**Device-based 24-hour movement behaviours in adult phase III cardiac rehabilitation service-users during the COVID-19 pandemic: a mixed-methods prospective observational study**

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 Word count: 5703

**Abstract**

**Purpose**
To examine changes in device-based 24-hour movement behaviours (MB), and facilitators and barriers to physical activity (PA) and exercise, during remotely-delivered cardiac rehabilitation (RDCR).
**Materials and methods**
This prospective observational study used wrist-worn GENEActiv accelerometers to assess MB of 10 service-users (63±10 years) at the start, middle, and end of three-months of RDCR. Barriers and facilitators to PA and exercise were explored through self-report diaries and analysed using content analysis.
**Results**
At start, service-users were sedentary for 12.6 ± 0.7 hours$∙$day-1 and accumulated most PA at a light-intensity (133.52 ± 28.57 minutes$∙$day-1) – neither changed significantly during RDCR. Sleep efficiency significantly reduced from start (88.80 ± 4.2%) to the end (86.1 ± 4.76%) of CR, with values meeting health-based recommendations (≥85%). Barriers to RDCR exercise included exertional discomfort and cardiac symptoms, and reduced confidence when exercising alone. Setting meaningful PA goals, self-monitoring health targets, and having social support, facilitated PA and exercise during RDCR.
**Conclusions**
Our RDCR programme failed to elicit significant changes in MB or sleep. To increase the likelihood of successful RDCR, it is important to promote a variety of exercise and PA options, target sedentary time, and apply theory to RDCR design, delivery, and support strategies.

(199/200 words)

**Keywords**: exercise, sedentary behaviour, physical inactivity, movement behaviours, remote-delivery, cardiac rehabilitation

**Introduction**

Cardiac rehabilitation (CR) has a robust evidence base for reducing cardiovascular mortality and morbidity, lowering acute hospitalisation, and enhancing health-related quality of life (HRQoL) post-cardiac event [1-3]. Service-users typically attend an 8-12-week programme focused on exercise as well as other lifestyle risk factors, such as habitual physical activity (PA), sedentary behaviour (i.e., an energy expenditure of <1.5 metabolic equivalents [METs] while sitting, lying down, or in a reclined position) and sleep [4]. As these three movement behaviours (i.e., physical activity, sedentary behaviour and sleep) do not occur in isolation, they are best considered from within a 24-hour cycle, recognising that an increase or reduction in one would affect another [5].

To maximise its benefit, service-users need to remain physically active post-CR to sustain improvements in exercise capacity and HRQoL [6, 7]. International guidelines [8] recommend 150-300 minutes of moderate-intensity physical activity (MPA), and 75-150 minutes of vigorous-intensity physical activity (VPA) per week to maintain health and wellbeing; aiming specifically to undertake 2-3 structured aerobic endurance exercise sessions per week at 40-60% heart rate reserve (HRR) for 20-30 minutes [9]. In addition, obtaining a recommended 7-9 hours of good quality sleep per night [10] and reducing sedentary behaviour, has been shown to improve cardiovascular (CV) outcomes [11-13].

PA and the structured sub-component, exercise, are key to the success of CR delivery in the management of cardiovascular disease, given the associated benefits, such as improved myocardial perfusion, endothelial function, and regression of cardiac atherosclerosis [14-17]. A systematic review and meta-analysis of 40 randomised controlled trials (6,480 adults with cardiac disease) emphasised how challenging this can be, with only 26% of CR programmes significantly improving PA levels compared to controls, whereby CR increased the proportion of service-users who met PA recommendations in only 9/40 studies in the short-term (≤12 months) [18]. Given that most studies included self-reported measures of PA, this may even be an overestimate due to self-reporting bias [19]. UK-based CR services are susceptible to the same issue as PA levels at baseline and at discharge are typically assessed via self-report measures [4]. Furthermore, despite their importance, sleep and sedentary behaviour are not routinely assessed within CR [4], and hence, there are calls for more robust assessments of 24-hour movement behaviours (i.e., PA, sedentary time, and sleep) in CR. One proposed solution to this issue is the use of ‘gold standard’ device-based assessment as it offers superior validity and reliability [20, 21] and enables measurement of sleep, sedentary time, and rest-activity patterns in addition to PA [22, 23].

