIT protocols [6].

What is pertinent is that these changes were elicited despite a significantly reduced time commitment compared to HIIT protocols from Hulzebos et al. [7] and Gruber et al. [6], further challenging the

assumption that larger volumes of exercise are needed to elicit favourable physiological adaptations. The volume of high-intensity exercise was also significantly reduced with each REHIT session amounting to a maximum of 40s high-intensity work compared to 10 [7] and 5 minutes [6] used in previous research. This is a concept echoed by Sawyer [19], where the total training time, inclusive of warm-up and cool-down is similar to that in this case study (10 minutes). However, given that reported negative affective valence decreases for every maximal sprint completed [10], it could be assumed that the total number of sprints suggested (6 × 30s) in this RCT will elicit a negative affect response amongst most individuals. Conversely, REHIT still offers a significantly reduced time commitment with regards to high-intensity activity, with a maximum of 40s per session, as opposed to 3 minutes. Taken together, this questions the efficacy and likelihood that individuals will adhere to the protocol outlined in Sawyer [19], further highlighting that current HIIT/SIT exercise prescription protocols for those with CF may not only be time in-efficient but also unnecessarily strenuous, especially for those with more advanced pulmonary limitation.

Undeniably, for any exercise prescription to be effective, adherence is imperative. Therefore, the potential health improvements must be balanced with the accessibility and the ability to overcome individual barriers to exercise. As such, exploring the minimum dose of exercise required to elicit enhanced aerobic fitness and HRQoL is crucial to identifying long-term, effective strategies. The current findings suggest that the *intensity* of work, as opposed to the total *volume*, may be the key factor when considering the training stimulus [8]. Although the mechanisms which underpin the adaptation to REHIT remain uncertain, it is widely suggested that peripheral adaptations involving the rate of glycogen depletion and activation of glycogen-bound protein kinases during initial sprint efforts play a significant role [20]. For those whose pathological pulmonary constraints and frequent exacerbation limit daily PA to short intermittent efforts, peripheral muscular adaptation may represent an opportunity to improve exercise capacity despite a diminished ability for pulmonary improvement. In accord with findings in severely affected adults with CF in response to HIIT [6], the improvement in exercise capacity at the GET may reflect these muscular adaptations.

For those who present with an exacerbation more than two times per year, there should be a focus on promoting an active lifestyle that does not require substantial effort [21]. Given that qualitative findings suggest that perceptions of REHIT are enhanced when sprints are shorter [22], altering the REHIT protocol to 4 × 10s sprint should hypothetically induce similar physiological adaptations. Indeed, this not only ensures a matched workload, but may be a more favourable and manageable experience in comparison to both traditional REHIT and MICT, whilst still placing minimal toll on the respiratory system. Whether or not REHIT has an effect on exacerbation rate, is yet to be established, however, it can be assumed, based on the increase in airway surface liquid in response to exercise [23,24], that REHIT has the potential to elicit clinically relevant effects on both lung function and exacerbation frequency when studied on a longitudinal basis with a larger cohort.

The current case study identifies key psycho-social elements that may underpin the success of this specific protocol, furthering our understanding of how individuals with CF may experience and perceive the REHIT protocol. Indeed, by understanding the influence of perceptions such as *short-term exercise commitment, peer* support and *management of fatigue,* participant's experience of the protocol can be optimised, and thereby facilitate adherence. Given typical attrition rates associated with general exercise interventions, an in depth understanding of individual facilitators to exercise is vital. That is, for REHIT to be considered effective, retention of participants in future, larger studies is key to elucidating the true viability and validity of REHIT, before it can be considered for use more broadly, as an exercise prescription. Similarly, for a population that may experience feelings of low competence, self-esteem and motivation to exercise [5], understanding the motives and facilitators/enablers of exercise, as well as ensuring that exercise is perceived as 'fun' and not a 'treatment' [25] will underpin the development of effective therapeutic strategies in the future.

The short-term exercise commitment associated with REHIT was cited as a key element in maintaining adherence over the six-week period. Specifically, the limited weekly time-commitment, coupled with the brief nature of the individual sessions, ensured REHIT was perceived as 'manageable', despite the high-intensity bouts. Although it is suggested that high-intensity exercise may be perceived as too arduous, evoking lower levels of self-esteem [26], the manageability of each REHIT session induced increased levels of motivation in the current study, through enhanced self-efficacy; with the individual also noting that completing each session adding to a sense of achievement. As opposed to MICT, HIIT enabled the individual to experience multiple mastery experiences per session, thus enhancing the participant's self-efficacy towards the interval training [27]. Such increases in self-efficacy and motivation are important for the development of sustainable, long-term health behavior patterns [28]. Furthermore, Segar et al. [29] reported that individuals are unlikely to be motivated towards exercise for health reasons alone, highlighting the need to utilise protocols that promote differing motives to exercise. Given that the affective response to REHIT improves during a training intervention, even in sedentary individuals with other co-morbidities [30] it could be postulated that the same positive effect could be replicated in sedentary and/or poorly motivated CF individuals. For those with poor baseline conditions, altering the protocol to 4 × 10s sprints will further enhance the perception of REHIT being 'manageable', whilst giving the individual additional mastery experiences, thus making REHIT a viable and motivating option even for those with severe disease progression.

