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Informing behaviour change intervention design using systematic review with Bayesian meta-analysis: physical activity in heart failure

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ABSTRACT

Embracing the Bayesian approach, we aimed to synthesise evidence regarding barriers and enablers to physical activity in adults with heart failure (HF) to inform behaviour change intervention. This approach helps estimate and quantify the uncertainty in the evidence and facilitates the synthesis of qualitative and quantitative studies. Qualitative evidence was annotated using the Theoretical Domains Framework and represented as a prior distribution using an expert elicitation task. The maximum a posteriori probability (*MAP*) for the probability distribution for the log *OR* was used to estimate the relationship between physical activity and each determinant according to qualitative, quantitative, and qualitative and quantitative evidence combined. The probability distribution dispersion (*SD*) was used to evaluate uncertainty in the evidence. Three qualitative and 16 quantitative studies were included ($N = 2739$). High pro-b-type natriuretic peptide (*MAP* = −1.16; 95%*CrI*: [−1.21; −1.11]) and self-reported symptoms (*MAP* = −0.48; 95%*CrI*: [−0.40; −0.55]) were suggested as barriers to physical activity with low uncertainty ($SD = 0.18$ and 0.19, respectively). Modifiable barriers were symptom distress (*MAP* = −0.46; 95%*CrI*: [−0.68; −0.24], $SD = 0.36$), and negative attitude (*MAP* = −0.40; 95%*CrI*: [−0.49; −0.31], $SD = 0.26$). Modifiable enablers were social support (*MAP* = 0.56; 95%*CrI*: [0.48; 0.63], $SD = 0.26$), self-efficacy (*MAP* = 0.43; 95%*CrI*: [0.32; 0.54], SD = 0.37), positive physical activity attitude (*MAP* = 0.92; 95%*CrI*: [0.77; 1.06], $SD = 0.36$).

Introduction

Heart Failure (HF) is a complex clinical syndrome of symptoms that suggest reduced efficiency with which the heart pumps blood around the body (National Institute for Healthcare and Excellence, 2018). It is a prevalent condition worldwide, affecting 2% of the general adult population (Groenewegen et al., 2020). The condition affects older adults, with the prevalence rising to 6.6% among

individuals aged 65 and over and to 13.5% among individuals aged 80 and over (Mozaffarian et al., 2015). HF is a debilitating condition characterised by symptoms of peripheral water retention (i.e., oedema), breathlessness, and fatigue. Despite advances in medical treatment, HF is a major cause of morbidity and mortality (Bragazzi et al., 2021).

Physical activity is associated with improved quality of life (Davies et al., 2010; Lewinter et al., 2015; Sagar et al., 2015; Taylor et al., 2019), reduced hospitalisation (Sagar et al., 2015) and increased longevity (Belardinelli et al., 2012; ExTraMATCH Collaborative, 2004) in individuals living with HF. Therefore, regular physical activity is a key component of recommended treatment (Ponikowski et al., 2016). While the minimal clinically important difference in physical activity levels in HF is not known (Dibben et al., 2018; Shoemaker et al., 2013), the recommendation for older adults, in general, is to perform a minimum of 75–150 minutes per week of moderate to vigorous intensity aerobic physical activity; and engage in functional balance and muscle strength training at a moderate intensity at least three and two days a week, respectively (WHO, 2020).

A structured form of physical activity, exercise, is included in cardiac rehabilitation (CR) and is offered to newly diagnosed HF patients (National Institute for Healthcare and Excellence, 2018). However, uptake of CR programmes is less than 1% among individuals diagnosed with HF (Doherty & Harrison, 2017). Levels of everyday physical activity in HF are also low (Jaarsma et al., 2013; O'Donnell et al., 2020), partially due to the many challenges individuals with HF face in initiating and maintaining a physically active lifestyle, as proposed by the European Society of Cardiology (Conraads et al., 2012). Understanding how best to improve physical activity in individuals living with HF is warranted.

Interventions informed by a behaviour change theory are potentially promising in achieving physical activity improvements in HF (Tierney et al., 2011b). A recent meta-analysis found that interventions integrating an exercise programme with behaviour change theory and interventions delivered by a physiotherapist are efficacious in obtaining short-term improvements in physical activity levels among individuals living with HF (Amirova et al., 2021). However, the effect of these interventions varied considerably. In addition, the extent to which a theory informed interventions was limited (Amirova et al., 2021). Research on the barriers and enablers influencing physical activity is needed as it may inform the choice of behaviour change theory and intervention development.

Guidelines for developing behaviour change interventions recognise that the modifiable and contextual barriers and enablers need to be systematically identified and described to inform intervention design (Araújo-Soares et al., 2019; Hagger et al., 2020; Kok et al., 2016; Michie et al., 2011; O'Cathain, Croot, Duncan, et al., 2019). Knowledge about relevant determinants increases the intervention's chances to be effective and conserves research effort and resources (Craig et al., 2008; O'Cathain, Croot, Sworn, et al., 2019). Systematically identified evidence concerning modifiable and contextual barriers and enablers can guide theory choice and therefore inform behaviour change intervention design.

However, the factors influencing physical activity participation in individuals living with HF are not well understood. A systematic review of qualitative studies found a lack of research on individual accounts of barriers and enablers to physical activity in individuals living with HF (Tierney et al., 2011b). The review reported sparse summaries about physical activity extracted from the studies that elucidated beliefs and personal accounts of living with HF in general, including physical activity only as one of many themes (Tierney et al., 2011b). The following enablers: knowledge of risks and benefits associated with physical activity (e.g., reduced mortality and morbidity, and improved quality of life); confidence in one's ability to engage in physical activity; anticipated outcomes of physical activity; and social support, as well as a barrier such as weather, were previously identified in a systematic narrative review (Tierney et al., 2011b). However, these barriers and enablers have not been confirmed in quantitative studies. The review highlighted the need to explore further what influences physical activity in HF (Tierney et al., 2011b).

A recent paper called for the adoption of Bayesian statistics in Health Psychology research (Beard & West, 2017; Depaoli et al., 2017; Hamilton et al., 2017; Heino et al., 2018). This approach may also be useful in understanding the contextual and modifiable determinants influencing physical activity in

HF. The Bayesian approach views evidence synthesis as a decision-making process (Roberts et al., 2002); new evidence is considered in light of existing evidence, beliefs, and practices. Beliefs are often presented in the form of qualitative research. Qualitative research is readily available from research studies on health and health management; however, its findings are not utilised in health-care decision-making and policy development (Roberts et al., 2002). Qualitative research provides rich data, but the required formal systematic evaluation impedes the inclusion of qualitative evidence in decision-making and policy development (Roberts et al., 2002). This makes it difficult for qualitative evidence to inform policy-making (Roberts et al., 2002). It is also recommended to account for stakeholders' needs – the needs of those living with HF in this instance – in research concerning intervention development (Craig et al., 2008). While Bayesian methods provide an opportunity to incorporate qualitative evidence in decisions about health management (Spiegelhalter et al., 2003). Therefore, Bayesian methods are useful when evidence from diverse sources needs to be synthesised.

However, to perform Bayesian synthesis, qualitative research should be formally and systematically catalogued before it can be integrated with quantitative findings, which is often not straightforward (Roberts et al., 2002). The Theoretical Domains Framework (Cane et al., 2012) is a tool developed through an international collaborative effort that systematically describes domains and constructs that may influence behaviour under investigation. In the current study, the identified physical activity barriers and enablers in HF were categorised in accordance with the TDF. In addition, the COM-B model, developed from a systematic synthesis of behaviour change frameworks (Michie et al., 2011), was used to inform future behaviour change interventions targeting physical activity in HF. In particular, following the consensus on the link between barriers and enablers, the intervention's proposed mechanisms and strategies (Connell et al., 2019), and several behaviour change techniques (BCTTv1: Michie et al., 2013) that are likely to enhance the identified relevant enablers or reduce the barriers were proposed.

Objectives

The present review with meta-analysis aims to systematically integrate qualitative and quantitative evidence on the clinical, environmental, and psychosocial barriers and enablers influencing physical activity in those living with HF. The secondary aim, which is a response to the recent call to embrace the Bayesian approach (Beard & West, 2017; Depaoli et al., 2017; Hamilton et al., 2017; Heino et al., 2018), is to apply the Bayesian approach in synthesising evidence regarding barriers and enablers to physical activity in HF in a way that can inform behaviour change intervention development.

Method

The systematic review with meta-analysis was implemented adhering to guidance on conducting systematic reviews and meta-analyses of observational studies of aetiology, COSMOS-E (Dekkers et al., 2019). The review is reported following PRISMA 2020 guidelines (Page et al., 2021). The review's protocol was registered on PROSPERO: CRD42021232048.

Eligibility criteria

Qualitative and observational studies investigating any clinical, environmental, social, or psychological barriers and enablers to physical activity in adults diagnosed with HF were included in this review (supplement 1). Physical activity was defined as any bodily movement that requires metabolic energy expenditure (WHO, 2020), of any mode (e.g., walking); any intensity (e.g., moderate to vigorous); in any setting (as exercise prescription or otherwise). For practical reasons, the search results were further restricted to peer-reviewed articles in English.

Information sources

A total of 14 online databases were searched from inception to 05 January 2020 (Embase, Global Health, HMIC Health Management Information Consortium, MEDLINE; PsychINFO; CINAHL; Health policy reference centre; PsychARITCLES; PubMed; The Cochrane Library; Academic search complete, Pedro). The reference lists of the obtained articles included at full-text screening were hand searched for relevant studies meeting the inclusion criteria. In addition, ClinicalTrial.gov was searched for observational studies but yielded no results.

Search strategy

The MeSH terms and keywords describing the Population of interest (i.e., HF and nine synonyms combined using a Boolean operator 'OR') and Outcome of interest (i.e., physical activity and 21 synonyms combined using a Boolean operator 'OR') were combined using a Boolean operator 'AND' (supplement 2). The initial search yielded 11,678 hits.