Recently, a meta-analysis of 15 studies involving people with CVD (*n* = 1,434) using device-based assessments found moderate improvements in PA and sedentary time immediately following CR compared to controls and favourable maintenance of long-term (6–12-month follow-up) activity behaviours [24]. Nevertheless, closer analysis showed that while eight studies indicated significant change in activity behaviours, seven did not. One explanation for this difference is the high heterogeneity across studies due to differences in exercise-based CR protocols (e.g., frequency, duration, and intensity of exercise, home vs. centre-based, concurrent training vs. aerobic only) [24]. Therefore, an ongoing challenge for CR is understanding how to best support service-users’ activity behaviours, including optimal delivery modes both during their rehabilitation programme and after discharge. In this regard, qualitative data can provide meaningful insight and has been shown to illuminate issues not easily brought to light via ‘gold standard’ quantitative approaches – helping to provide a fuller, context-sensitive picture of service-user experiences of CR [25, 26].

Amidst the Coronavirus 2019 pandemic (COVID-19), issues pertaining to the support of service-users were exacerbated whereby CR services were challenged to ‘do more with less,’ [27-29] within the context of reduced population-level PA [30, 31]. The sudden transfer to remote working associated with COVID-19 – in the United Kingdom staff were redeployed and assessments were delivered remotely [27-29] – encouraged innovation in some services to provide home-based support, including the use of digital technologies [32], such as technology-based wearables and obtaining personalised feedback remotely [33]. Pre-pandemic, there was some evidence to support the effectiveness of non centre-based CR programmes [34, 35]. However, the large-scale shift to remote CR by under-resourced and under-staffed services raised questions regarding the quality of pandemic-adapted CR, service-user experiences of this adapted delivery and the ability of services to meet the British Association for Cardiovascular Prevention and Rehabilitation (BACPR) standard core components, including improvement in lifestyle risk factors, such as PA and sleep [4].

In response to these challenges, our study adopted mixed methods to address two main aims. Firstly, to examine changes in service user 24-hour movement behaviours during remotely delivered CR as a result of COVID-19. Given the unprecedented circumstances service-users found themselves in, our second aim was to explore service-user’s perceived barriers to and facilitators of structured CR exercise and habitual PA during strict COVID-19 protocols and restrictions.

**Materials and methods**

***Study design***

The study employed a mixed-methods design and provided a longitudinal analysis of 24-hour movement behaviours at the start of CR (within one month of a baseline phase III assessment), two months after beginning CR, and at the end of the three-month programme. The programme was a phase III CR service remotely delivered during the COVID-19 pandemic. A favourable ethics opinion was granted by National Health Service (NHS) Research Ethics Committee and Health and Care Research Authority Wales (21/EE/0032) and the study was pre-registered on Clinical Trials.gov (ID No. NCT04740489). The STROBE (strengthening the reporting of observational studies in epidemiology) checklist was used when preparing this manuscript (supplementary material 1).

***Participants***

Inclusion criteria were phase III CR service-users ≥18 years participating in a remotely delivered three-month CR programme and who were within four weeks of an initial CR baseline assessment and had capacity to provide consent.

***Setting***

Data were obtained March 2021 – March 2022 in a UK-based, pandemic-adapted, core NHS (Southern England) CR programme. Core CR is a comprehensive outpatient programme within the CR care pathway, categorised as phase III CR in the UK [36]. Over the course of this study, 50% of CR staff were redeployed to COVID-related roles elsewhere in the NHS and CR standard care transformed from centre-based to remotely delivered support. Service-users received telephone support alongside access to instructional exercise videos and booklets (Supplementary material 2). The amount of contact each service-user received from staff (including cardiac nurses, physiotherapists, and exercise instructors) depended upon personal need, with most receiving telephone support twice per month for three months following recommended minimal provision [37].

Individualised, remotely delivered CR was guidelines-based, providing 2-3, 20-30-minute structured aerobic endurance exercise sessions per week at an intensity of 40-60% heart rate reserve (HRR) and subjective ratings of perceived exertion (RPE) of 4-6 on the modified Borg- [38] RPE scale [9]. The aim was to safely progress service-users towards this optimum PA level suggested in CR guidelines through completion of structured exercise (i.e., aerobic interval training using a circuit in the home) and/or PA (i.e., a walking programme), depending on service-user preference. Exercise was tailored to individual needs, considering baseline PA, presence of cardiac symptoms, and individuals’ previous experience, familiarity and confidence with engaging in PA and structured exercise training. Habitual PA was also encouraged in line with UK guidelines [39].

