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Change in exercise capacity, physical activity and motivation for physical activity at 12 months after a cardiac rehabilitation program in coronary heart disease patients: a prospective, monocentric and observational study

Paul Da Ros Vettoretto¹, Anne-Armelle Bouffart¹, Youna Gourronc¹, Anne-Charlotte Baron², Marie Gaumé², Florian Congnard³, Bénédicte Noury-Desvaux³, Pierre-Yves de Müllenheim^{*3}

¹ Cardiac rehabilitation unit, Hospital center of Cholet – Cholet, France

² Clinical research unit, Hospital center of Cholet – Cholet, France

³ APCoSS, UCO-IFEPSA – Les Ponts-de-Cé, France

*Corresponding author

Correspondence: pydemull@uco.fr

ABSTRACT

The main objective of this study was to determine the change in mean six-minute walking test (6MWT) distance in patients with coronary heart disease (CHD) at 12 months after a cardiac rehabilitation (CR) program compared to the end of the CR program. We also explored the decile shifts and the typical (median) individual change for 6MWT distance (12 months vs end of the CR program), physical activity (IPAQ-SF MET-min/week: 12 months vs 6 months post-program) and motivation for physical activity (EMAPS scores: 12 months vs end of the CR program), as well as barriers to physical activity perceived at 12 months. Eighty-three patients (77 men; median (25th – 75th percentile) age: 59 (53 – 64) yr; 27.6 ± 4.0 kg/m²) were recruited at the end of a CR program. We found that, for an average patient, 6MWT distance was trivially increased at 12 months (+12.56 m; $d_{av} = 0.16$; $P = 0.005$). However, the decile shifts analysis did not confirm that the positive shift of the distribution of the performances over time was uniform. In contrast, we did not observe any significant change in physical activity (between 6 and 12 months) when considering both the group of patients as a whole and the typical individual change. The results regarding the EMAPS scores were mixed, with significant and non-uniform shifts of the deciles towards scores depicting degrees of autonomous and controlled motivations as well as amotivation that would be more in favor of physical activity, but with no significant typical individual changes except for introjected regulation. Unfavourable weather, the lack of time, the fact to be tired, and the fear of injury were the most commonly reported barriers to physical activity at 12 months post-program (respectively with the following percentages [95% CI]: 35.1% [24.5%; 46.8%], 29.9% [20.0%; 41.4%], 19.5% [11.3%; 30.1%] and 18.2% [10.3%; 28.6%] of the participants).

Keywords: coronary artery disease, cardiac rehabilitation program, walking capacity, movement behaviors, self-determined motivation, follow-up

Introduction

Coronary heart disease (CHD) is one of the major clinical heart and circulatory disease conditions, with an estimate of more than 244 million of people suffering from ischemic heart disease worldwide (Tsao et al., 2023). In CHD patients, mortality risk is associated with exercise capacity as assessed using cardiopulmonary (Ezzatvar et al., 2021) and walking distance tests (Cacciatore et al., 2012) and is also related to self-reported physical activity level (Bouisset et al., 2020). As a result, cardiac rehabilitation (CR) programs, which include exercise training and physical activity counselling as core components (Balady et al., 2007), are recommended for CHD patients with appropriate indications (Virani et al., 2023).

While progress in exercise capacity is beneficial for survival in CHD patients, it has been recently shown that exercise capacity reached at the end of a CR program would be the best predictor for long-term survival in CHD patients compared to baseline and change in exercise capacity during the CR program (Carbone et al., 2022). Moreover, beyond the physical activity level observed at a given time point, physical activity trajectory would have a significant influence on mortality in CHD patients (Gonzalez-Jaramillo et al., 2022), being active and remaining active over time being the most favourable trajectory compared to being inactive and remaining inactive. These recent results support the interest of investigating the long-term evolution of exercise capacity and physical activity level in CHD patients after a CR program, but also the evolution over time of motivation for physical activity as it could be related to physical activity behaviour in cardiac patients after a CR program (Russell & Bray, 2009).

Several studies investigated the evolution of exercise capacity and physical activity level after a CR program (Boesch et al., 2005; Giallauria et al., 2006; Mildestvedt et al., 2008; Steinacker et al., 2011; Pavy, Tisseau, et al., 2011; Ramadi et al., 2016; Nilsson et al., 2018; Racodon et al., 2019; Taylor et al., 2020; Kim et al., 2021; Batalik et al., 2021), but not all tested the change between the end of the CR program and the follow-up measurements (Boesch et al., 2005; Giallauria et al., 2006; Pavy, Tisseau, et al., 2011; Ramadi et al., 2016; Nilsson et al., 2018), and very few studies tested a change after a CR program with ≥ 1 -year follow-up measurements (Boesch et al., 2005; Nilsson et al., 2018). To our knowledge, no studies analysed the change in motivation for physical activity over time in cardiac patients after a CR program. Finally, no studies implemented analyses to quantify, beyond the change in the central tendency (e.g., the mean), how the whole distribution of patients' results (exercise capacity, physical activity level, or motivation for physical activity) evolves over time after a CR program, as well as the typical (median) individual change, letting unclear the real success of the program for maintaining or increasing exercise capacity, physical activity, and motivation for physical activity over time when considering the whole cohort of the patients, not the average patient only.

The main objective of the present study was to determine if there is a change in mean exercise capacity of CHD patients 12 months after completing a CR program compared to the end of the program. A first secondary objective was to explore how the distributions of exercise capacity, physical activity level and motivation for physical activity evolve between the end of the CR program and 12 months after the program, as well as the typical individual changes in these outcomes over this period of time. A second secondary objective was to describe the barriers to physical activity reported by CHD patients 12 months after the CR program.