Selection process

Two reviewers (AA and LT) independently screened titles and abstracts and selected articles meeting the criteria for full-text screening in Rayyan. Qualitative studies meeting the eligibility criteria informed the prior elicitation task (i.e., appraisal by a panel of experts). Quantitative studies were included in the frequentist meta-analysis.

Data collection process

Two reviewers (AA and LT) independently extracted relevant data items from the reports of the included studies.

Data items

The Strengthening the Reporting of Observational Studies in Epidemiology items, STROBE (von Elm et al., 2007) were utilised to design the data extraction form (supplement 3).

Study risk of bias assessment

Two reviewers (AA and LT) independently assessed the study-level risk of bias present in the included quantitative studies. The following sources of bias were considered: selective reporting, participant selection, missing data (including non-respondents and dropouts), confounding (measured and unmeasured confounds; time-varying confounds in cohort studies), and outcome definition and measurement (i.e., information bias) (Dekkers et al., 2019). Due to the lack of a comprehensive risk of bias tool designed specifically for observational studies (Page et al., 2018), three instruments were used jointly: the Appraisal tool for Cross-Sectional Studies (AXIS), Working Group Item Bank (WGIB), and Risk Of Bias In Non-randomised Studies – of Interventions (ROBIN-I; Page et al., 2018; Sanderson et al., 2007; Viswanathan et al., 2013). The ROBIN-I items concerning the randomisation procedure were omitted; an 'intervention' was substituted with 'exposure'.

Synthesis methods

Bayesian updating is defined as a procedure of updating prior belief by incorporating new information. Degrees of belief about the probability of an event or an outcome, within a Bayesian

prediction model, are represented in the form of a prior distribution (Spiegelhalter et al., 2003). Thus, prior distribution is an initial belief about a phenomenon. Likelihood distribution for a belief is the extent to which the hypothesis is likely given the newly observed evidence. Bayesian updating is the process by which the prior changes upon consideration of new evidence. The result of Bayesian updating is a new probability distribution representing the updated belief, which is called posterior probability distribution (Spiegelhalter et al., 2003).

Bayesian meta-analysis was conducted in R[1] (Figure 1) following methods outlined in (Spiegelhalter et al., 2003). Bayesian updating was performed to obtain the log Odds Ratio (*log OR*) for the association between physical activity and a barrier or enabler (Roberts et al., 2002). In this review, qualitative evidence was used to elicit the prior distribution, and quantitative evidence was used to elicit the likelihood. Posterior distribution was obtained by updating the qualitative evidence with the quantitative evidence. Detailed statistical analysis is reported in supplement 3. Parameters for prior and likelihood were sampled from a normal distribution: $\mathbf{N}(\mu, \sigma^2)$.

STEP 1
Qualitative evidence (**qual, n = 3**) was appraised using TDF Cane et al. (2012).

Expert elicitation task was developed as informed by the findings of the TDF-based analysis. This was used to elicit the **prior**.

Three reviewers (AA, AC, BV) independently, line-by-line, annotated the qualitative studies' result section using the Theoretical Domains Framework, TDF (Cane et al., 2012). The coding agreement was high (AA vs AC: 87%; AA vs BV: 76%; BV vs AC: 86%). The descriptions of the important influences on physical activity in HF provided by the authors of the included qualitative studies were annotated using TDF. These descriptions were compared to the definitions of various psychosocial constructs from the TDF, APA dictionary (American Psychological Association, 2007), and NICE HF guidelines (National Institute for Health & Excellence, 2011).

A prior elicitation task (Albert et al., 2012; Azzolina, Berchialla, Gregori, & Baldi, 2021; O'Hagan, 1998) was developed to capture experts' beliefs about the probability distribution for physical activity conditioned on the constructs identified relevant in qualitative evidence (i.e. informative prior), The task asked the experts to share their belief about the probability of physical activity in 30 scenarios. The scenarios illustrated hypothetical HF patients. The 30 hypothetical HF patients were described to either display a construct or not in three sets of combinations of the constructs identified in qualitative studies. Six reviewers (AA; LT; BV; NA; AC; AT) completed the expert elicitation task.

STEP 2
Quantitative evidence (**QUANT, n =16**) was summarised in a frequentist meta-analysis (i.e., **likelihood**).

The association between physical activity and determinants assessed in quantitative studies were summarised in a meta-analysis including univariate associations using a random-effect model with maximum likelihood estimation (REML). The bivariate correlation (Pearson's *r* coefficient, unadjusted) between physical activity and an associated variable and the standardised mean differences (*SMD*) between groups in the dichotomised assessment were summarised in a pooled estimate, separately. The meta-analyses were implemented in R using the metafor library (Viechtbauer, 2010). The sampling distribution variance was standardised using an *r-z* transformation. This was done to mitigate heterogeneity in the measurement of the outcome. *SMD* between exposure and control was estimated for the same reason. ES.compute in R was used to convert effect sizes to log ORs.

STEP 3
Bayesian analysis elicited the probability of physical activity conditioned on a barrier/enabler when both qualitative and quantitative evidence are considered (i.e., **posterior**).

Bayesian analysis was performed following methods described by Roberts et al.(Roberts et al., 2002) Detailed statistical analysis is reported in supplement 3. When barrier or an enabler was present in both qualitative and quantitative evidence the prior was updated with likelihood using Bayesian Update.
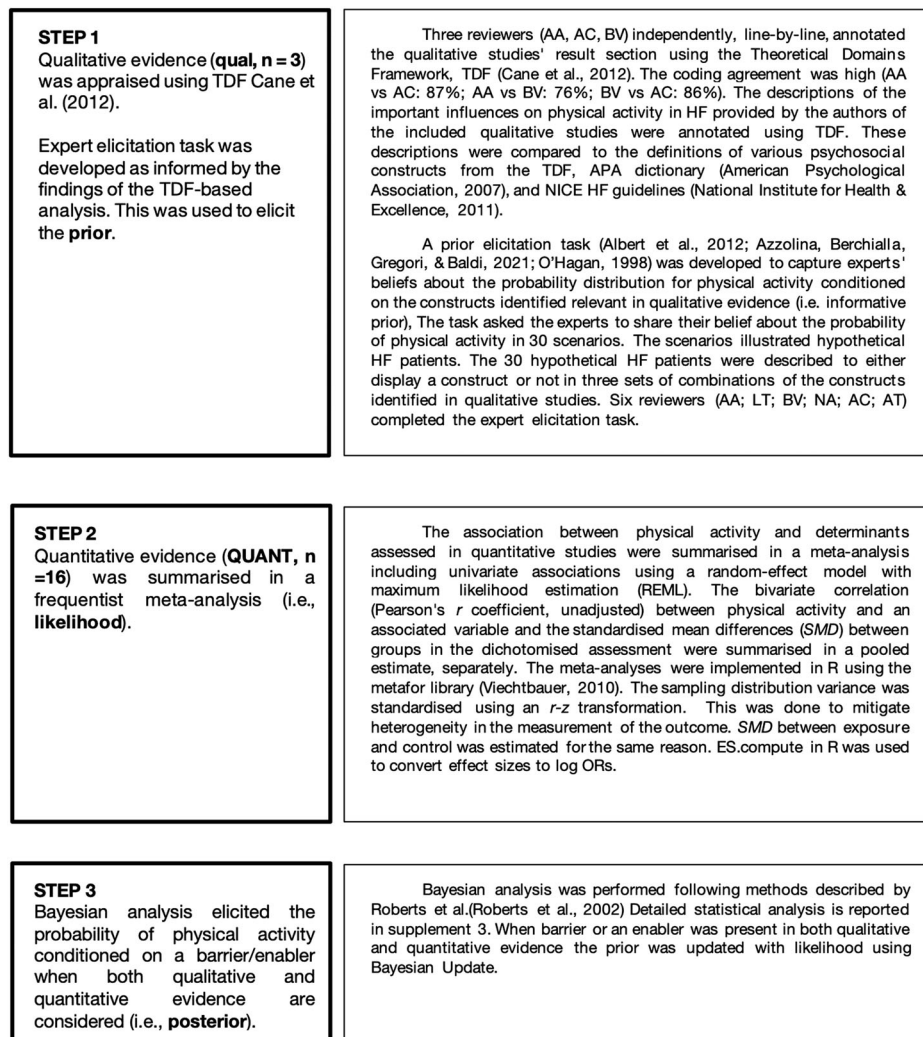
Figure 1. Statistical analysis.

Prior distribution

The qualitative evidence was synthesised using the Theoretical Domains Framework, TDF (Cane et al., 2012). Three reviewers (AA, BV, AC) independently annotated line-by-line the identified qualitative papers using the TDF. Disagreements were resolved through discussion. Then, based on the findings of the TDF analysis, a prior elicitation task was developed to capture experts' (n = 6) beliefs about the probability distribution for physical activity conditioned on the constructs identified as relevant in qualitative evidence (i.e., informative prior). The prior elicitation task developed for this review is described in supplement 3. Six reviewers (AA; LT; BV; NA; AC; TFT) completed the expert elicitation task (Figure 1). The reviewers made a judgement on whether the hypothetical HF patient met the recommended levels of physical activity or not. The *log OR* distribution was generated from the results of the expert elicitation task (i.e., prior) using the following parameters for the normal distribution: mean (μ) and variance (σ^2). The mean (μ) was the *log OR* representing the association between a construct being present in a hypothetical scenario describing a patient and the experts' judgement that the patient was physically active was calculated. The variance (σ^2) was the sampling variance of the association between a construct being present in a scenario and experts' judgement that the hypothetical patient in the scenario is likely to be active.

$$\text{Prior} = \mathbf{N}(\mu_{\text{prior}},\ \sigma^2_{\text{prior}}),$$

where μ_{prior} is *log OR* from the expert elicitation task and σ^2_{prior} is sampling variance from the expert elicitation task.