***Data collection***

*Device-based assessment of PA and sleep*

Due to COVID restrictions and limited staff capacity we were unable to obtain pre-CR measures of PA. Therefore, the first data point (‘start’) occurred within four weeks of service-users completing their initial standard CR assessment (supplementary material 3), and 2-4 weeks after commencing their exercise programme[[1]](#footnote-1). Each service-user was sent a wrist-worn accelerometer (GENEActiv, Activinsights, Kimbolton, Cambridge, UK), sampling at 100 Hz, and measuring acceleration across three axes in gravity (*g*) units (1 *g* = 9.81 m.s2-1). The magnitude of signals from the triaxial movement minus 1 *g* (with negative numbers rounded zero) was used to quantify acceleration due to movement in mg (1 m*g* = 0.00981 m.s2-1) [40]. Service-users were instructed to wear the accelerometer on the non-dominant wrist for seven consecutive days. GENEActiv accelerometers have been used across clinical population [41, 42], and have been validated for the assessment of sedentary time, sleep and PA in healthy adults [43]. These data collection methods were subsequently repeated at the two-month and three-month (end of CR) points.

*Self-reported PA and barriers and facilitators*

Service-users completeda seven-day self-report PA diary to capture the type of PA engaged in over the course of remotely delivered CR, including the frequency, duration, and intensity (Borg category-ratio 10 scale [38] and HR [finger pulse oximeter, ATMOKO LED: CMS50DL1, Hebei Province, Republic of China]) of structured CR and habitual PA. Participants received the pulse oximeter and Borg scale via post from a research team member and were encouraged to measure their intensity during each planned PA and exercise sessions as convenient. Service-users were also asked several open-ended questions in the diary to elaborate on their perceived barriers and facilitators to structured CR exercise and habitual PA (supplementary material 4).

***Data Analysis***

Accelerometer data were processed in R (R Core Team, Vienna, Austria) using the open-source GGIR software package (http://cran.r-project.org). Total PA (minutes.day-1, TPA), light-intensity PA (LPA), MPA, VPA, moderate to vigorous intensity PA (MVPA), 10-minute bouts of MVPA, and sedentary time were quantified using validated acceleration threshold values for older adults (sedentary to LPA = 255 g$∙$min-1; LPA to MVPA 588 g$∙$min-1, for 60 s epochs) [44].

An open-source sleep detection algorithm using GGIR software determined device-based sleep variables. Periods of sleep were defined as nocturnal periods characterised by minimal movement frequency and magnitude of changes to the angle of the arm (i.e., the angle of orientation relative to the horizontal plane) [45]. Sleep efficiency was calculated from sleep duration as a proportion of time in bed, where sleep duration was defined as the sum of all recorded sleep, and time in bed was defined as periods of sustained inactivity measured by changes of less than five degrees in a rolling five-minute window. Periods of accelerometer non-wear time were identified on the basis of the standard deviation and the value range of each accelerometer axis, described in detail elsewhere [40]. Days where accelerometer wear-time was < 16 hours were excluded from analyses.

Statistical analyses were conducted using IBM Statistical Package for the Social Sciences software (Version 28, UK) and are presented as means and standard deviations for PA and sleep, unless otherwise stated. Change scores from data point one (‘start’) to two (2-months), and data point one (‘start’) to three (‘3-months') were calculated for 24-hour movement behaviours. Means and standard deviations for frequency (sessions∙week-1) of home-based CR circuits and walking were calculated from self-reported diary data at data points one, two and three. Linear mixed models were used to assess changes in outcomes over time using a compound symmetry covariance structure, and Least Significant Difference (LSD) for pairwise comparisons, in post hoc analysis. Statistical significance was set as *p* < 0.05.

*Content analysis of qualitative diary data*

Qualitative diary data were analysed by the first author (SJM) using content analysis, a systematic technique for organising data into codes and content categories and interpreting meaningful patterns related to a phenomenon of interest [46, 47]. Initially, PA diaries were read and re-read to immerse and get a sense of the data relating to PA barriers and facilitators during CR. The next step involved analysing patterns and separating the data into meaning units then condensing these, shortening the text while still preserving the core meaning of the data. Condensed meaning units were then labelled by formulating codes in a deductive format with influence from previous knowledge (e.g., research and theory on PA barriers and facilitators). Codes were grouped into categories through author interpretations in relation to the research question and previous knowledge [46, 48]. This was an iterative process of coding and categorising then returning to the raw data to reflect on initial analyses [48]. To ensure rigour, a second investigator (CW) acted as a critical friend during the analysis process, including discussing coding and theme generation [49]. CW analysed 30% of diaries separately, in which no significant discrepancies in codes and categories were found. Recognising the ongoing debate in the qualitative research literature regarding rigour/trustworthiness [50] our approach represented one recommended by leading qualitative scholars in exercise [49].