Methods

Study overview

We conducted a prospective, monocentric, and observational study. This study has been approved by the relevant regulatory authorities and institutional ethics committee ("APA&Co" project; CPP Ile de France X, France; ClinicalTrials.gov ID: NCT04732923). The recruitment of the participants was conducted at the hospital center of Cholet (France). The study was presented at the beginning of the last week of the CR program (week 4) to the patients who fulfilled the following criteria: has an acute coronary syndrome; is ≤ 70 years old; has completed a CR program; can respect the protocol constraints; is registered with, or can benefit from, social security; has signed the informed consent form; has not a

heart failure condition; is not a pregnant, parturient, or breast feeding woman; is not deprived of liberty due to judicial or administrative decision; is not forced to follow treatments for psychiatric disorders; is not hosted in a medical and social establishment for reasons other than research; is not concerned by legal safeguards or can express his/her consent. Patients could then notice to the investigators their interest to participate to the study during the visit planned at the end of the last week of the CR program. The recruitment and data collection periods took near of two years (start of the study: 2021-02-10; completion of the study: 2023-02-09).

We obtained information regarding age, sex, height, and surgery history at the end of the CR program. Participants also completed the measurements of weight, exercise capacity, physical activity level, and motivation for physical activity at three time points: at the end of the CR program (last week of the CR program), at 6 months after the CR program, and at 12 months after the CR program. Barriers to physical activity were assessed at 12 months after the CR program only.

Content of the cardiac rehabilitation program

The CR program used in the present study was based on the guidelines from the French Society of Cardiology (Pavy, Illiou, et al., 2011). Patients who followed the program had to come to the center four days (08:30 am to 4:30 pm) per week during four consecutive weeks. Patients could have five collective activities per day. A typical week included the followings: 4 indoor aerobic training sessions; 2 to 3 sessions of either resistance training, gymnastic, or adapted physical activity; 2 to 3 sessions of walking or Nordic walking; 2 to 3 sessions of lifestyle counselling; an individual consultation depending on the needs of the patient (with either a cardiologist, a psychologist, a dietician or a tobaccologist); and an ergotherapy session for some patients. Finally, a consultation at 6 months after the end of the program was planned with a nurse. During this consultation, the nurse conducted an interview-based assessment of patient's knowledge about the disease, the treatments, the strategies to cope with stress, the benefits and risks of physical activities, and the principles of a healthy diet. They also assessed quality of life, and asked the patients about the return to work. We took the opportunity of this follow-up visit to perform intermediary evaluations (exercise capacity, physical activity level, motivation for physical activity). These evaluations were performed following the consultation with the nurse and were judged useful for monitoring the patients and for conducting potential secondary analyses of the project. During this visit, patients were not informed on the results obtained following their previous evaluations, and they did not receive any pieces of advice relating to these intermediary evaluations.

Tests and instruments

Exercise capacity

Exercise capacity was studied throughout the use of the six-minute walking test (6MWT). All 6MWTs were conducted in a 25-m corridor by the same assessor. At each test, the principle of the test was explained to the participant, and the same information was provided during the test, that is, the time elapsed at the first two minutes of the test, the time at the middle of the test, and the remaining time at the last two minutes of the test. The test performed at the end of the CR program actually was the second test experienced by the participants after the first one performed at the beginning of the CR program. Of note, in CHD patients, the 6MWT has a 2 to 8% test-retest mean change with an intraclass correlation coefficient (ICC) of 0.97, as well as a moderate correlation (around 0.5) with peak oxygen uptake (Bellet et al., 2012).

Physical activity level

Physical activity level was assessed using the International Physical Activity Questionnaire-Short Form (IPAQ-SF). The IPAQ-SF measures the number of days and the usual daily time spent during the previous week in (i) moderate physical activity (MPA), (ii) vigorous physical activity (VPA), (iii) walking, and (iv) sitting, but only considering bouts longer than 10 minutes (except for sitting). Then, it allows the computation of weekly physical activity dose in MET-min by multiplying weekly durations of physical activity by appropriate coefficients (4.0 for MPA, 8.0 for VPA and 3.3 for walking). While the IPAQ-SF has a weak validity for measuring physical activity dose, with correlations with objective standards ranging from 0.09 to 0.39 (Lee et al., 2011), it has an acceptable test-retest reliability with a pooled Spearman

coefficient based on the literature of 0.76 (Craig et al., 2003). For the present study, we used the French IPAQ-SF version proposed in the 'Pralimap' trial (Pralimap, 2007) shown in Supplementary Material 1. With this questionnaire, total physical activity durations were directly recalled at the week level, not using a typical daily duration as in the original English version. Furthermore, total walking activity had to be reported using the number of ≥ 10 -min periods performed during the week. This number was then multiplied by 10 to obtain total weekly walking minutes. To the best of our knowledge, the psychometric properties of this specific IPAQ-SF version are unclear.

Motivation for physical activity

Motivation for physical activity was measured using the EMAPS (*Echelle de Motivation envers l'Activité Physique en contexte de Santé*) questionnaire (Boiché et al., 2019). The EMAPS is based on the self-determination theory framework and uses 18 items, with 3 items for each of the six motivational constructs of the theoretical framework: intrinsic motivation ("individuals perform a behaviour for the pleasure and satisfaction they directly derive from it", p.1), integrated regulation ("the behaviour is conceived as congruent with individuals' core values and personal lifestyle", p.2), identified regulation ("individuals perform an action because they believe this could help them to reach a personally valued goal", p.2), introjected regulation ("pressures to execute the behaviour have been interiorized, and (...) individuals act to avoid negative feelings of shame or guilt, or to enhance feelings of self-worth", p.2), external regulation ("the behaviour is performed in response to external contingencies such as rewards or punishments, and (...) individuals comply to social pressure", p.2), and amotivation ("individuals feel that there is no way to achieve positive outcomes through their actions", p.1) (Boiché et al., 2019). Each item is associated with a 7-point Likert scale (1 = "Does not correspond at all"; 7 = "Corresponds very strongly"). A score is obtained for each of the motivational constructs by averaging the scores relating to the 3 corresponding items. For one patient, a score related to one item was lacking. The average was then computed from the two remaining items. The EMAPS, which is a French language questionnaire, is a valid tool with reliability ICCs ranging from 0.616 to 0.790 depending on the motivational construct (Boiché et al., 2019). In the present article, an increase in the scores depicting the most autonomous forms of motivation (intrinsic motivation, integrated regulation, identified regulation) and introjected regulation on one side, and a decrease in the scores depicting external regulation and amotivation on another side, were considered as beneficial. These considerations are based on the work by Teixeira et al. (2012) who found positive associations of autonomous forms of motivation and introjected regulation with physical activity, and negative associations of external regulation and amotivation with physical activity.