Likelihood distribution

Effect sizes reported in the individual papers were converted into *log OR* using *compute.es* library in R (Del Re, 2020). Meta-analysis was performed by pooling individual studies *log OR*s in a meta-analysis using *metafor* library (Viechtbauer, 2010). The likelihood distribution was elicited with the following parameters: the mean ($\mu_{\text{likelihood}}$) was the pooled *log OR* across the included quantitative studies; and the variance ($\sigma^2_{\text{likelihood}}$) was the sampling variance across the included studies.

$$\text{Likelihood} = \mathbf{N}(\mu_{\text{likelihood}},\ \sigma^2_{\text{likelihood}}),$$

where $\mu_{\text{likelihood}}$ is pooled *log OR* from the meta-analysis including quantitative studies, and $\sigma^2_{\text{likelihood}}$ is sampling variance from the meta-analysis including quantitative studies.

Posterior distribution

The findings of the prior elicitation task were updated with quantitative evidence concerning each barrier/enabler (i.e., likelihood) using the formula for the Bayesian updating of a normal distribution (p63. Spiegelhalter et al., 2003):

$$\text{Posterior} = \mathbf{N}(\mu_{\text{posterior}},\ \sigma^2_{\text{posterior}}),$$

where mean is: $\mu_{\text{posterior}} = (\mu_{\text{prior}}/\sigma^2_{\text{prior}} + \mu_{\text{likelihood}}/\sigma^2_{\text{likelihood}})/(1/\sigma^2_{\text{prior}} + 1/\sigma^2_{\text{likelihood}})$ and variance is: $\sigma^2_{\text{posterior}} = 1/(1/\sigma^2_{\text{prior}} + 1/\sigma^2_{\text{likelihood}})$.

Summary measures

Standardised mean differences (*SMD*) were estimated to describe the impact of exposure on the levels of physical activity as follows: (a) cross-sectional assessment of the differences between the group presenting with a characteristic and the group not presenting with a characteristic (e.g., female = 1; male = 0); (b) pre- post-assessment of physical activity in a cohort study before and after an event of interest (e.g., *SMD* between physical activity outcome before surgery and after surgery); cross-sectional assessment of differences between exercise compliant and non-compliant participants on a range of continuous variables (e.g., *SMD* in self-efficacy between compliers and

non-compliers). The r-z transformation was applied in the frequentist meta-analysis of coefficients to mitigate heterogeneity in measurements across studies. The Hartung-Knapp (Sidik-Jonkman) adjustment was made for the evaluation to mitigate small sample size bias (van Aert & Jackson, 2019). compute.es library in R was used to convert effect sizes reported in each included study into *log OR*.

For the Bayesian meta-analysis, the expected value for the *log OR* according to the expert elicitation task, quantitative evidence, and the posterior (qual + QUANT) were calculated. *MAP* and *CrI* as a summary statistic. The dispersion in the probability distribution for log OR associated with each barrier enabler was used to evaluate the level of uncertainty in the evidence in support of that barrier and enabler. The dispersion (i.e., standard deviation, SD) was interpreted relative to the dispersion in the probability distribution for physical activity in the general HF population (i.e., hyperprior) elicited from a large international study (Jaarsma et al., 2013) (see GitHub repository[2]). The SD> 0.70 corresponds to wide dispersion, 0.69–0.21 to medium dispersion, and SD <0.20 corresponds to narrow dispersion.

Applying findings to intervention development

The identified barriers and enablers in qualitative and quantitative evidence were mapped onto the TDF (Atkins et al., 2017; Cane et al., 2012) and COM-B (Michie et al., 2011). Accordingly, several corresponding behaviour change techniques (BCTs) that are likely to enhance these enablers or reduce the barriers were proposed following the consensus on the link between barriers and enablers and the strategies (Connell et al., 2019).

Sensitivity analysis

To assess the impact of the qualitative evidence on the findings of this meta-analysis, we performed a sensitivity analysis by excluding the qualitative evidence. In addition, the meta-analysis was stratified by the physical activity outcomes included in the identified studies.

Certainty assessment

In quantifying the uncertainty in the evidence, the width of the distribution dispersion (*SD*) was used to estimate the level of uncertainty for each barrier or enabler separately. Wide, medium, and narrow dispersion corresponds to high, moderate, and low uncertainty, respectively.

Results

Study selection

The search results are summarised in Figure 2. A total of 9026 titles and abstracts and 80 full-text articles were screened. Nineteen studies cited in supplement 4 (N = 2739) were included in the review. Studies that might appear to meet the inclusion criteria but were excluded, as well as the reasons for exclusion, are reported in supplement 5.

Study characteristics

Studies were conducted in the United States of America (n = 8), United Kingdom (n = 3), Netherlands (n = 2), Sweden (n = 2), Australia (n = 1), Germany (n = 1), Taiwan (n = 1), and South Korea (n = 1). The majority of the included studies were of a cross-sectional design (n = 7, Table 1). The average sample size for quantitative and empirical qualitative studies were 150 and 17, respectively. Physical activity assessment methods and barriers and enablers assessment methods are reported in supplement 6. The mean age of the participants was 63.44 years old (*SD* = 8.39, median = 62.15, *IQR*: [59.5;
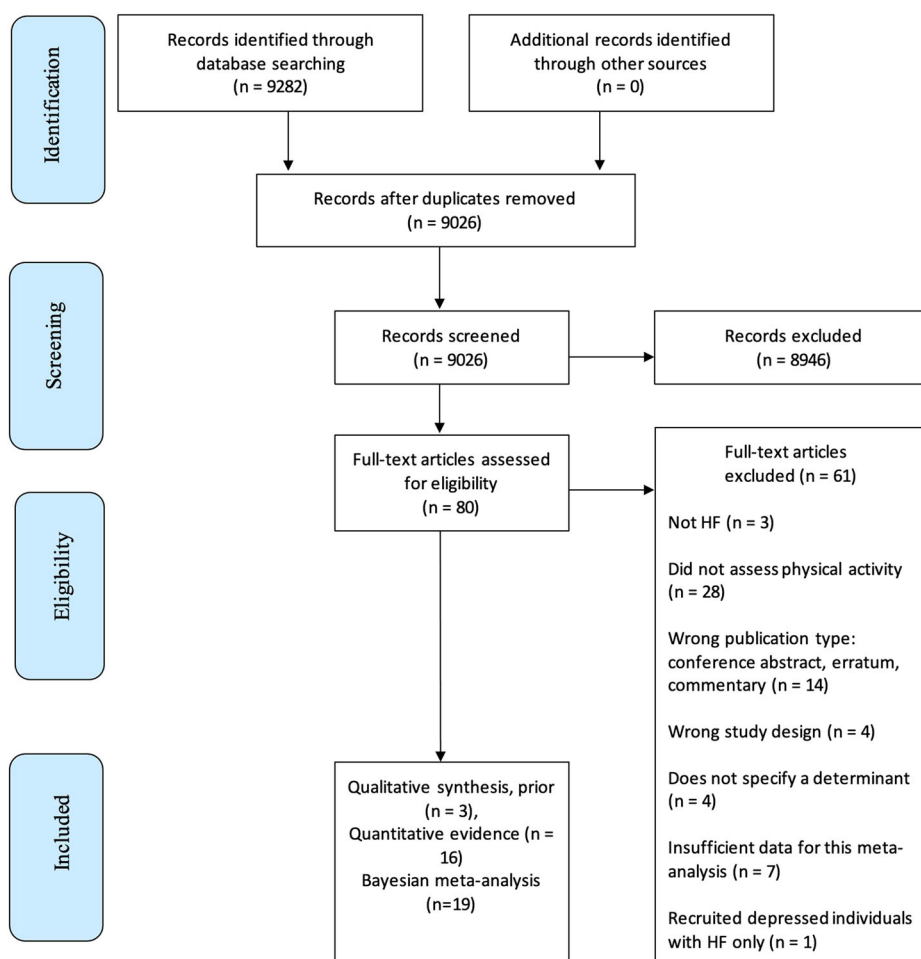
Figure 2. Meta-analysis of barriers and enablers of physical activity in HF: PRISMA diagram.

68]). The Left Ventricular Ejection Fraction (LVEF, %) was moderately low (mean = 34.52%, *SD* = 9%). Overall, the majority of samples in the included studies were homogeneous.

Risk of bias in studies

The risk of bias across the included studies is reported in Figure 3. The low overall risk of bias was present in 12 (75%) studies, moderate – in three (18.75%) studies (Alosco et al., 2012; Chien et al., 2014; Corvera-Tindel et al., 2004), and serious – in one study (Evangelista et al., 2001). One (6.25%) study was exposed to a serious risk of reporting bias, as only statistically significant results were reported (Evangelista et al., 2001). A total of nine (56.25%) studies did not have a pre-registered protocol, and therefore no information on the bias in the selection of reported results was available. The measurement bias caused by the dichotomisation of the age variable was present in two (12.50%) studies (Evangelista et al., 2001; Evangelista et al., 2003). Participant selection bias was present in one (6.25%) study (Klompstra et al., 2018). Out of four prospective (25%) studies, only one (6.25%) controlled for time-confounding variables by matching participants in exposed and unexposed groups (Moreno-Suarez et al., 2019). Only three (18.75%) studies were exposed to a low risk of bias attributed to confounding: two matched participants (i.e., gender

Table 1. Study characteristics.

Author, year	Country	Study design	Study aims/objectives	Additional inclusion criteria	Sample	The summary of the main findings
Alosco et al., 2012	USA	A cross-sectional study	To examine the role of depression in physical activity in HF as assessed using accelerometers. To determine if low physical activity is associated with death hospitalisationtion.	Age: 50–85 years old; NYHA class: II and III; without any history of severe neurological disease, injury, sleep apnoea, renal failure and substance abuse	N = 96 Mean age = 69.81 (SD= 8.79); Male: N = 60 (63.5%)	The number of years of education was significantly associated with a number of steps (b = 0.21, $p <$ 0.05) in a simple linear regression. Age, gender, and comorbidities were not identified as significant individual predictors of step count. When adjusted for comorbidity, age was identified as a significant predictor of the daily step count. Comorbidities were not suggested to be associated with the outcome when adjusting for age, gender and education. When adjusting for age, gender, comorbidities and education, the increased depression (BDI-II) was associated with the decreased daily count.
Chien et al., 2014	Taiwan	A prospective observational study	To explore physical activity predictors (as assessed at discharge) one month after discharge.	75 years old or younger; NYHA class: I-III.	N = 111 Mean age = 63.2 (SD = 11.5); Male: N = 69 (62.2%)	19.12% of daily energy expenditure (DEE) was within low intensity (<three METs), 7.20% within high (3–5 METs), and only 1.42% was intensive (>five METs). BMI, age, self-efficacy for instrumental activities of daily living, and educational level were predictors of total DEE one month after discharge. Self-efficacy for instrumental activities of daily living, gender, and BMI were predictors of high DEE. Age, BMI, and symptom distress were predictors of intensive DEE.
Corvera-Tindel et al., 2004	USA	A prospective observational study	To evaluate clinical and psychosocial characteristics among exercise complaint and non-compliant HF patients.	–	N = 39 Mean age not reported, Male: not reported	Compliance with the recommendation to walk weekly was associated with higher HF duration, higher comorbidity, lower BMI, and lower hostility
	Netherlands	A cross-sectional study				

Table 1. Continued.