**Results**

***Participants***

Ten service users in phase III CR provided fully-informed written consent to participate in the study (Figure 1). Participant characteristics, including the range of cardiac events experienced in this cohort, are presented in Table 1. Pseudonyms have been used to protect service user’s identity.

*Figure 1 Here*

*Table 1 Here*

***Physical activity and exercise***

*Device-based measurement*

Eighty seven percent of accelerometer data met >16 hours∙day-1 compliance. Device-based data of movement behaviours over the course of CR are presented in Table 2. Twenty percent of the sample (*n* = 2) achieved ≥ 150 minutes of MVPA in10-minute bouts at all three data points. There were no significant changes (*p* > 0.05) in TPA, sedentary time, LPA, MPA, VPA, MVPA, or 10-minute sustained bouts of MVPA between time points over the course of the three-month CR programme (Figure 2).

*Figure 2 Here*

*Self-reported measurement*

At data point 1 (‘start’), 60% of the sample completed structured CR exercise in the form of home-based circuits and 80% completed weekly walks - frequency of exercise was 1.9 ± 1.8 circuits∙week-1 and 5.1 ± 2.6 walks∙week-1. There were no significant changes in circuit, or walking frequency over time (i.e., between data points 1, 2 and 3; F(2, 44.27) = 0.06 *p* = 0.95), but service-users completed significantly more weekly walks than circuits during CR (F(1, 42.97) = 27.7; *p* < 0.001).

*Table 2 Here*

***Sleep duration and efficiency***

At data point one (‘start’), service-users spent 7.25 ± 0.94 hours∙night-1 asleep, with a sleep efficiency of 88.80 ± 4.23%, and 60% of the sample achieved sleep recommendations (7-9 hours∙night-1 [10]). There were no significant changes in sleep duration between data points one, two, and three (Table 2). Main effects for change in sleep efficiency over time approached significance (F(2, 14.75) = 3.55, p = 0.05). Post hoc analysis indicated sleep efficiency was significantly lower at the end of CR compared to the start (*p* = 0.04) and middle (*p* = 0.04), although values remained within a range considered healthy (≥ 85%) [10].

***Perceived barriers and facilitators to PA and exercise***

Four hierarchical categories were constructed from content analysis of free-text, qualitative diary data: *(1)* perceived capability (*n* [no. of codes] = 92), *(2)* social influences, (*n* = 56), *(3)* motivation (*n* = 33), and *(4)* environmental influences (*n* = 22, Figure 3).

*Figure 3 Here*

*Perceived capability*

Perceived capability was categorised into *(1)* physical and *(2)* psychological capability. Participants’ perceived physical capabilities were challenged by medication side effects and cardiac symptoms, such as chest pain, aching leg muscles, wound discomfort, breathlessness, and feelings of fatigue:

For example, Jenny (70 years of age) was still experiencing debilitating symptoms after her elective PCI (percutaneous coronary intervention), indicating she*, ‘felt stabbing pain on the left-hand side of my chest. I used my spray once. I also had slight palpitations during the week.’*

Similarly, Sophie (68 years), who was undergoing changes to her medication to improve management of heart failure, remarked, *‘I’m tired and feeling a bit “under par” this week. Everything felt like an effort, and I had to push myself to go out. Just wish I had more energy and stamina.’*

Service-users felt frustrated that they struggled to perform their normal ADLs:

For example, Andrew (76 years), who was recovering from open heart surgery indicated he was, ‘*feeling frustrated at not being able to do jobs, such as lifting things that I could do previously.’*

Nevertheless, throughout CR, Andrew’s perceptions of enhanced physical function, including improved fitness and reduced symptoms facilitated PA, and a gradual return to ADLs:

‘Everything felt *a bit easier this morning – I had no symptoms…. ‘I am now* *able to help with chores in the house and garden again.’*

Other participants noticed gradual improvements in function, such as Ted (71 years) who reported, ‘my *walking pace was quicker this week’;* a big achievement after suffering a severe aortic dissection.