Barriers to physical activity

Barriers to physical activity were assessed using the items proposed by the French National Authority for Health (Haute Autorité de Santé, 2022): unfavourable weather; lack of time; heavy effort / too tired; fear of injury / pain; lack of interest; difficulty to move; too old; social isolation / weak social network; too costly. For each of the items, the participant had to indicate whether the item was considered as a barrier or not.

Sample size determination

Sample size was determined from the objective of analysing the change in mean 6MWT distance at 12 months post-program compared to the end of a CR program in CHD patients. More precisely, sample size determination was based on the results of a French study by Pavy et al. (2011) who found, in 202 patients with CHD, a mean \pm SD of 511 ± 91 m for the 6MWT distance at the end of the CR program. Assuming the participants of the present study would achieve approximately the same average exercise capacity at the end of the CR program as in the Pavy et al. (2011) study, we considered that an absolute mean change ≥ 50 m post-program could be viewed as important since it would represent a change $\geq 10\%$ of the mean 6MWT distance achieved at the end of the program, that is a change greater than the potential learning effect of 2 to 8% (Bellet et al., 2012) in the case of a positive change. Sample size was then computed to be able to detect, if any, effect sizes compatible with such a population mean change (± 50 m), assuming an alpha level of 5% and a power of 90%. To determine sample size, the considered mean change of 50 m described above had to be converted to a standardized effect size (d_z) by dividing

this value of 50 m by the expected within-subject SD of differences. As we had no information about the expected within-subject SD of differences, we first decided to conduct a power analysis for the study as if it were a between-subject design using a theoretical population Cohen's d_s effect size computed from a mean difference of 50 m for the numerator and an assumed pooled SD of 91 m for the denominator basing on the Pavy et al. (2011) results. This led to a d_s of ≈ 0.55 . Then, we computed the sample size theoretically required (N_B) to detect a statistically significant effect, assuming a 90% power, an alpha level of 5%, and a true d_s of 0.55, while using a two-sided unpaired t-test ($N_B = 140$). Finally, we derived from N_B the sample size for a within-subject design (N_W) based on the formula $N_W = N_B \times (1-r) / 2$ provided by Maxwell, Delaney, and Kelley (2004) cited by Caldwell et al. (2022), where r is the correlation between the two dependent variables in a within-subject design study. Here, r was set to 0 to likely overestimate rather than underestimate the sample size required to detect a statistically significant effect assuming a true d_s of 0.55. The final sample size obtained was 70. Assuming a 10% loss of participants during the study, we aimed at recruiting at least 77 participants. Power calculation was performed using the BiostaTGV software (Sentinelles, 2021). Supplementary Material 2 shows how the software was used to determine the required sample size.

Statistical analysis

All data analyses were performed using R programming language v4.3.2. (R Core Team, 2023) and the RStudio environment ("Ocean Storm", v2023.12.1). The initial tasks of the data analysis workflow (import, tidy, and transform data) were mainly completed using the {tidyverse} package collection (Wickham et al., 2019) and the {tidyselect} package (Henry & Wickham, 2022). Otherwise specified, the figures have been produced using the {ggplot2} (Wickham, 2016), {Hmisc} (Harrell, 2023), {patchwork} (Lin Pedersen, 2022), {ggbeeswarm} (Clarke et al., 2023), {ggrepel} (Slowikowski, 2023), {rlang} (Henry & Wickham, 2023), and {ragg} (Lin Pedersen & Shemanarev, 2023) packages. The interactive tables displayed in supplementary materials were obtained thanks to the {reactable} (Lin, 2023) package. All .html format-based supplementary materials have been generated thanks to the {rmarkdown} (Xie et al., 2023) package.

Participant characteristics

The distributions of the continuous variables were graphically analysed using raincloud plots with the {ggrain} package (Allen et al., 2021) and q-q plots. In the tables, the continuous variables are shown as means \pm SD when the distributions appeared approximately gaussian or as medians and interquartile ranges (IQR, 25th percentile – 75th percentile) otherwise. The categorical variables have been summarized as counts and percentages. Statistics were obtained using the {skimr} (Waring et al., 2022) and {questionr} (Barnier et al., 2023) packages.

Change in 6MWT distance, IPAQ-SFMET-min/week, and EMAPS scores

Only participants who had data at both the time points of interest were used for analysing the considered variable. First, as initially planned during the power analysis stage of the study, we tested a null difference between the means of the 6MWT distances obtained respectively at 12 months after the CR program and at the end of the program using a two-sided paired t -test implemented in the 't.test' function of the {stats} package (R Core Team, 2023). The results of the t -test have been reported along with the Pearson correlation coefficient ({stats} package) depicting the strength of the linear link between the 6MWT performances at 0 and 12 months post-program, and with a Cohen's d effect size using the average standard deviation (d_{av}). Then, for the 6MWT distance, the IPAQ-SF MET-min/week and the EMAPS scores, we exploratory analysed (i) the change in the distribution of the scores (no consideration of the individual trajectories) and (ii) the distribution of the participant changes (consideration of the individual trajectories) between the two time points of interest (0 and 12 months for 6MWT and EMAPS, and 6 months and 12 months for IPAQ-SF to consider free-living physical activity behaviour only), respectively using (i) a shift function and (ii) the median of the changes and a difference asymmetry function. These computations have been performed using the {rogme} package (Rousselet et al., 2017). Of note, a shift function consists of plotting and allowing inferences about the differences between the quantiles of two distributions (e.g., quantile 0.10 of 6MWT distance at 12 months post-program minus quantile 0.10 of 6MWT distance at the end of the program) as a function of the quantiles