Author, year	Country	Study design	Study aims/objectives	Additional inclusion criteria	Sample	The summary of the main findings
Dontje et al., 2014				NYHA class: I and III; with 1-year survival prognosis; without any implantable devices; who have not undergone any surgical interventions; without AF and arrhythmia; without a recent embolism.	N = 68 Mean age = 62 (SD = 14), Male: N = 48 (71%)	Sig. difference in steps/day between patients within NYHA I-II (median = 6113) and patients within NYHA III (median= 3150) ($p < 0.001$); between patients with EF ≤40 (median= 5854) and patients with EF >40(median = 3246) ($p < 0.05$); no significant difference in steps/day between men and women ($p = 0.389$). Steps/day was only significantly correlated to age (Spearman's rho=-.43) and self-efficacy (Spearman's rho = .40), but not to other characteristics. NYHA classification, EF, age, and self-efficacy explained 42% of the variance in steps/day (F = 8.69; $p < 0.001$) in a linear regression model.
Evangelista et al., 2001	USA	A cross-sectional study	To identify precipitating determinants of self-care noncompliance.	–	N = 82 <60 y.old: N = 52 (63.4%), Male: N = 51 (62.2%)	Significant correlates of exercise compliance included higher physical (r =0.507) and mental health (r =0.468) and health satisfaction (r = 0.435) lower neuroticism scores (r =−0.317).Age, race, education, and marital status were not significantly associated with physical activity levels.
Evangelista et al., 2003	USA	A case-controlled (matched) cross-sectional study	To describe physical activity differences in older (>70 years old) and younger (<70) individuals diagnosed with HF	Diagnosis duration for over a year	N = 140 Mean age = 68.59, Male: N = 94 (67%)	The mean compliance score was significantly different between older (>70 y. old) and younger (<70 y. old) adults, 67.14 ± 32.28 and 55.00 ± 29.05, respectively, $p= 0.021$.
Gallagher et al., 2011	USA	RCT; only the results of the baseline assessment were included in this review	To determine the types and level of social support in HF provided by partners; to evaluate the impact of the partner's social support levels on self-care behaviours compared to an individual without partners on HF.	Not scheduled for or underwent any surgical interventions in the past six months	N = 333 Mean age = 72 (SD = 11), Male: N = 220 (66%)	The extent of regular exercise ('I exercise regularly': 5-point Likert scale) between groups with low social support (no partner), medium, and high was significantly different, mean = 2.95 (SD = 1.28), mean = 2.81 (SD =

						1.27), mean = 2.41 (SD = 1.29), respectively. The authors concluded that not having a partner did not significantly change physical activity levels in individuals with HF. However, the perception of low social support vs high social support did.
Klompstra et al., 2018	Sweden	A cross-sectional study	To evaluate the mediating role of exercise self-efficacy on the relationship between motivation and physical activity.	With life expectancy not shorter than six months	N = 100 Mean age = 70 (SD = 10), Male: N = 73 (73%)	Exercise motivation significantly predicted physical activity in a bivariate linear regression (b = 0.58, p = .02). . After controlling for exercise self-efficacy, the effect of exercise motivation on physical activity was zero (b = 0.76, P = .06). Authors concluded that self-efficacy fully mediated the effect of motivation on physical activity. Age (b = −0.03, P = .22), and NYHA class (b = −0.41, P = .46) did not predict the amount of physical activity
Lee et al., 2016	South Korea	A cross-sectional study	To describe the relationships between physical functioning, physical activity, exercise self-efficacy, and QOL in individuals with CHF.	–	N = 116 62.15 (9.06) 93 (80.2)	Correlations between physical activity and self-efficacy, quality of life, age, income, education, and LVEF were assessed. Physical activity significantly and negatively correlated with age (r = −0.194, p < 0.01)
Moreno-Soarez et al., 2019	Australia	A case-controlled prospective study(well-matched patients with a Left Ventricular Assist Device (LVAD) versus well-matched patients with CHF, but no LVAD)	To describe daily PA levels in patients with LVAD support compared with well-matched participants with advanced CHF without LVAD support.	Without hypertension	N = 32 Exposed: Mean age: 59.1 (SD = 10.8), Male: N = 26 (81%) Unexposed: Mean age: 58.3 (SD = 8.7), Male: N = 26 (81%)	In a matched for age (±5 yr.), sex, and New York Heart Association (NYHA) class, cohort study, participants with a fitted LVAD had higher levels of energy expenditure than individuals with HF who were not fitted with the device, 404.1 ± 169.1 kcal/d ay and 222.5 ± 163.4 kcal/day, respectively.
Oka et al., 1996	USA	A cross-sectional study	To describe the relationship between Knowledge, attitudes	Diagnosis duration for at least 23 months; without obstructive valvular disease;	N = 43 Median age: 59.9 [IQR:	The association between physical activity and physical fitness (Peak VO$_2$); knowledge, attitudes, and

Table 1. Continued.

Author, year	Country	Study design	Study aims/objectives	Additional inclusion criteria	Sample	The summary of the main findings
			and beliefs, and physical activity levels in HF patients.	congenital hear1 disease; and tachycardia pacemakers; severe pulmonary hypertension	33;91], Male: N = 35 (81.4%)	beliefs including self-efficacy for general activity, perceived exertion during daily activity; and marital status was assessed. Self-efficacy was sugested as a significant ($p = 0.015$) predictor of physical activity.
Pihl et al., 2011	Sweden	Phenomenological analysis of qualitative interviews	To describe qualitatively how individuals with HF conceived their limitations in daily life activities.	A stratified recruitment strategy to obtain variation in the sample in terms of gender, age, place of residence, education, and NYHA class.	N = 15 Mean age not reported, Male: not reported	The study supported the relevance of the following domains to physical activity in HF: *Knowledge*, *Social/Professional Role and Identity*, *Beliefs about Capabilities*, *Beliefs about Consequences*, *Goals* (low relevance), *Memory, Attention and Decision Processes* (low relevance), *Social Influences*, *Emotion*, and *Behavioural Regulation*.
Pozehl et al., 2018	USA	RCT; only the results of the baseline assessment were included in this review	To describe physical activity levels (using accelerometer) ; to determine the proportion meeting the recommended levels of physical activity; to describe determinants associated with physical activity.	Coronary artery bypass surgery, or biventricular pacemaker less than six weeks prior; participation in 3 times per week aerobic exercise in the past eight weeks; plans to move more than 50 miles from the exercise site within the next year; peak oxygen uptake (pVO2) in females > 21 ml/kg/min and in males > 24 ml/kg/min; and pregnancy planned or current.	N = 204 Mean age = 60.4 (SD = 11.5) Male: N = 224 (56%)	The MVPA (mins/day) was significantly higher in males (than females $p < 0.01$), Caucasians than non-Caucasian ($p < 0.05$), those within NYHA class II compared to those within NYHA class III. The higher Charlson comorbidity index and PROMIS anxiety score were significantly associated with a higher level of MVPA. The ejection fraction was not significantly correlated with MVPA.
Snipelisky et al., 2017	USA	RCT; only the results of the baseline assessment were included in this review	To describe the relationships between daily activity with clinical features and standard HF assessments (NYHA class, 6MWD, HF QOL scores and NT-proBNP) at baseline and the relationship between changes in activity and changes in standard HF assessments with ISMN relative	Patients were eligible for study participation if they had NYHA class II-IV were at least 50 years of age. They had preserved (≥50%) EF who attributed inactivity to HF-related symptoms as assessed using a screening questionnaire.	N = 110 Mean age = 69 (SD not reported), Male: N = 44 (40%)	Participants in the group with the lower daily accelerometer units were more likely to have had hospitalisationtion, orthopnea, diabetes and anaemia, be treated with beta-blockers, have higher EF, relative wall thickness and left atrial volume and worse NYHA class, HF specific quality of life

			to baseline (controlling for sex, age, and body size).			(QOL) scores, six-minute walk distance (6MWD) and NT-proBNP ($p < 0.05$ for all).
Tierney et al., 2011a	UK	A narrative review of qualitative studies	To summarise the findings of interview studies on living with HF that concern beliefs about physical activity.	Qualitative studies (n = 20) aiming to describe HF beliefs and accounts of living with HF	N = 306 (average = 15) Mean age not reported, Male: not reported	The review identified sparse summaries about physical activity from the studies that elucidated beliefs and personal accounts of living with HF in general, including physical activity only as one of many themes. The reported beliefs supported the relevance of the following domains: *Knowledge*, *Social/Professional Role and Identity*, *Beliefs about Capabilities*, *Beliefs about Consequences*, *Goals*, *Environmental Context and Resources*, *Social Influences*, *Emotion*.
Tierney et al., 2011b	UK	A qualitative semi-structured interview study	To explore why individuals with HF do and do not engage in regular physical activity.	–	N = 22 Mean age not reported, Male: not reported	The reported beliefs were coded into the following domains: *Knowledge*, *Social/Professional Role and Identity*, *Beliefs about Capabilities*, and *Beliefs about Consequences*. Also, Mental outlook theme was coded as *Optimism/Emotion* (medium relevance), *Goals* (low relevance), *Environmental Context and Resources*, *Social Influences*, *Intention* (low relevance).
van der Wal et al., 2006; 2010	Netherlands	A baseline assessment (cross-sectional) from a prospective study investing clinical outcomes	To investigate the association between compliance with non-pharmacological recommendations (diet, fluid restriction, weighing, exercise) and outcome in patients with heart failure (HF).	–	N = 830 Mean age = 72 (SD = 11), Male: N = 300.6 (60%)	At baseline assessment, the participants who did not adhere to the exercise recommendation were older, more likely to be female, and have comorbid Atrial fibrillation, diabetes, stroke, and previous HF admission. Depressive symptoms and knowledge were negatively associated with compliance to exercise recommendation.
Werhahn et al., 2019	Germany	A prospective observational study evaluating an	To evaluate the feasibility and usability of A mobile application	Newly diagnosed HF	N = 10 Mean age =	Everyday physical activity (the MDSC captured by built-in pedometer

Table 1. Continued.