 Perceived psychological capability was impacted by confidence and safety concerns when exercising at home without supervision. For example, Derek (65 years) described experiencing anxiety when exercising alone, even with the availability of tailored CR resources:

*‘It will be good to go somewhere to exercise, as I’m not motivated to do it at home and unsure of how to safely go about exercising at home even with the CR booklets.’*

Confidence influenced service-users’ PA dose, with low confidence associated with reduced exercise intensity and duration.

For example, Ben (44 years) questioned the safety of movement after the shock of suffering a heart attack, resulting in a cautious return to PA: *‘I cut my walk short due to not being confident with walking a longer duration.’*

*Social support and influences*

Various social aspects influenced PA engagement, including: *(1)* availability of support from a health professional, *(2)* prioritisation of social commitments over exercise, and *(3)* availability of social support from family and friends. Social support was a key factor in coping after a cardiac event, including receiving support from a spouse, friends, and the CR team.

For example, Jenny, who continued to struggle with cardiac symptoms indicated, *‘My emotions are a little up and down. I am coping as I have the support of my husband and knowing I have the support of the CR team.’*

Similarly, Andrew had essential social support from his wife, who made changes to her own lifestyle to help motivate Andrew*, ‘My wife has much improved her acceptance of our situation. We have agreed to have professional help with the gardening and decorating. We have also agreed to maintain our physical exercise.’*

Nevertheless, family could sometimes be perceived as hindering PA progress, as expressed by Ted whose wife was having difficulty coming to terms with his diagnosis:

“My *wife is still being overprotective.”*

Social events and responsibilities were also prioritised over exercise by some individuals, such as visiting friends and family, or attending to care responsibilities. For example, two male service-users indicated:

*‘My time in the evening is taken up by family, and my weekends are busy.’* (Derek)

‘*No exercise for me this week as I have been looking after my ill wife.’* (Ben)

 Generally, service-users received regular health professional support from the outpatient rehabilitation team and their General Practitioner (GP). However, some experienced frustration and anxiety regarding poor communication and follow up from NHS services. For example, after experiencing major heart surgery to treat severe cardiac disease (CABG x3), Nicholas (59 years) expected more comprehensive personalised support and was disappointed, indicating he, ‘*felt deflated at the follow-up by the cardiac department at (name) hospital, it felt like a paperwork exercise.*’

*Motivation*

Motivation was classified into: *(1)* reflective personal drive and *(2)* the influence of emotions. Setting meaningful PA goals, possessing no desire to exercise, and self-monitoring shaped reflective personal drive. For example, at the start of CR Derek described a lack of motivation and ambivalence to exercise, such as feeling there was no need to exercise when he already felt healthy after treatment:

*‘I feel fine as if nothing has happened. So why would I start exercising? I don’t know how I’m meant to be feeling; I don’t have a reference point. I’m not exercising. I get up from my desk during work to walk around the garden. I’m not motivated to exercise. Why would I when I feel well?’*

However, goals to resume ‘normal’ activities enjoyed pre-cardiac event, such as pleasurable hobbies, and a desire to improve health, motivated service-users to engage in structured exercise. For example, after engaging with the CR programme, including education and goal setting with the CR team, Derek indicated:

*‘[Exercise] may help prevent a reoccurrence of a heart attack and improve my general health….Exercise helps me to feel better, both emotionally and physically.’*

Self-monitoring of treatment targets appeared to improve service-users’ motivation when they perceived they were on track, noted by Ben who was meeting his weight loss goals:

*‘I am happy that clothes are starting to fit me.’*

Nevertheless, a lack of clear progress created frustration in others:

Ted indicated he was, ‘*Coping well, but I am still a little frustrated at my perceived lack of progress.’*

Service-users described disruptive and positive emotions throughout CR, including feelings of depression, such as:

being ‘*tearful*’, reported by Sophie and Jenny, and two male service-users expressing:

feeling ’*low*’ (Ben); feeling ‘*happy* (Roland)*.*’

Roland’s happiness could be explained by his sense of gratitude and luck that he had treatment before deterioration of his cardiac condition:

‘*Overall, I have positive emotions and I am coping well. I am feeling positive as the bypass surgery has given me a renewed level of energy… I am still grateful my condition was caught before a major heart event. I am coping fine.’*