of a reference distribution (e.g., the quantiles of 6MWT distance at the end of the program). In the present article, the shift functions use the differences between the estimated deciles of the two marginal distributions to be compared. A flat shift function above or below 0 will reveal respectively a uniform positive or negative shift of the distribution (same distribution shape, but shifted position), while an increasing or a decreasing shift function will reveal a more positive shift in favour of the last or the first deciles of the distribution, respectively. Regarding the difference asymmetry function, it shows the sum of quantiles = $q + (1-q)$ of the distribution of the individual differences between the two time points of interest, with 0.05 standing for the sum of quantile 0.05 + quantile 0.95, 0.10 standing for the sum of quantile 0.10 + quantile 0.90, etc. (Rousselet et al., 2017). A flat, increasing, or decreasing difference asymmetry function will depict a symmetric, left-skewed, or right-skewed distribution of the individual differences, respectively, and the null, positive, or negative parts of the function will highlight respectively a rather neutral, positive, or negative shift of the participant scores. The estimates of the deciles of the marginal distributions, the quantiles (including the median) of the individual changes, the decile shifts (shift function) and the quantile sums (difference asymmetry function) shown in the present article were obtained using the Harrell-Davis estimator (Rousselet et al., 2017). The medians of the individual changes, the decile differences from the shift functions and the quantile sums from the difference asymmetry functions are provided with relating percentile bootstrap 95% confidence intervals (non-adjusted for multiple comparisons) and also, only for the shift and difference asymmetry functions, *P* values adjusted for multiple comparisons. *P* values were adjusted using the Benjamini-Hochberg False Discovery Rate method (Yekutieli & Benjamini, 1999) implemented in the ‘p.adjust’ function of the {stats} package (R Core Team, 2023). Claims about changes were made based on the *P* values for the *t*-test and the shift and difference asymmetry functions, and on the 95% confidence interval (95% CI) for the median of the differences, this assuming a 5% error rate in the long run.

Barriers to physical activity

Proportions of the participants citing a given barrier to physical activity at 12 months after the CR program were computed along with their respective 95% Clopper and Pearson CIs using the ‘binom.test’ function of the {stats} package (R Core Team, 2023).

Results

A total of 83 participants were included in the study. Participant characteristics are shown in Table 1. Participants were on average overweight, mainly men, most of them having had an angioplasty.

Table 1 - Participant characteristics at the inclusion stage (*N* = 83)

Participant characteristic	Descriptive statistics
Sex (W / M)	6 / 77; 7% / 93%
Age (yr)	59 (53 – 64)
Height (cm)	173 ± 7
Weight (kg)	82.5 ± 13.6
Body mass index (kg/m ²)	27.6 ± 4.0
Surgery history	
Angioplasty	66 (79.5%)
Bypass	21 (25.3%)

Note: W = women; M = men

All 6MWT distances, IPAQ-SF MET-min/week and EMAPS scores measured during the study, and relating descriptive statistics, are shown in figures and tables in Supplementary Material 3. The data and results regarding the change in 6MWT distance, IPAQ-SF MET-min/week and EMAPS scores are respectively shown in Figure 1, Figure 2, and Supplementary Material 4. Statistical details relating to the shift and difference asymmetry functions are provided in Supplementary Material 5.

Regarding the 6MWT distances, the 75 participants with complete data at both 0 and 12 months had a mean \pm SD 6MWT distance of 605.44 ± 71.96 m at the end of the CR program. When analysing the change in 6MWT distance at 12 months post-program at the group level using the mean, we found a significant and trivial improvement compared to the end of the program (+12.56 m; $r = 0.88$; $t(74) = 2.8614$; $d_{ov} = 0.16$; $P = 0.005$; Figure 1A). However, our exploratory analyses failed to demonstrate that the change in 6MWT distance was uniform, with a significantly positive shift only for the 5th (+17.42 m, $P < 0.001$), 6th (+19.53 m, $P < 0.001$) and 7th deciles (+19.61 m, $P < 0.001$) as shown in Figure 1E. The typical individual change as assessed using the median [95% CI] of the differences (Figure 1D) was also significantly positive (+13.25 [1.54; 25.08] m), while the difference asymmetry function (Figure 1F), with most of the quantile sums being significantly positive ($P < 0.001$) except the first one, revealed that the positive individual changes were larger than the negative ones except when comparing the most extreme quantiles.