Author, year	Country	Study design	Study aims/objectives	Additional inclusion criteria	Sample	The summary of the main findings
		intervention; only the results of the baseline assessment were included in this review	designed to enhance self-management.		46.3 (SD = 7.8) Male: N = 6 (40%)	functions of smartphone and smartwatch)averaged over 14 days was low following hospital discharge (3612 ± 3311), increased significantly to the first follow-up (6927 ± 4871; $P < 0.0001$) and to the end of study (7069 ± 5006; $P < 0.0001$) The MDSC correlated significantly with exercise capacity parameters – the distance in the conventional 6MWT and Peak VO$_2$ in CPET. A strong association with patient-reported outcomes in the MLHFQ and KCCQ, especially with the sub-scores representing health-related QoL, HF symptoms, and PA, was observed.
Witham et al., 2006	UK	RCT; only the results of the baseline assessment were included in this review		Older adults (>70) without ventricular fibrillation, aortic stenosis with peak gradient >30 mm Hg, atrial fibrillation with a ventricular rate of >10	N = 82 Mean age = 80.5 (SD = 5), Male: N = 45.1 (55%)	Daily physical activity (accelerometer) was significantly associated with the 6-minute Walking Test (distance in metres).
Total number of studies: 19		cross-sectional study = 7 (matched = 3); baseline assessment (RCT) = 4; prospective observational study = 4 (matched = 1); qualitative study = 2; narrative review = 1.			N = **2739**	

and severity of the disease) when assessing differences in exposed and unexposed groups (Evange-lista et al., 2003; Moreno-Soarez et al., 2019), and one measured appropriate confounding variables (Klompstra et al., 2018). The study-level risk of bias assessment is reported in supplement 7.

Results of synthesis

Qualitative evidence

The qualitative evidence synthesis and results are detailed in supplement 3. Overall*,* the following TDF domains (presented in italics) barriers and enablers influencing physical activity performance by individuals living with HF were found <u>uniquely</u> in qualitative evidence: *Social/Professional Role and Identity*, *Behavioural Regulation*, *Environmental Context and Resources*, *Social Influences*, and *Knowledge* according to three included qualitative studies (Tierney et al., 2011a; Tierney et al., 2011b; Pihl et al., 2011). Coded themes included '*Losing one's social role in daily life', which* was anno-tated as *Social/Professional Role and Identity*. It captured how the loss of participants' social network and position in society negatively influenced their engagement in physical activity (Pihl et al., 2011). Another theme from the literature, '*Need of finding practical solutions in daily life*' (Pihl et al., 2011), was coded as *Behavioural Regulation* and summarised the need for effective problem solving that enables the integration of physical activity in daily life with ease (supplement 3). One study (Tierney et al., 2011a) identified the relevance of the following TDF domains: *Environmental Context & Resources*, *Social Influences*, *Knowledge* (supplement 3).

The determinants that were reported by both qualitative and quantitative studies were: age, per-ceived symptoms of HF, functioning, comorbidity, negative attitude, positive physical activity atti-tude, social support, and self-efficacy. In qualitative studies, the influence of ageing processes was described as '*Changing Soma' (Beliefs about Capabilities)* (Tierney et al., 2011b). Perceived symptoms of HF were described as '*Fluctuating health*' (*Beliefs about Consequences)* which impacted physical activity participation (Tierney et al., 2011b). A positive attitude toward physical activity in qualitative studies was described as '*Mental Outlook' (Belief about Consequences*) (Tierney et al., 2011b), negative attitude in response to physical activity was described as '*Negative emotional responses', (Emotion/ Optimism)* (Tierney et al., 2011b), social support was described as '*Interpersonal Influences' (Social Influ-ences)* (Tierney et al., 2011b), and self-efficacy as '*Not believing in one's ability*' (*Beliefs about Capabili-ties)* (Pihl et al., 2011). These qualitative findings informed the expert elicitation task (supplement 3).

Bayesian meta-analysis results

The distributions for the log ORs for the association between physical activity and the identified bar-riers and enablers are described in Figures 4 and 5. The expected values according to qualitative evi-dence, quantitative evidence and both are summaries in Table 2.

Contextual factors:

High pro-b-type natriuretic peptide, pro-BNP (*MAP* value for *log OR* = −1.16; 95% *CrI*: [−1.21; −1.11]) was suggested as a barrier to physical activity with narrow distribution dispersion (*SD* = 0.18). Another contextual barrier with narrow dispersion (*SD* = 0.19) are self-reported symptoms (*MAP* value for *log OR* = 0.48; 95% *CrI*: [0.40; 0.55]). Contextual barriers with moderate uncertainty judged from the distribution dispersion ranging from 0.26–0.41 were age (years) (*MAP* value for *log OR* = −0.29; 95% *CrI*: [−0.41; −0.18]), comorbidity measured using Charlson Comorbidity Index (*MAP* value for *log OR* = −0.62; 95% *CrI*: [−0.76; −0.48]), depression measured using HADS-D CES-D, and PROMIS-29 (*MAP* value for *log OR* = −0.54; 95% *CrI*: [−0.71; −0.38]), digoxin prescription (*MAP* value for *log OR* = −1.06; 95% *CrI*: [−1.33; −0.79]), high doppler estimated filling pressure (*MAP* value for *log OR* = −0.71; 95% *CrI*: [−0.82; −0.60]), HF duration (*MAP* value for *log OR* = −0.95; 95% *CrI*: [−1.19; −0.71]), Left Atrial Volume index, LAV (*MAP* value for *log OR* = −1.12; 95% *CrI*: [−1.23; −1.01]), and living with partner (*MAP* value for *log OR* = −0.37; 95% *CrI*: [−0.51; −0.24]).
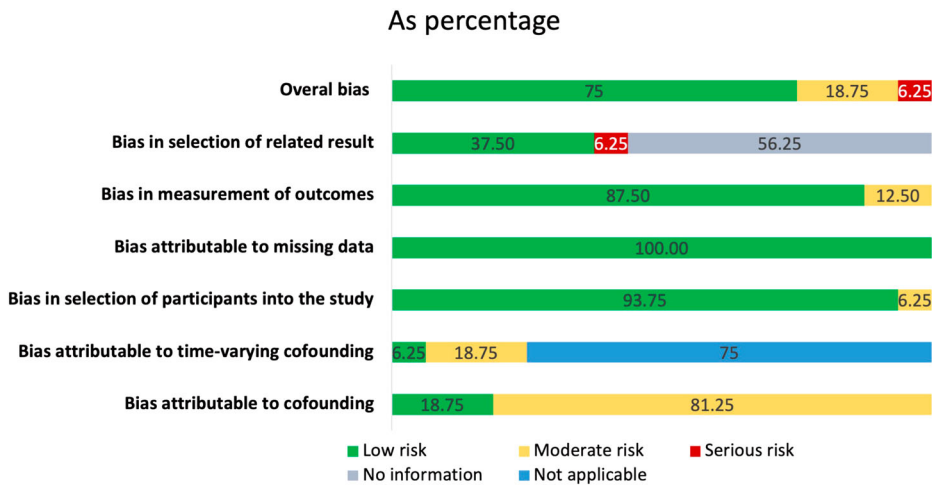
As percentage

Figure 3. Study-level risk of bias: based on WIB, ROBIN-I, and AXIS items combined into six categories proposed by Page et al., 2018 with an addition of the confounding bias described in ROBIN-I.

Contextual enablers with medium dispersion (*SD* ranged from 0.26–1.09) were physical functioning (measured using MOS SF-36, KCCQ; *MAP* value for *log OR* = 0.18; 95% *CrI*: [0.01; 0.36]), high 6-minute walking test result (6MWT; *MAP* value for *log OR* = 1.77; 95% *CrI*: [1.00; 2.54]), having an implantable device (left ventricular assistant device, LVAD; *MAP* value for *log OR* = 1.98; 95% *CrI*: [1.60; 2.36]), renal function (glomerular filtration rate (ml/min); *MAP* value for *log OR* = 1.07; 95% *CrI*: [0.96; 1.18]).

Modifiable factors:

Modifiable barriers were symptom distress (measured using mSAS-SF; *MAP* value for *log OR* = −0.46; 95% *CrI*: [−0.68; −0.24]), and negative attitude (Negative attitude scale; *MAP* value for *log OR* = −0.40; 95% *CrI*: [−0.49; −0.31]), the distribution dispersion of *SD* = 0.36 and 0.26, respectively, indicating a moderate uncertainty in the evidence.

Modifiable enablers were social support (*MAP* value for *log OR* = 0.56; 95% *CrI*: [0.48; 0.63]), self-efficacy (*MAP* value for *log OR* = 0.43; 95% *CrI*: [0.32; 0.54]), positive physical activity attitude (*MAP* value for *log OR* = 0.92; 95% *CrI*: [0.77; 1.06]), distribution dispersion: *SD* = 0.26, 0.37, and 0.36, respectively, indicating moderate uncertainty in the evidence.

Sensitivity analysis results

The results of the sensitivity analysis comparing qualitative evidence to quantitative evidence and the results of the analysis combining both are summarised in Figure 5.