*Environmental influences*

Environmental influences on PA and exercise included *(1)* weather, and *(2)* COVID restrictions. Disruptive weather, such as rain and hot conditions, were a barrier to habitual PA, while clement weather conditions encouraged outdoor PA, such as walking and gardening. For example, Ted indicated:

*‘The weather is hot and humid – it is a real struggle today, I’m feeling frustrated’*

*Similarly, Jenny wrote, ‘My walks were motivated by the lovely weather this week.’*

Finally, COVID restrictions were perceived to facilitate PA engagement due to a reduction in social activities:

Andrew indicated, *‘Social activities have reduced due to COVID so I have more time to exercise.’*

**Discussion**

The aims of this study were to examine service-users’ movement behaviours (including sleep), and to explore barriers and facilitators of PA and exercise, during a three-month remotely delivered, hybrid CR programme modified as a result of the COVID-19 pandemic. We found no improvements in PA, sleep efficiency, or sedentary time over the course of a three-month pandemic-adapted CR programme. Cardiac symptoms, exertional discomfort and a lack of confidence engaging in exercise without in-person supervision were key barriers to remote CR exercise, while setting meaningful PA goals, self-monitoring health targets, and having social support, facilitated exercise engagement. Walking was the preferred modality during remote CR compared to structured exercise (i.e., home-based CR circuits).

There were no significant changes in service-users’ PA over the course of CR, suggesting CR was not successful in supporting service-users to increase levels of PA. This outcome falls short when compared to similar pre-pandemic studies demonstrating CR significantly improved device-based PA compared to service-users’ pre-intervention levels as well as to control groups not receiving structured rehabilitation guidance [51, 52].

Qualitative data through service-user diary entries provided important context regarding PA engagement, and based on service-user entries, several issues were identified that could potentially explain low engagement in PA. For example, exercise and PA was not seen as important to a service-user who ‘already’ felt fine. This is consistent with other literature that report participants not experiencing health exacerbations currently may view exercise and/or PA as unimportant or irrelevant [53]. Similar to other studies [54], inclement weather was perceived to deter participation in PA. Finally, service-users noted experiencing a wave of emotions both during and post-CR which result in ‘good days, and bad days.’ As a result, engagement can be sporadic as service-users navigate their emotions during a process that can be traumatic [55]. These considerations, as well as others to be discussed later, provide insight into the complexity of supporting increased and maintained PA engagement among CR service-users.

***Considerations for PA and sedentary behaviour***

The majority of service users’ PA was LPA, which is potentially important as an accumulation of LPA has been shown to positively impact CVD risk factors (e.g., high blood pressure, lipids and blood glucose control) [13, 56] and reduce all-cause mortality [57, 58]. Furthermore, the MVPA observed (49.19 ± 30.53 minutes∙day-1), is consistent with previous CR studies [51, 59-62] and is in line with national PA guidelines for health (150-300 minutes of MVPA per week) [8]. Only 20% of the sample (*n* = 2) achieved *sustained bouts* of MVPA. Nevertheless, scholars have begun to advocate for an approach within CR that focuses less on individual intensities (e.g., moderate to vigorous) [24] in favour of more holistic approaches that include LPA and reductions in sedentary time [13, 58]. Furthermore, it has been suggested that health benefits can be realised at a threshold much lower than 150 minutes [63].

An analysis of diary data revealed a potential preference for less structured forms of PA such as walking, which has become a common training modality especially in home-based CR programmes. Service-users completed significantly more walks per week than circuit-based structured exercise and despite CR’s traditional focus on structured exercise (i.e., circuits) [64], there is evidence to suggest that brisk walking (≥70% HRR) can improve cardiorespiratory fitness in cardiac groups [65, 66]. Such evidence, alongside preferences for walking and barriers associated with structured exercise such as service-user unfamiliarity [67], should be considered when elements of CR are designed and discussed with service-users. Consistent with the latter point, diary data also revealed service-user’s safety concerns regarding exercising at home without supervision. Particularly among those who are unfamiliar with exercise, or lack prior history engaging in exercise, concerns regarding safety and physical capabilities have been identified as important barriers [68, 69]. In contrast, walking is generally highly accessible and poses little risk of injury in populations more likely to have co-morbidities and physical and social barriers to attending CR in-person [70].