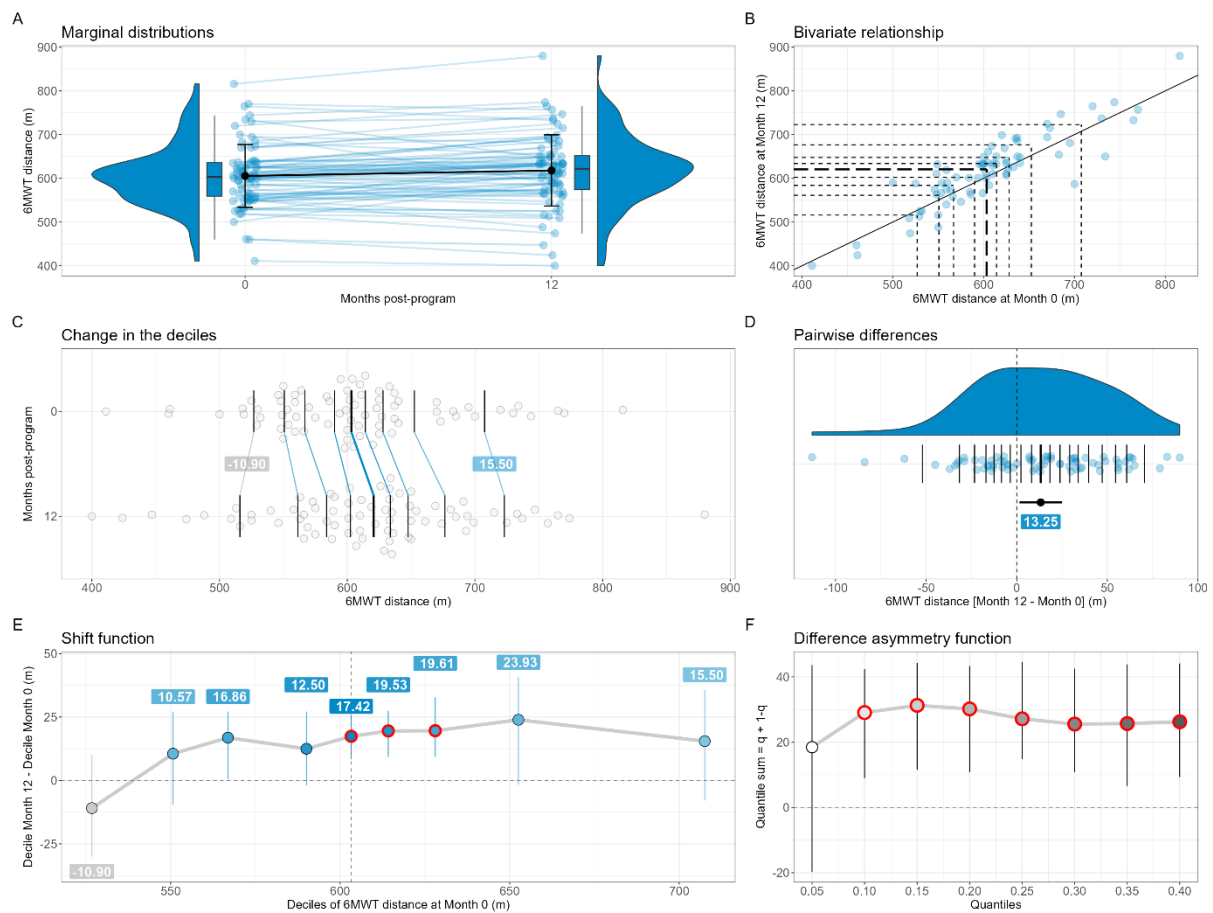


Figure 1 - Change in 6-min walking test (6MWT) distance between 0 and 12 months ($N = 75$). On panel A, the errors bars over the points are the standard deviations around the means, while on panel D it is the percentile bootstrap 95% confidence interval around the median estimate. On panels E and F, the error bars are percentile bootstrap 95% confidence intervals non corrected for multiple comparisons. On panels B, C and D, the horizontal and/or vertical segments are the estimates of the deciles (panels B and C) or the quantiles (panel D, step of 0.05) of the distributions; the thickest segments are the median estimates. On panel B, the diagonal black line depicts the identity line. If any, significant results (based on adjusted p-values) in the shift (panel E) and difference asymmetry (panel F) functions are highlighted using thick red circles. A small pseudo-random movement has been added horizontally and vertically to the raw data displayed on panel B to minimize the presence of points fully overlapped. The estimates of the deciles of the marginal distributions (panels B, C and D), the quantiles of the individual differences

(panel D), the decile differences (panel E) and the quantile sums (panel F) have been computed using the Harrell-Davis estimator.

Regarding IPAQ-SF scores, the 77 participants with complete IPAQ-SF data at both 6 and 12 months had a median (25th – 75th) IPAQ-SF score of 3318 (1680 – 4914) MET-min/week at 6 months after the end of the program. Our exploratory analyses did not reveal any change in physical activity level at the group level, with no statistically significant decile shift (Figure 2E). Similarly, the typical individual change as assessed using the median [95% CI] of the differences (Figure 2D) was not statistically significant (-62.54 [-457.28; 424.54] MET-min/week), and the difference asymmetry function (Figure 1F), showing no statistically significant quantile sums (Figure 2F), did not reveal any imbalance between the magnitude of the negative and the positive individual changes at any level of the distribution of the individual changes.