A widely purported limitation to the utility of HIIT is that it is not enjoyable, and as a result, the majority of people will not engage in this type of exercise in the longer-term [9]. However, recent studies suggest that the affective response to REHIT is similar to that experienced in MICT [31], although the applicability of these findings to those with CF may be limited. Specifically, whilst the total session RPE reported in the current case study is in accord with Metcalfe et al., [8], it is important to account for factors such as CF-related fatigue and muscle weakness, which may mean that individuals with CF experience higher levels of negative affect during each sprint compared to healthy counterparts. One potential strategy to avoid such issues would be to reduce the resistance to 5% as utilised elsewhere [32] as the high resistance contributed to the presently reported negative perception of the protocol. However, any such reduction in intensity would need to be balanced with the potentially reduced potency of this protocol to elicit clinically significant physiological benefits. Conversely, 5% resistance may still be perceived as strenuous for those who are sedentary or those with moderate-to-severe disease progression. As such implementing effective strategies identified within the narrative, such as positive feedback, encouragement and promoting optimism towards the next session through visualization and goal-setting, may contribute to enhancing enjoyment and decreasing negative affect.

The present study also highlighted the pivotal role of social support in the implementation of, and adherence to, this protocol. Social support has been demonstrated as a positive predictor of health behaviours and associated with increased PA participation in CF populations [5]. The current findings support the tenets of the social cognitive theory (SCT; [33], whereby increased informational and emotional social support is proposed to enhance individual's levels of self-efficacy and motivation. Support and feedback on a session-by-session basis were noted as promoting a positive perception of the REHIT protocol and was a major contributing factor in ensuring that each session was perceived as manageable. Incorporating motivational goal-setting tools, such as a 'countdown' for the final seconds of the sprint helped maintain effort and increase a sense of mastery/accomplishment at the end of each sprint. Given the socially-isolated nature of CF, with some individuals feeling they are unable to exercise with their 'able-bodied peers', support from family, friends or a member of the individual's care team is

evidently essential to help individuals engage with the REHIT protocol, and future physical activity [5]. With the importance placed on parental support, especially for younger individuals, implementation of the protocol in a home environment may facilitate the active engagement of parents with their child's exercise and PA [5].

When considering barriers to exercise, it was highlighted that fatigue negatively influenced enjoyment and self-efficacy, whilst also being the only factor linked to potential withdrawal from the study. Interestingly, CIS data suggests that the individual presented with severe fatigue prior to starting the protocol. Given that a higher fatigue score is associated with a decrease in the individuals perception of physical functioning [15], the individual's baseline level of fatigue may have negatively altered the perception of the protocol, as opposed to the protocol itself being overly strenuous. As 26% experience severe fatigue [15], addressing the underlying physiological and psychosocial factors that underpin this fatigue is key to maintaining REHIT adherence. Accordingly, implementation of the CIS into both a research and medical setting may aid in identifying individuals with a higher probability of experiencing fatigue, enabling strategies to be put in place to manage this and potentially reduce attrition rates.

Whilst fatigue was raised as a concern, REHIT was not associated with negative physical experiences, such as breathlessness and coughing, which have been consistently associated with early termination, or complete avoidance, of exercise [5]. Both narrative and physiological data highlighted the limited impact REHIT had on levels of dyspnoea, with the individual noting how a lack of symptoms enhanced their positive perception of REHIT and willingness to adhere. Whilst there is likely to be a large variance in dyspnea severity in response to REHIT between individuals, muscular fatigue and dynamic hyperinflation have been identified as the two greatest predictors of dyspnoea in those with mild-to-moderate disease severity [34]. Given that the REHIT model encompasses large rest periods and a low-volume of high-intensity work, it may represent an exercise mode that could promote a positive association with exercise for those with CF, by placing limited strain on the respiratory system and promoting an increased sense of mastery.

6. Limitations

Although there are numerous strengths of the present study, it is pertinent to note that the generalisation of the results from a case study must be considered with caution. Specifically, the individual in the current case study presented with a positive perception of exercise prior to partaking in the exercise protocol, with exercise viewed as an instrument to demonstrate that CF had not 'defined him' (see Moola et al., [5]. Given that exercise is part of the individual's identity [35], the ability to self-generate motivation towards exercise could have played a key role in his willingness to adhere to the programme, despite adversity over the six-week period. Whether such ability to overcome adverse periods would be the case for other individuals, or those with a negative perception of exercise needs to be explored with the aim of ensuring that REHIT is accessible to every CF individual in the future. It is also important to highlight that the participant chose to continue with regular physical activity (weightlifting) throughout the six-week intervention, which may have had an additional training and fatigue effect that cannot be quantified within the case study. However, it is also pertinent to note the participant's high baseline fitness, according to CF-specific fitness levels [3]. It could therefore be postulated that REHIT may be able to elicit considerably greater improvements in those with low baseline fitness, given its inverse relationship with the magnitude of change in response to an exercise intervention [3].

7. Conclusion

The present case study identifies REHIT as a feasible and potentially effective alternative to HIIT and MICT for CF individuals. Given that current HIIT and MICT exercise modes have been suggested to be unnecessarily strenuous, REHIT could represent a time-effective alternative that may be more accessible for a wider CF population. The current study identifies key facilitators and barriers to REHIT for those with CF, which should be considered in future studies seeking to implement HIIT. Specifically, the pivotal role of self-efficacy and social support for long-term adherence was highlighted, with adherence facilitated by the short duration of each sprint and overall session. Whilst initial findings are promising, further research is needed to fully elucidate the applicability and effectiveness of REHIT within the CF population.

Declaration of competing interest

The main author, Sean Aspinall, was also the participant. All other co-authors have no conflicts of interest directly relevant to the content of this review.

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