Service users were sedentary most of the day (12.57 ± 0.59 hours∙day-1) and this did not change significantly over the course of CR. This is significant as daily sedentary time exceeding 9.5 hours is associated with an increased risk of all-cause mortality and morbidity [56]. Our data suggest CR services as delivered in this study would benefit from interventions specifically targeting reduction of total sedentary time and breaking up sedentary bouts [13, 71]. For instance, the SIT LESS intervention utilised behaviour change techniques and a smartphone application as an adjunct to CR standard care [13]. Although there were no significant differences in sedentary time compared to controls, the proportion of service-users with a sedentary time above 9.5 hours∙day-1 was significantly lower post-rehabilitation in SIT LESS (48%) versus controls (72%). Breaking up long periods of sedentary time may also be perceived as more achievable than exercising at vigorous intensities, especially for clinical populations unfamiliar with exercise who possess greater physical restrictions [72-74]. Furthermore, reducing sedentary time by as little as an hour in clinical populations has been shown to significantly improve cardiometabolic risk factors, such as waist circumference, fat percentage, and glycaemic control [75].

***Considerations for sleep***

With respect to sleep, six out of ten service users achieved sleep recommendations of 7-9 hours∙night-1 and while sleep efficiency significantly reduced from start to end of CR, values remained within recommendations for healthy sleep (≥85%). Typically, existing research has assessed sleep using self-report questionnaires (e.g., Pittsburgh sleep quality index) and polysomnography [76-78]. Therefore, a strength of this study is its insight into sleep, post-cardiac event, via wrist-worn accelerometers which are less burdensome than polysomnography and more objective than self-report instruments [45].

In comparison to previous literature, we did not detect sleep disruptions during recovery after a cardiac event [79] which is important as studies investigating self-reported short (< 6 hours) and long (> 9 hours) sleep duration, as well as poor sleep quality (e.g., difficulty falling asleep), have been associated with an increased risk of CHD and higher risk of mortality in healthy adults [80-82]. However, in this relatively small sample, 40% (4 out of 10), did not meet healthy sleep recommendations [10]. It is difficult to reach a firm conclusion as to why this was the case, but one possible explanation relates to lifestyle changes and disrupted sleep during the COVID-19 pandemic – including decreased sleep quality [83-86]. Additional factors include psychosocial changes associated with living and coping with a new cardiac diagnosis, such as reduced self-efficacy (e.g., confidence to engage with ADL) [87], and kinesiophobia (i.e., fear of movement) [88]. In turn, these psychosocial states can have a profound influence on physical behaviours, such as sleep and PA [87, 89, 90]. Moreover, sleep disorders, such as insomnia and obstructive sleep apnoea are prevalent in cardiac populations [91-94].

***Implications for CR***

The challenges identified with respect to service-users’ 24-hour movement behaviours during remotely delivered CR in the current study provided an opportunity to consider ‘best practice’ approaches. Barriers to CR’s effectiveness in terms of PA/exercise adherence during CR included decreased monitoring through staff redeployment, exercise without in-person supervision, and difficulty learning how to exercise virtually – potentially influencing dose-response in this programme. Similar challenges associated with remotely delivered CR have been reported elsewhere [95]. Furthermore, a perceived lack of confidence when exercising alone was likely exacerbated during remote delivery which eliminated the possibility to receive individualised in-person instruction. This was highlighted as a concern in service-user diaries and other studies have pointed out the importance of in-person and/or personalised support and encouragement [96, 97]. Going forward, the recent Smartphone Cardiac Rehabilitation Assisted Self-Management (SCRAM) programme which uses a mobile phone app plus a heart rate sensor, may serve as a model to guide future remotely delivered CR [98]. It enables CR practitioners to receive data electronically to monitor exercise performance and provide personalised coaching [98].

To facilitate and sustain improved engagement with behavioural changes, such as increased PA and exercise, but also improved sleep and reduced sedentary time, remotely delivered CR should be underpinned with behaviour change techniques (BCTs) to provide client-centred, empowering interventions [99-101]. For example, a systematic review comprising 11 studies (1,907 adults with CHD) found that effective remotely delivered CR programmes used social support, goal setting, monitoring, and instruction on how to perform behaviours [99]. Our qualitative data reinforced the importance of these factors. For instance, motivation for PA was improved by setting meaningful goals (e.g., return to ADL and improved health), self-monitoring health targets (e.g., weight, changes in symptom severity, progression of walking distance and speed), and receiving social support (e.g., encouragement from family and CR staff). CR should also be theoretically-informed but this did not appear to be the case based on our observations. Given the quick adaptation of services due to pandemic restrictions, this is not surprising. Furthermore, numerous other challenges associated with the application of theory in CR have been identified [102]. Despite these challenges, and the lack of emergence of one ‘gold standard’ theory to guide CR programming, self-determination theory has been recommended as a promising approach in this regard [103]. It appears likely that social-ecological frameworks would also support the maintenance of PA post-CR, but recent research in this area has not yet demonstrated this empirically for service users [104].