Heterogeneous physical activity outcomes were combined in the main meta-analysis. This included accelerometer units (n = 2), duration, mins/day assessed using an accelerometer (n = 1), energy expenditure estimated from accelerometer data (metabolic equivalents, METs; n = 4), self-reported exercise compliance (n = 6), self-reported general physical activity, measured using International Physical Activity Questionnaire, IPAQ (n = 2), self-reported adherence to prescribed exercise self-care behaviour (n = 1), steps per day (n = 3), and one study included both energy expenditure (METs) and duration (mins/day), supplement 6.

The sensitivity analysis results stratified by physical activity outcome assessed in quantitative evidence (likelihood) are reported separately for each barrier and enabler in supplement 8. Sensitivity analysis highlighted the following changes in the evidence compared to the main results. Studies (n = 2) assessing physical activity using an accelerometer did not support depression as a considerable

barrier to physical activity. Studies (n = 4) assessing the relationships between energy expenditure (METs) provided evidence with moderate uncertainty regarding perceived symptoms in comparison to the main results suggesting that perceived symptoms are a barrier with low uncertainty in the evidence. Studies (n = 3) that assessed steps per day using an accelerometer suggest considerably high uncertainty in the evidence regarding the barriers (i.e., Pro-BNP) and enablers (i.e., 6MWT, physical functioning, LVEF, Peak VO$_2$). The findings of the meta-analysis restricted to the studies assessing self-reported physical activity duration per day, self-reported exercise recommendation compliance, self-reported physical activity (IPAQ), and physical activity as self-care behaviour did not differ from the main results (supplement 8).

Applying findings to intervention development

Table 3 reports barriers and enablers identified in qualitative evidence that need to be further investigated in quantitative studies (high uncertainty) and barriers and enablers supported in quantitative evidence with low or moderate uncertainty and the behaviour change strategies that may be useful in addressing them.

Discussion

This review aimed to identify, describe, and compare contextual and modifiable barriers and enablers to physical activity in heart failure (HF) using a Bayesian approach. This work extends the limited research on the modifiable barriers and enablers for physical activity participation by individuals living with HF. Both qualitative and quantitative studies were included in this review and meta-analysis. The contextual barriers supported by the evidence with low uncertainty are high pro-BNP and perceived symptoms. Older age, Left Ventricular Ejection Fraction (LVEF, %), depression, HF
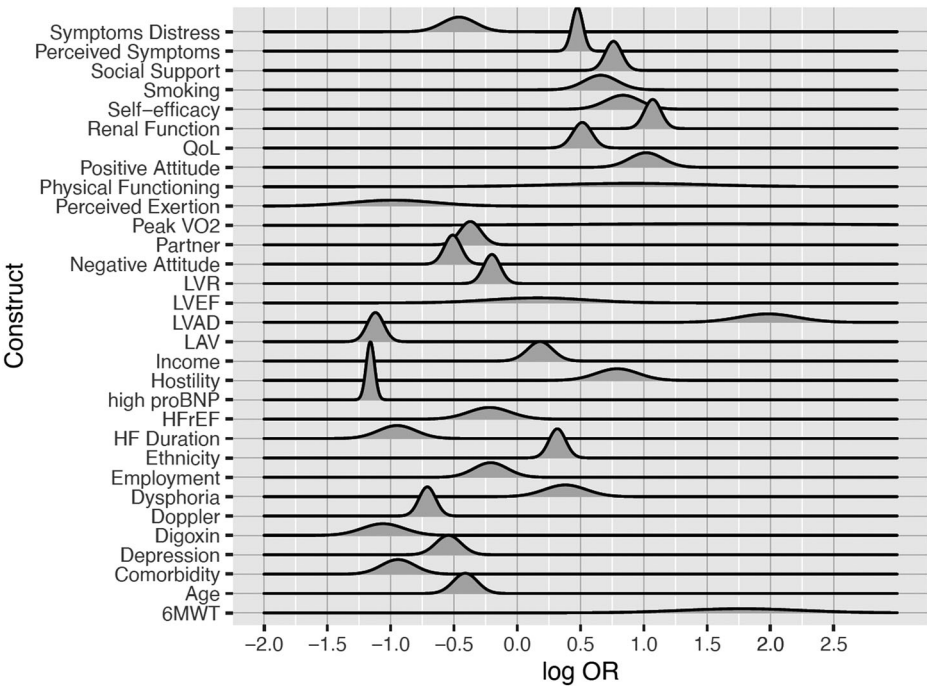

Figure 4. The probability distribution for the expected value of the *log OR* of physical activity conditioned on identified determinants as suggested by the quantitative evidence (QUANT), i.e., likelihood.
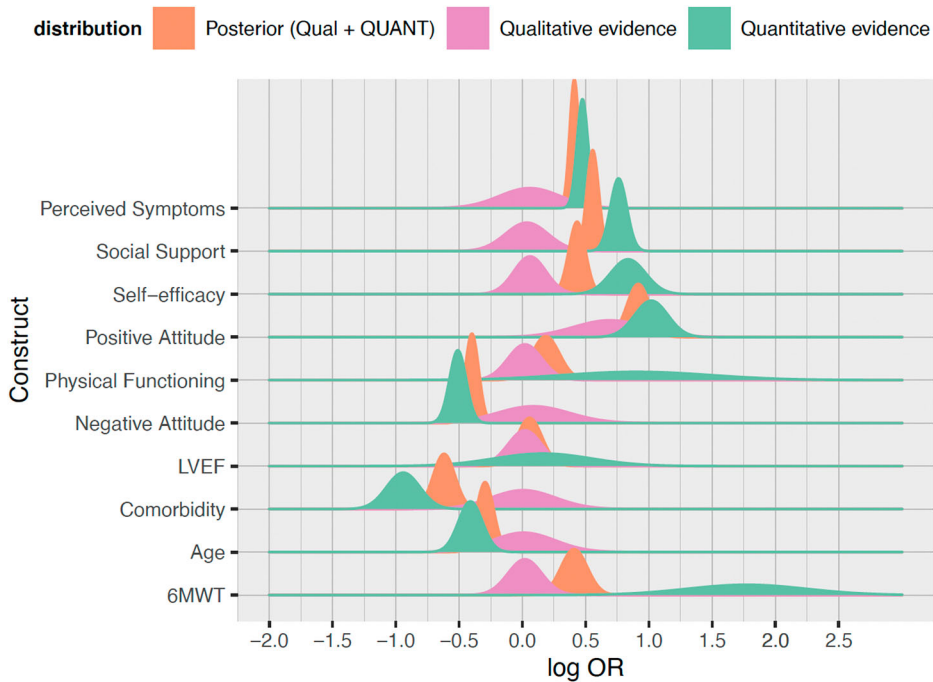
Figure 5. Bayesian updating: the probability distribution for the expected value of the *log OR* of physical activity conditioned on identified determinants according to qualitative evidence (prior expert elicitation task), quantitative evidence alone (likelihood), and qualitative combined with quantitative evidence (qual + QUANT).

duration and living with a partner. Evidence concerning the modifiable barriers: negative attitude and symptom distress; and enablers: social support, positive physical activity attitude, and self-efficacy is moderately uncertain.

This review also aimed to demonstrate the applicability of the Bayesian approach in evidence synthesis informing behaviour change interventions. MRC framework for designing complex interventions (Craig et al., 2008; Skivington et al., 2021) urges researchers to consider evidence from a diverse set of sources when developing interventions. Several methods have been proposed, including the use of mixed-methods studies where one type of evidence (e.g., qualitative) informs the research design of the complimenting study (e.g., quantitative). However, it is less clear how to compare findings from a broad range of studies (qualitative and quantitative) and how to estimate uncertainty in the evidence. The Bayesian approach presents a unique opportunity for research informing complex intervention development by providing a workflow and analysis equipped to combine different evidence and evaluate uncertainty in the evidence. This review synthesised evidence from different sources. The prior elicitation task facilitated this. The results of the expert elicitation task were updated with quantitative evidence. Such Bayesian updating of the probability of physical activity in HF conditioned on each construct summarises both qualitative and quantitative evidence. This approach was first implemented by Dixon-Woods and colleagues (Dixon-Woods et al., 2005; Roberts et al., 2002). Dixon-Woods et al. (Dixon-Woods et al., 2005; Roberts et al., 2002) advocated for integrating qualitative research in healthcare decision making because it provides valuable insights and places the patient in the heart of care by bringing their perspective into account. However, Roberts et al. (2002) highlighted the following shortcoming of using Bayesian meta-analysis. Qualitative research should be formally and systematically catalogued before it can be integrated with quantitative findings, which is often not straightforward. Using the TDF (Cane et al., 2012) in the present review, we mitigated this limitation.

Table 2. Summary of the evidence: the expected value for the *log OR* according to the expert elicitation task, quantitative evidence, and the posterior (qual + QUANT) describing the association between physical activity and identified barriers and enablers.