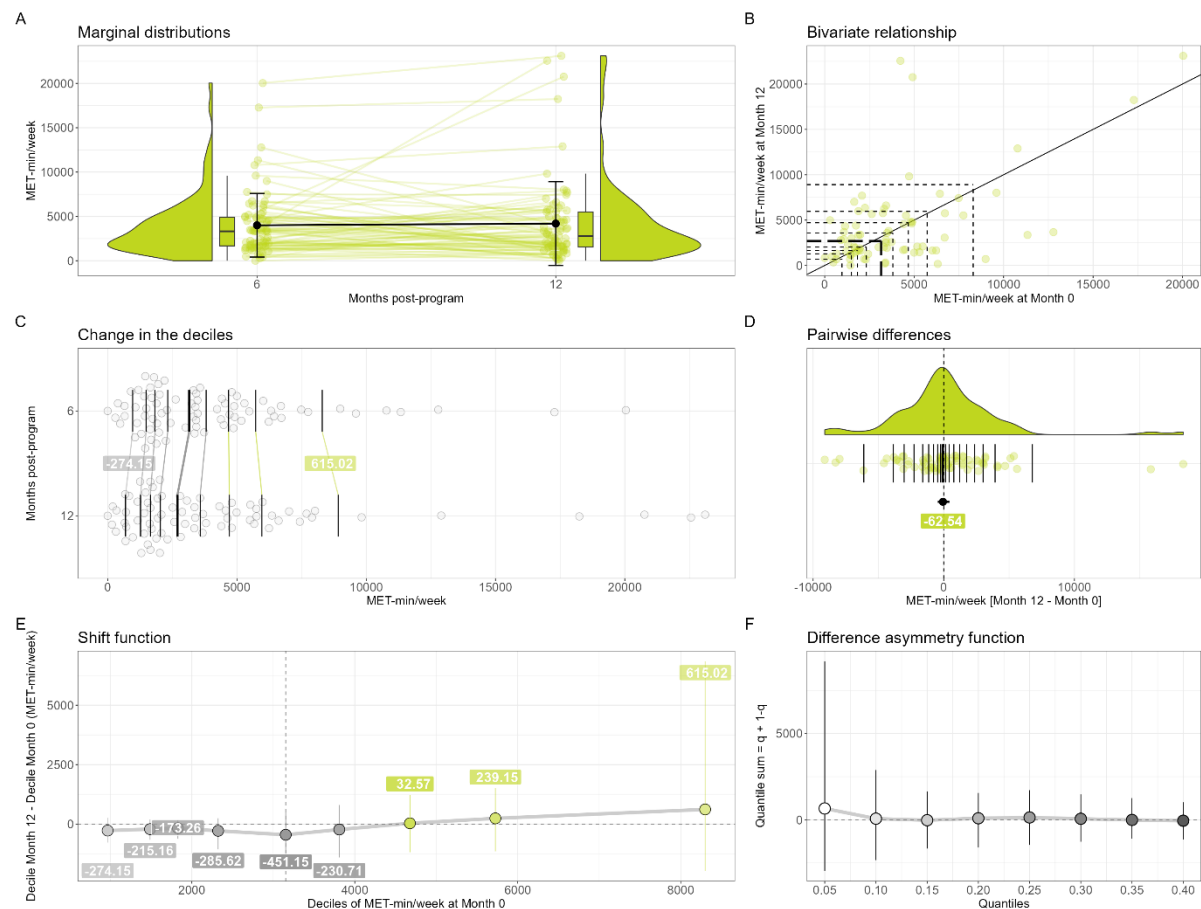


Figure 2 - Change in IPAQ-SF MET-min/week between 6 and 12 months (N = 77). On panel A, the errors bars over the points are the standard deviations around the means, while on panel D it is the percentile bootstrap 95% confidence interval around the median estimate. On panels E and F, the error bars are percentile bootstrap 95% confidence intervals non corrected for multiple comparisons. On panels B, C and D, the horizontal and/or vertical segments are the estimates of the deciles (panels B and C) or the quantiles (panel D, step of 0.05) of the distributions; the thickest segments are the median estimates. On panel B, the diagonal black line depicts the identity line. If any, significant results (based on adjusted p-values) in the shift (panel E) and difference asymmetry (panel F) functions are highlighted using thick red circles. A small pseudo-random movement has been added horizontally and vertically to the raw data displayed on panel B to minimize the presence of points fully overlapped. The estimates of the deciles of the marginal distributions (panels B, C and D), the quantiles of the individual differences (panel D), the decile differences (panel E) and the quantile sums (panel F) have been computed using the Harrell-Davis estimator.

Concerning the EMAPS scores, the 76 participants with complete EMAPS results at both 0 and 12 months had a median (25th – 75th) of 5.67 (5.00 – 6.00) for intrinsic motivation, 5.33 (4.00 – 6.00) for integrated regulation, 6.00 (5.67– 6.67) for identified regulation, 4.17 (3.58 – 5.33) for introjected regulation, 1.00 (1.00 – 1.67) for external regulation and 1.00 (1.00 – 1.33) for amotivation at the end of the CR program. When considering the change in EMAPS scores at the group level, our exploratory analyses globally showed beneficial but possibly non-uniform changes in the different forms of motivation for physical activity, with significant decile shifts that were generally inferior to 1 point and only regarding the 5th (+0.31, $P = 0.045$) and 6th (+0.28, $P < 0.001$) deciles for intrinsic motivation, the 6th (+0.55, $P < 0.001$) and 7th (+0.49, $P = 0.045$) deciles for integrated regulation, the 5th (+0.89), 6th (+0.87), 7th (+0.61) and 8th (+0.37) deciles ($P < 0.001$) for introjected regulation, the 5th (-0.04, $P = 0.030$) and 6th (-0.31, $P < 0.001$) deciles for external regulation, and the 6th (-0.02), 7th (-0.24), 8th (-0.85) and 9th (-1.39) deciles ($P < 0.001$) for amotivation. However, when looking at the typical individual change as assessed using the median [95% CI] of the individual changes, it was not significant for intrinsic motivation (0.04 [-0.1; 0.29]), for integrated regulation (+0.31 [-0.01; 0.67]), for identified regulation (+0.11 [-0.08; 0.32]), for external regulation (0 [-0.08; 0]) and for amotivation (0 [0; 0]). It was significant only for introjected regulation (+0.29 [0.01; 0.69]) while remaining of little practical interest (less than 0.5 point on the 7-point EMAPS scale). Only quantile sums from the difference asymmetry function relating to amotivation were significant, revealing a marked left-skewed distribution of the individual changes, with negative changes being larger than the positive ones, depicting a trend towards less amotivation.

The most frequently evoked barriers to physical activity were mainly “unfavorable weather”, “lack of time”, “heavy effort / too tired”, and “fear of injury / pain” (in order of importance), with corresponding percentages being between 18% and 35% of the participants ($N = 77$), and the remaining items reaching scores below 4% (Figure 3).