While this study identified challenges, such as reduced training intensity and lack of face-to-face support, remotely delivered programmes *can* foster tailored one-to-one communication (something that was acknowledged by participants of our study), offer service-users flexible scheduling, minimise travel barriers, and help integrate behavioural modification with existing home routines, encouraging independence [67]. The necessity of remotely delivered support during COVID-19 has forced expansion and development of remotely delivered services within rehabilitative settings, and with the return of multidisciplinary teams, the addition of remote approaches could offer greater choice and flexibility in how service-users engage with CR [33, 98, 105] - consistent with the NHS’ long-term plan within the UK to increase the range of digital health tools and services [106]. To maximise service-user outcomes, and to ensure the success of remotely-delivered CR, our findings suggest service-user preferences for unstructured PA and regularly accessible support from professional staff must be duly considered and supported alongside an appropriately theoretically-informed delivery approach. Remotely-delivered CR must consider sedentary behaviour reduction as well as encouraging and supporting PA.

***Strengths and limitations***

There are numerous strengths of the study, including device-based measurement of movement behaviours and sleep, to which compliance was good, as well as incorporating bout analyses to distinguish between sporadic activities of daily living and volitional PA, allowing deeper insight into a clinical population group’s rest-activity patterns [23]. Moreover, we used a mixed-methods approach contextualising (dis)engagement in structured exercise and PA through a combination of device-based data with qualitative data from service-user diaries. These data allowed us to ‘dig deeper’ into aspects of PA and exercise engagement. There are, however, limitations that need to be acknowledged. For example, this was a study of convenience with no comparison group, nor pre-rehab measures of PA with a relatively small sample size with no long-term follow-up of outcomes. Consequently, generalisability may be limited – although we would maintain analytic generalisability is a more appropriate metric given our mixed methods approach [107]. Future research should explore CR through different cultural lenses with inclusion of perspectives from a variety of racial, ethnic, gender, sexuality, class, and (dis)ability backgrounds. Moreover, long-term follow-up of outcomes, exploring PA, sedentary behaviour and sleep >12 months post-CR is needed. Finally, in-depth qualitative inquiry based on service-users’ experiences of remote delivery would offer important insight to shape the design and implementation of future adapted CR, such as deeper exploration of communication modes, and safety concerns. Although we have captured qualitative data through service-user diaries, further insight is necessary – obtained through more in-depth methods such as interviews and/or focus groups.

**Conclusion**

We found no improvements in movement behaviours (which included sleep) over the course of a three-month pandemic-adapted CR programme. A lack of confidence engaging in structured exercise without in-person supervision, and restricted exercise coaching through a quick transfer to telephone support during the pandemic were key barriers to remote CR exercise. Notwithstanding the importance of social support and goal setting in facilitating exercise engagement, behaviour change techniques underpinned by a theoretically informed delivery approach is also needed to support service-users in returning to normal and valued activities after experiencing a cardiac event. Walking was the preferred exercise modality during remote CR compared to structured CR circuits, highlighting that future programmes should consider interventions to target wider movement behaviours, including reducing sedentary time and increasing PA in manageable bouts to improve confidence and adherence to long-term behaviour change. While there were many challenges associated with continuing CR services during COVID-19, these difficulties have inspired a new era of hybrid models and a menu-based approach to the delivery of its core components to appropriately support service-users to maintain function, wellbeing and quality of life post-CR [101].

**Acknowledgements**

The authors would like to thank the cardiac rehabilitation service-users for their time participating in this research and for their valuable insights. Thanks also go to the cardiac rehabilitation team for their support with the study, and to the cardiac rehabilitation charity for providing funding for study resources.

**Declaration of interest statement**

No potential conflict of interest was reported by the author(s).

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1. [↑](#footnote-ref-1)