Construct	Expert elicitation task results (prior)			Quantitative evidence (likelihood)			Posterior (qualitative and quantitative evidence)	
	n qual. studies	Expected value (log OR)	95% CrI	n quant. studies	Expected value (log OR)	95% CrI	MAP (log OR)	95% CrI
Age	3	0.01	[−0.40; 0.42]	11	−0.41	[−0.57; −0.25]	−0.29	[−0.41; −0.18]
Six-minute Walking Test (6MWT) (*Changing Soma* in qualitative evidence)	3	0.02	[−0.20; 0.24]	5	1.77	[1.00; 2.54]	0.41	[0.24; 0.58]
Perceived Symptoms	2	0.06	[−0.34; 0.45]	1	0.48	[0.40; 0.55]	0.41	[0.35; 0.47]
Left Ventricular Ejection Fraction (LVEF), % (*Changing Soma* in qualitative evidence)	3	0.02	[−0.20; 0.24]	6	0.16	[−0.47; 0.79]	0.06	[−0.11; 0.22]
Self-efficacy	2	0.06	[−0.15; 0.27]	6	0.84	[0.61; 1.06]	0.43	[0.32; 0.54]
Social support	1	0.03	[−0.24; 0.31]	1	0.76	[0.65; 0.87]	0.56	[0.48; 0.63]
Comorbidity	1	0.01	[−0.41; 0.43]	2	−0.94	[−1.16; −0.72]	−0.62	[−0.76; −0.48]
Negative attitude	1	0.09	[−0.38; 0.56]	1	−0.51	[−0.62; −0.40]	−0.40	[−0.49; −0.31]
Physical functioning	1	0.02	[−0.20; 0.24]	4	0.90	[−0.06; 1.86]	0.18	[0.01; 0.36]
Positive physical activity attitude	1	0.69	[0.22; 1.16]	1	1.02	[0.80; 1.23]	0.92	[0.77; 1.06]
Depression	–			6	−0.54	[−0.71; −0.38]	–	
Digoxin prescription	–			1	−1.06	[−1.33; −0.79]	–	
Doppler estimated filling pressure	–			1	−0.71	[−0.82; −0.60]	–	
Dysphoria	–			1	0.38	[0.11; 0.65]	–	
Employment	–			2	−0.21	[−0.42; 0.01]	–	
Ethnicity (Caucasian vs non-Caucasian)	–			2	0.32	[0.21; 0.42]	–	
HF duration	–			2	−0.95	[−1.19; −0.71]	–	
HFrEF (Yes, vs HFpEF)	–			1	−0.22	[−0.49; 0.05]	–	
High pro-BNP	–			1	−1.16	[−1.21; −1.11]	–	
Hostility	–			1	0.79	[0.52; 1.06]	–	
Income	1	0.18	[0.02; 0.34]	–			–	
Left Atrial Volume index (LAV)	–			1	−1.12	[−1.23; −1.01]	–	
Left Ventricular Assist Device (LVAD)	–			1	1.98	[1.60; 2.36]	–	
Left Ventricular Remodelling (LVR)	–			1	−0.20	[−0.31; −0.09]	–	
Living with Partner	–			2	−0.37	[−0.51; −0.24]	–	
Peak VO$_2$	–			2	1.54	[−0.41; 3.49]	–	
Perceived exertion	–			1	−0.98	[−1.52; −0.44]	–	
Quality of Life (QoL)	–			3	0.51	[0.39; 0.64]	–	
Renal function	–			1	1.07	[0.96; 1.18]	–	
Smoking	–			1	0.66	[0.44; 0.88]	–	
Symptom distress	–			1	−0.25	[−0.47; −0.03]	–	

Note. *OR* – Odds ratio; *CrI* – Credible Interval.

Contextual barriers and enablers

Older age is a barrier to physical activity in HF, as suggested by both qualitative and quantitative evidence. This result further reiterated the finding of a meta-analysis (Amirova et al., 2021) that older adults living with HF need more support to attain higher physical activity levels.

Depression is a considerable barrier, as identified by the quantitative evidence. Depression is a large burden on the HF population. It is associated with poor adherence to pharmaceutical treatment (Goldstein et al., 2017) and is an independent predictor of morbidity (Moudgil & Haddad, 2013). The physiological determinants perpetuating depression in HF include inflammation, blood cell abnormalities, Central Nervous System (CNS) changes and changes in health-protective behaviours (Huffman et al., 2013). The association between depression, HF, and lack of physical activity is complex. Like any cardiovascular disease, HF is a consequence of low physical activity in clinically depressed individuals (Gold et al., 2020). More research investigating the mechanism via which depression impacts physical activity in HF is needed.

The review findings concerning employment are in accord with a qualitative semi-structured interview study with a non-clinical sample of adults transitioning to retirement, which found that retirement is perceived as providing opportunities to become physically active (McDonald et al., 2015). On the other hand, authors also reported that this was not always the case, and an individualised approach may be required (McDonald et al., 2015). Similarly, a national survey of 1550 adults aged 60–69 in England in 2007 reported that work commitments and lack of leisure time were major barriers to physical activity (Chaudhury & Shelton, 2010). Context, social norms surrounding physical activity in older age may impact how physical activity is enacted in older adults who transitioned to retirement (Koeneman et al., 2017; McPhee et al., 2016).

The diagnosis of HFrEF and its duration may engender a higher risk of physical *in*activity than the diagnosis of HFpEF. However, the available evidence is uncertain, and more evidence is needed before drawing any definitive conclusions. Non-cardiovascular comorbidities in HF include Diabetes Mellitus (type 2), chronic obstructive pulmonary disease (COPD), and renal dysfunction (Rushton et al., 2015). A frequent comorbid cardiovascular condition is atrial fibrillation (Ling et al., 2016). These comorbidities increase both morbidity and mortality in HF (Rushton et al., 2015). This review identified that a greater number of comorbidities reduce the physical activity engagement in HF. Another clinical barrier identified by the present review is longer HF duration which is likely to result in deterioration of physical functionating. Overall, it is likely that longer HF diagnosis duration, as well as multimorbidity, contribute to limited physical activity levels.

These contextual factors need to be carefully considered in both future cross-sectional studies and randomised-controlled trials evaluating the mechanism of change. Understanding the contextual determinants influencing behaviour is useful in informing the design of quantitative research studies investigating modifiable determinants influencing physical activity (Rothman et al., 2008). Contextual differences (i.e., age, LVEF, and depression) indicate that different approaches to behaviour change interventions for these subgroups that take into account their unique clinical characteristics and align with the European Society of Cardiology (Ponikowski et al., 2016) and NICE (National Institute for Healthcare and Excellence, 2018) guidelines are required. The review encourages the consideration of these patient characteristics in the intervention design and its tailoring. However, contextual understanding does not provide insights into what can and needs to be changed for these demographic and clinical subgroups to engage in physical activity. This urges research on modifiable barriers and enablers to physical activity in HF in these subgroups.

Modifiable barriers and enablers

Both qualitative and quantitative evidence included in this meta-analysis suggests that perceived symptoms and negative attitude (*Emotion*) are relevant barriers. While social support (*Social Influences*), positive physical activity attitude (*Beliefs about Consequences*) and self-efficacy (*Beliefs*

Table 3. Summary of the barriers and enablers suggested by qualitative and quantitative evidence and proposed behaviour change techniques (BCTs).

Construct	Type of evidence	Distribution SD	Distribution dispersion/ Uncertainty in the evidence	COM-B	TDF domain	Mechanisms of Action (MoAs)	Proposed behaviour change techniques (BCTTv1)
Contextual factors							
Perceived Symptoms	Qual + QUANT	0.19	narrow/low	Psychological Capability, Physical Capability	–	–	–
Age	Qual + QUANT	0.26	medium/moderate	Psychological Capability, Physical Capability	–	–	–
Comorbidity	Qual + QUANT	0.29	medium/moderate	Psychological Capability, Physical Capability	–	–	–
6MWT	Qual + QUANT	0.32	medium/moderate	Psychological Capability, Physical Capability	–	–	–
Physical Functioning	Qual + QUANT	0.33	medium/moderate	Psychological Capability, Physical Capability	–	–	–
LVEF	Qual + QUANT	0.32	medium/moderate	Psychological Capability, Physical Capability	–	–	–
High proBNP	QUANT	0.18	narrow/low	–	–	–	–
Depression	QUANT	0.31	medium/moderate	Automatic Motivation	–	–	–
Digoxin	QUANT	0.41	medium/moderate	–	–	–	–
Doppler	QUANT	0.26	medium/moderate	–	–	–	–
Dysphoria	QUANT	0.41	medium/moderate	–	–	–	–
Employment	QUANT	0.36	medium/moderate	–	–	–	–
Ethnicity	QUANT	0.26	medium/moderate	–	–	–	–
HF duration	QUANT	0.38	medium/moderate	–	–	–	–
HFrEF (Yes)	QUANT	0.41	medium/moderate	–	–	–	–
Hostility	QUANT	0.41	medium/moderate	–	–	–	–
Income	QUANT	0.31	medium/moderate	–	–	–	–
LAV	QUANT	0.26	medium/moderate	–	–	–	–
LVAD	QUANT	0.48	medium/moderate	–	–	–	–
LVR	QUANT	0.26	medium/moderate	–	–	–	–
Living with Partner	QUANT	0.29	medium/moderate	–	–	–	–
Perceived exertion	QUANT	0.57	medium/moderate	–	–	–	–
QoL	QUANT	0.27	medium/moderate	–	–	–	–

Table 3. Continued.

Construct	Type of evidence	Distribution SD	Distribution dispersion/ Uncertainty in the evidence	COM-B	TDF domain	Mechanisms of Action (MoAs)	Proposed behaviour change techniques (BCTTv1)
Renal function	QUANT	0.26	medium/moderate	–	–	–	–
Smoking	QUANT	0.36	medium/moderate	–	–	–	–
PeakVO$_2$	QUANT	1.09	wide/high	–	–	–	–
Modifiable factors							
Social support	Qual + QUANT	0.26	medium/moderate	Social Opportunity	Social Influences	Social Influences	Social support (unspecified), Social support (emotional), (Social support practical)
Negative attitude	Qual + QUANT	0.26	medium/moderate	Automatic Motivation	Emotion/Optimism	Emotion	Reduce negative emotions, Information about health consequences, Information about emotional consequences
Positive physical activity attitude	Qual + QUANT	0.36	medium/moderate	Reflective Motivation	Beliefs about Consequences	Attitude towards the behaviour	Information about consequences, Salience of consequences, Feedback on behaviour, Feedback on the outcome of behaviour, Pros and cons, Emotional consequences, Csensitisationsation, Anticipated regret, Comparative imagining of future outcomes, Vicarious reinforcement
Self-efficacy	Qual + QUANT	0.37	medium/moderate	Reflective Motivation	Beliefs about Capabilities	Beliefs about Capabilities	Behavioural practice and Rehearsal, Graded tasks, Social comparison, Focus on past success, Verbal persuasion about capability
Symptom distress	QUANT	0.36	medium/moderate	Automatic Motivation	Emotion	Emotion	Reduce negative emotions, Information about health consequences, Information about emotional consequences
Beliefs about ageing	Qual	–	high	Reflective Motivation	Beliefs about Capabilities	Beliefs about Capabilities	Behavioural practice and Rehearsal, Graded tasks, Social comparison, Focus on past success, Verbal persuasion about capability
Social role/self-identity	Qual	–	high	Reflective Motivation	Social/ Professional Role and Identity	Self-image	Identity associated with changed behavior, Reframing, Cognitive dissonance
Local environment	Qual	–	high	Physical Opportunity	Environmental Context and Resources	Environmental Context and Resources	Adding objects to the environment, Prompts/cues, Avoidance/changing exposure to cues for the behaviour
Outcome expectancies	Qual	–	high	Reflective Motivation	Beliefs about Consequences	Beliefs about Consequences	Information about consequences, Salience of consequences, Feedback on behaviour, Feedback on the outcome of behaviour, Pros and cons, Emotional consequences, sensitisation, Anticipated regret, Comparative imagining of future outcomes, Vicarious reinforcement
Problem solving	Qual	–	high	Psychological Capability	Behavioural Regulation	Behavioural Regulation	Action planning, Self-monitoring behaviour, Problem solving, Goal setting outcome, Feedback on behaviour, Habit formation