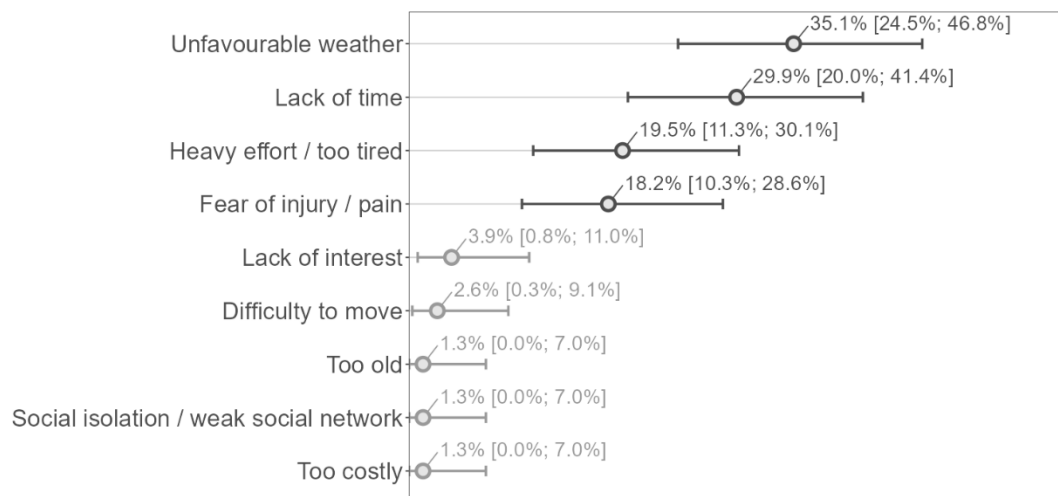


Figure 3 - Barriers to physical activity ($N = 77$). Answers have been translated from French to English for the reader's understanding of the figure. The most frequently evoked barriers have been highlighted with darker colours. Percentage estimates are provided with their respective 95% Clopper and Pearson confidence intervals.

Discussion

The overall objective of the present study was to describe how exercise capacity, physical activity level and motivation for physical activity evolve over a long period of time (12 months) after a CR

program in CHD patients, with a main focus on exercise capacity assessed using the 6MWT. Contrary to the previous studies, we were not interested in the change of scores over time compared to the results obtained at the entry in the CR program. The main results can be summarised as follows: there was a trivial and possibly non-uniform improvement in exercise capacity for the CHD patients at 12 months, both when considering the group as a whole and the individual trajectories throughout the follow-up period; we did not observe any significant change for physical activity level both when considering the group as a whole and the individual trajectories between 6 months and 12 months post-program; the changes in the different forms of motivation for physical activity were non-uniformly beneficial at the group level but without evidence of improvement when looking at the typical individual change for most of the motivational constructs.

The comparison of 6MWT results with previous works cannot be straightforward because studies did not use both the same follow-up duration and the same exercise test. Indeed, studies compared follow-up measurements with the end of the CR program using either ≥ 1 -yr post-program measurements with a laboratory maximal exercise test (Boesch et al., 2005; Nilsson et al., 2018) or ≤ 6 -month post-program measurements with a 6MWT or a laboratory maximal exercise test (Giallauria et al., 2006; Pavy, Tisseau, et al., 2011; Ramadi et al., 2016). Regarding long-term follow-up studies, Nilsson et al. (2018) observed a statistically significant increase in mean peak oxygen uptake on the treadmill ($+0.9$ mL/min/kg; $+2.5\%$) for the whole sample 1 year after the CR program, while Boesch et al. (2005) found a non-statistically significant change in mean maximal workload ($+8.4$ W; $+5\%$) on the cycle ergometer 2 years after the CR program. Regarding the other studies, Ramadi et al. (2016) observed, 3 months after a “traditional” and a “fast track” program, respectively non-statistically significant mean changes of -5 m (-0.8%) and $+15$ m ($+3\%$) in 6MWT distance. Pavy et al. (2011) did not observe at 6 months after the CR program a statistically significant change in 6MWT distance (mean change = 2 m; $+0.3\%$). Finally, Giallauria et al. (2006) found, in patients discharged with general instructions, a statistically significant decrease in mean peak oxygen uptake on the cycle ergometer 3 months after the CR program (-2.3 mL/min/kg). Overall, while previous studies showed mixed results regarding statistically significant changes in exercise capacity over time after a CR program, the magnitude of the variations appeared relatively small, both a few months and 1 to 2 years after the CR program, as in the present study. Beyond the fact the mean change in 6MWT distance we found at 12 months seems to be relatively small, it could be difficult to consider that change as clinically relevant for the group of patients since it clearly remained within the learning effect zone of the 6MWT (Bellet et al., 2012). That being said, it is unknown whether a learning effect is actually maintained 1 year after a previous measurement in CHD patients. Interestingly, beyond the positive mean change in 6MWT distance, our results suggest an incomplete shift of the whole cohort of patients towards better walking performances. Indeed, while the top part of the bulk of the distribution (5th, 6th, and 7th deciles) had a significant positive shift of similar magnitude for the different deciles, the other decile shifts were not significant. In particular, the first decile had a non-statistically significant negative shift, meaning the lowest walking performances at 12 months were lower than at the end of the program. This result could invite to conduct confirmatory studies to more precisely investigate the possible non-uniformity of the change in exercise capacity with an attention given to the reasons that could explain such a pattern. Such studies could then help clinicians targeting the patients with the more pronounced needs to implement strategies that would allow them to maintain or improve their capacities over time.

Regarding physical activity, while the individual changes between 6 and 12 months could be substantial (approximately ranging from $-10,000$ to $>15,000$ MET-min/week), we did not find any statistically significant change in the deciles nor in the typical individual change of the MET-min/week. This result is in line with Ramadi et al. (2016) who did not find a change in any physical activity parameters measured using the SenseWear Armband multi-sensor device but after 3 months post-program only. The absence of statistically significant changes in physical activity in the present study might have parallels with the absence of significant individual changes in most of the forms of motivation for physical activity (EMAPS scores), but this link remains for now highly speculative. Further studies and analyses should be conducted to confirm a maintenance in physical activity level and motivation for physical activity over time (e.g., using equivalence testing procedures) and to describe the link between the changes in physical activity level and motivation for physical activity. Unfortunately, we are not aware

of any study that reported on the change in EMAPS scores in CHD patients to allow meaningful comparisons with the literature about our EMAPS results.