Note. *The uncertainty in the evidence is judged from the dispersion in the distribution (i.e, standard deviation, SD) relative to the distribution for physical activity in general HF population (SD = 0.14; Jaarsma et al., 2013). The evidence from qualitative studies that was not confirmed in quantitative studies is considered high uncertainty in this review. QUANT indicates that the majority of the evidence (n = 16) was quantitative, and qual indicates that only three studies were qualitative. SD – standard deviation; TDF – Theoretical Domains Framework (Cane et al., 2012); COM-B model (Michie et al., 2011); Mechanisms of action (Connell et al., 2019). BCTTv1 (Michie et al., 2013).

about Capabilities) are suggested as enablers of the behaviour. Another review of qualitative and quantitative studies on barriers and enablers relevant to older adults (65–70 years old) and middle-aged adults (50–64 years old) identified that older adults might rely on social influence, social reinforcement and assistance in managing the change in lifestyle to a greater extent than the middle-aged adults (Spiteri et al., 2019). Older adults require social support in managing HF and daily life.

The following domains were identified uniquely in qualitative research: *Knowledge*, *Beliefs about Consequences*, *Environmental Context and Resources*, *Behavioural Regulation* and *Social/Professional Role and Identity*. According to qualitative evidence alone, individuals living with HF are driven by the motivation to achieve the desired outcome, such as reduced symptoms and improved health (*Beliefs about Consequences*). According to qualitative research, the local environment that encouraged physical activity (e.g., parks; *Environmental Context and Resources*) was fundamental for physical activity enactment. The need to find practical solutions to overcome limitations in physical activity (i.e., problem solving; *Behavioural Regulation*) played a crucial role in physical activity, according to the qualitative studies included in this review. While the change in perceived social role, described as a loss of social network and position in society brought about as a result of HF, had negative implications for physical activity (*Social/Professional Role and Identity*). However, these were not followed up with a quantitative study to confirm their relevance in a larger sample. This meta-analysis suggests exploring and confirming the role of these barriers and enablers in quantitative research.

Study-level limitations

Currently, there is no gold standard risk of bias assessment for observational studies (Page et al., 2018). Therefore, this review included categories of sources of bias traditionally proposed for assessing study-level bias. These include confounding bias, selection bias, measurement bias, missing data bias, and reporting bias (Page et al., 2018). These collectively formed the criteria for evaluating the risk of bias across the included studies. Overall, the majority of the studies (75%) were exposed to a low risk of bias. The major source of bias in the included studies is confounding, as observational studies included in the review (81.25%) did not control for confounding effects when assessing correlates of physical activity.

Strength and limitations of this review

We have adhered to the criteria for conducting Bayesian research , supplement 9 (Depaoli et al., 2017). However, there are a few limitations. First, this meta-analysis offered claims about the association, not causality. Second, the prior was elicited using an expert elicitation task with a limited panel of experts. Health psychology researchers appraised qualitative evidence. They then completed a task designed to elicit a prior probability for physical activity conditioned on the constructs identified in the included qualitative studies. While this is an established technique for formalising an informative prior, it is by definition subjective and thus depends strongly on the members of the expert panel (Albert et al., 2012). In this case, the panel was limited to health psychologists. It would have been beneficial to include other stakeholders, such as HF nurses or cardiologists. Third, the search was performed in January 2020 before the COVID-19 pandemic and has not been updated because the studies conducted since investigated the impact of COVID-19 and the lockdown on physical activity in HF. Such a global change posits an incomparable barrier to physical activity and is difficult to assess alongside general barriers and enablers summarised in this review. Heterogeneous physical activity outcomes were combined in the main meta-analysis. The qualitative evidence described physical activity in the general sense, while quantitative evidence included well-defined heterogeneous physical activity outcomes. Due to this limitation inherited from the qualitative data, in the main Bayesian meta-analysis, we combined heterogeneous physical activity outcomes. In a sensitivity analysis, we assessed the impact of this on the findings, where we stratified

the analysis of quantitative evidence by physical activity outcome (supplement 8). Physical activity outcomes included accelerometer units ($n = 2$), duration, mins/day assessed using an accelerometer ($n = 1$), energy expenditure estimated from accelerometer data (METs; $n = 4$), self-reported exercise compliance ($n = 6$), self-reported general physical activity, IPAQ ($n = 2$), self-reported adherence to prescribed exercise self-care behaviour ($n = 1$), steps per day ($n = 3$), and one study included both energy expenditure (METs) and duration (mins/day). The sensitivity analysis results revealed that depression is not a considerable barrier to physical activity assessed using an accelerometer, suggesting that studies assessing physical activity using self-reports may overestimate the impact of depression on actual physical activity levels. The evidence concerning perceived symptoms is moderately uncertain when only energy expenditure (METs) is included in the analysis. While steps per day are not associated with pro-BNP and enablers such as 6MWT, physical functioning, LVEF, and Peak VO$_2$. The latter may have resulted from the smaller number of studies being included in the stratified analysis. The findings concerning other barriers and enablers did not change once the analysis was stratified by physical activity outcome. Physical activity behaviour may be more homogeneous in HF than in the general population due to its low levels and physical limitations.

Recommendations for future research and clinical practice

Older adults (>70 years old) living with HF are at risk of low physical activity levels. It is important to explore beliefs about physical activity that are associated with older age. Research informing the development of interventions for this subgroup of the population is needed. The quantitative evidence suggests that physical activity levels are reduced in the presence of depression (*Emotion*). A better understanding of the mechanism through which depression impacts physical activity in HF and how it can be mitigated is needed. The quantitative evidence on physical activity conditioned on other clinical, demographic, and psychosocial barriers and enablers is uncertain. Research investigating a broad range of clinical, demographic, and psychosocial barriers and enablers to physical activity in HF is warranted. In addition, identified studies did not explore the mechanism underlying physical activity enactment, including how the barriers and enablers interact, which should be further explored in future research.

Finally, tentative suggestions are made for what a future physical activity intervention needs to include. Overall, the review findings indicate that to reduce the barriers and enhance the enablers, a behaviour change intervention containing the following BCTs are needed: identity associated with target behaviour, prompt/cues and adding objects to the environment, behavioural practice/rehearsal, and graded tasks. A previous meta-analysis of randomised controlled trials also suggested that these strategies are associated with the efficacy of interventions (Amirova et al., 2021). In addition, the qualitative evidence included in this review suggests that addressing the change in the social identity as a result of acquired HF diagnosis and the perceived appropriateness of physical activity in this context need to be addressed. *Social Influences, Beliefs about Consequences, Behavioural Regulation, and Emotion* via BCTs such as social support, information about health and emotional consequences of the behaviour, problem solving, and reducing negative attitude (*Emotion*), may be effective in increasing physical activity in HF, according to the present review. However, the latter suggestions need to be considered with caution, considering the high uncertainty in the evidence.

Conclusion

The identified contextual barriers and enablers to physical activity in HF need to be carefully considered when designing interventions and randomised controlled trials evaluating interventions. There is moderate evidence in support of the modifiable barriers – symptom distress (*Emotion*) and negative attitude (*Emotion*) – and modifiable enablers – social support (*Social Influences*), self-efficacy (*Beliefs about Capabilities*), and positive attitude towards physical activity (*Beliefs*

about Consequences). Interventions targeting these barriers and enablers warrant further investigation.

The Bayesian approach in this review enabled comparative predictions about barriers and enablers, helped elicit the extent of uncertainty in the evidence and enabled the combination of qualitative and quantitative evidence in a single synthesis. Thus, the present review supports the usefulness of the Bayesian approach to evidence synthesis concerning barriers and enablers to behaviour and in the development of behaviour change interventions.

Authors contribution

AA and LT searched electronic databases, performed screening of titles and abstracts and full texts, and carried out the risk of bias evaluation. The qualitative TDF-based analysis was carried out by AA, BV, and AC. The expert elicitation task was completed by AA, LT, BV, NA, AC, and TF. The Bayesian meta-analysis was carried out by AA. The manuscript was drafted by AA. All authors contributed to the interoperation of the results and manuscript revisions.

Notes

1. GitHub repository: https://github.com/AliyaAM/bayesian_meta_analysis.
2. GitHub repository: https://github.com/AliyaAM/bayesian_meta_analysis/blob/main/results_ordered_by_uncertainty.csv; https://github.com/AliyaAM/bayesian_meta_analysis/blob/main/dispersion_uncertainty.R.

Disclosure statement

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

Funding

Protocol

The review's protocol was registered on PROSPERO: CRD42021232048

Availability of data, code and other materials

Https://github.com/AliyaAM/bayesian_meta_analysis.

Supplements:

1. Detailed Inclusion criteria. The scope of the review: pi(e)cos and spider
2. Search strategy.
3. Statistical analysis.
4. Included studies.
5. Studies that appear to meet the inclusion but were excluded (with the reasons for exclusion).
6. Physical activity assessment across studies.
7. Individual studies risk of bias.
8. The results of the sensitivity analysis stratified by physical activity outcome.
9. Checklist: criteria for evaluating studies employing Bayesian statistics (Depaoli et al., 2017).
10. PRISMA checklist: https://prisma.shinyapps.io/checklist/.

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