At the end of the follow-up period (12 months post-program), the most reported barriers to physical activity were an unfavourable weather, a lack of time, the fact to be too tired, and the fear of injury. Since previous studies used a different method from the present study to assess barriers to physical activity (Brown, 1999; Fleury et al., 2004), comparisons are difficult. Nonetheless, the lack of time appears to be an important and consistent barrier to physical activity when comparing with similar works (Brown, 1999; Fleury et al., 2004). Moreover, the relatively high percentages of positive responses for several intrapersonal barriers to physical activity (i.e., lack of time, the fact to be too tired, and the fear of injury) compared to interpersonal barriers (i.e., social isolation / weak social network) or to organizational barriers (i.e., financial costs) are in line with the results from the Fleury et al. study (2004) who found, using a qualitative approach (an open-ended question) and a categorization of the answers based on the social ecological framework, that intrapersonal factors were the most reported barriers to physical activity maintenance in CHD patients. The fact that an environmental factor was the most reported barrier to physical activity in the present study may be, however, surprising in comparison with the Fleury et al. (2004) results.

The present study has several strengths. First, it adds new data to a very scarce literature relating to the long-term change in exercise capacity and physical activity, but also motivation for physical activity, after a CR program in CHD patients. Second, the present study introduces for the first time an analysis considering not only the change in the central tendency, but also the change in the quantiles of the distribution of the considered outcome coupled with an analysis of the individual changes. This is important because clinicians are likely to be interested in the success of an intervention for a whole cohort of patients or a random patient from a given cohort, not only for an average patient. Such an approach allowed in the present study to observe non-uniform shifts of the different parts of the outcome distributions, with typical individual changes that did not always reflect the positive changes observed at the group level, in particular regarding motivation for physical activity. These observations need, however, to be confirmed with appropriately powered studies. Third, all the materials have been made available in a GitHub repository with detailed explanations about how to reproduce the analytical pipeline of the project, letting the opportunity to verify all the analyses and to compute additional statistics if needed.

The present study also has several limits. First, we used the 6MWT to depict exercise capacity. As the 6MWT remains a submaximal exercise task that is moderately correlated with maximal oxygen uptake, our results may not be valid to describe the change in some maximal physiological parameters and thus should be rather used to reflect on walking capacities. Second, the 6MWT performances were on average large at the end of the CR program compared to previous works (Pavy, Tisseau, et al., 2011; Ramadi et al., 2016; Racodon et al., 2019), suggesting the present sample of patients may show levels of performance that are not really representative of a typical CHD patient. Moreover, several factors known to influence physical behaviour and motivation for physical activity, as employment status or years of education (Fleury et al., 2004), were not measured in the present study, which hide the precise characteristics of the population that is actually concerned by the present results. Third, as we used an observational design with one group only, it is not possible to associate the observed changes only to the pure impact of the CR program and not to other unknown factors. Fourth, we used a French version of the IPAQ-SF with unclear psychometric properties, and some MET-min scores appeared surprisingly high for people with a chronic disease, thus questioning the validity of the measurements. Even if such high scores should have a minor impact on our results since they were based on quantile analyses, for these reasons the IPAQ-SF results should be used with caution, and future studies should prefer device-based methods to more accurately investigate the shift in physical activity level in CHD patients. Moreover, we could not compare measurements at 12 months vs the end of the CR program since the first measurement with the IPAQ-SF was not related to a week after patient discharge. Future studies should consider a measurement during the days following the end of the CR program to capture the patient behaviour in their natural environment and then to make meaningful analyses of behaviour change over time. Fifth, while several exploratory analyses led to several statistically significant results, in particular several changes in the deciles of several variables of interest, a lot of other decile changes were not statistically significant, likely because of a lack of statistical power to analyse such a number of changes while

controlling for the type I error rate. Finally, 12 months follow-up could be considered as a not so long follow-up duration and may not accurately depict the maintenance or the change of patient characteristics over several years.

Conclusion

The present study investigated the change in exercise capacity (6MWT), physical activity level (IPAQ-SF) and motivation for physical activity (EMAPS scores) using approaches that considered both the group as a whole and the individual trajectories between the time points of interest. Both the approaches revealed a trivial and possibly non-uniform improvement in exercise capacity of CHD patients 12 months after a CR program, but failed to highlight any change for the whole group and a typical individual regarding physical activity level between 6 months and 12 months post-program. The conclusions relating to motivation for physical activity are mixed, with possibly non-uniform changes at the group level towards higher degrees of the most autonomous forms of motivation (intrinsic motivation, integrated regulation, identified regulation) and introjected regulation, and towards lower degrees of external regulation and amotivation, but with no evidence of a typical individual change for most of the motivational constructs. Moreover, we observed that at 12 months post-program, CHD patients mainly reported barriers to physical activity relating to unfavourable weather, lack of time, the fact to be too tired, and fear of injury. Further work is needed to more precisely analyse the shift in the quantiles of 6MWT, IPAQ-SF, and EMAPS scores in a sample of patients who could be more representative of the population of patients with CHD who follow a CR program.

Authors contributions

PDRV, AAB, YG, ACB, and MG designed the study and conducted the experiments. PYM performed the analyses, made the figures, and drafted the manuscript. BND, and FC tested the code developed for analysis. PDRV, AAB, YG, ACB, MC, BND and FC critically reviewed the manuscript. All authors approved the final version of the manuscript.

Conflict of interest disclosure

The authors declare that they comply with the PCI rule of having no conflicts of interest in relation to the content of the article.

Data, scripts, code, and supplementary information availability

All the instructions and materials allowing the reproduction of the analyses and the results are available in a GitHub repository (<https://github.com/pydemull/APACo>) and have been archived in an Open Science Framework repository (de Müllenheim, 2024a) : <https://doi.org/10.17605/OSF.IO/S2XWU>. The proposed procedure consists of running an analytical pipeline producing four .html files embedding the results: a “main.html” file containing the results directly presented in the article, and three other files (“SM3.html”, “SM4.html” and “SM5.html”) containing the supplemental materials called in the present article.

The supplementary materials called in the present article are available in an Open Science Framework repository (de Müllenheim, 2024b) : <https://doi.org/10.17605/OSF.IO/FPCRv>.

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