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Personalised Interactive Music Systems for Physical Activity and Exercise: A Systematic Review and Meta-Analysis

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Personalised Interactive Music Systems for Physical Activity and Exercise: A Systematic Review and Meta-Analysis

The use of Personalised Interactive Music Systems (PIMS) may provide benefits in promoting physical activity levels. This systematic review and meta-analysis was conducted to assess the overall impact of PIMS in physical activity and exercise domains. Separate random effects meta-analyses were conducted for outcomes in physical activity levels, physical exertion, rate of perceived exertion (RPE), and affect. In total, 18 studies were identified. Of these, six studies (with 17 total intervention arms) reported data on at least one outcome of interest, from which an effect size could be calculated. PIMS were significantly associated with beneficial changes in physical activity levels (g = 0.49, CI [0.07, 0.91], p = 0.02, k = 4, n = 76) and affect (g = 1.68, CI [0.15, 3.20], p = 0.03, k = 4, n = 122). However, no significant benefit of PIMS use was found for RPE (g = 0.72, CI [-0.14, 1.59], p = 0.10, k = 3, n = 77) or physical exertion (g = 0.79, CI [-0.64, 2.10], p = 0.28, k = 5, n = 142). Overall, results support the preliminary use of PIMS across a variety of physical activities to promote physical activity levels and positive affect.

Keywords: physical activity, music intervention, health promotion, exercise, affect

Introduction

Regular physical activity is a proven factor for maintaining and improving human health and well-being. Among its numerous benefits, it helps to prevent and treat non-communicable diseases, such as cardiovascular diseases, cancer, and diabetes. It can also contribute to better mental health and quality of life (Posadzki et al., 2020). The World Health Organization (WHO) defines physical activity "as any bodily movement produced by skeletal muscles that requires energy expenditure" (WHO, 2022, p. 4), thus encompassing a broad range of activities, such as walking, sports, or dance.

However, despite the compelling evidence for its health benefits, one out of four adults worldwide fail to meet the global physical activity guidelines as recommended by WHO. Moreover, over 80% of adolescents are insufficiently physically active (WHO, 2022). Physical inactivity, i.e., insufficient amounts of moderate-to-vigorous physical activity, is closely related to, but conceptually distinct from, sedentary behaviour, which is defined as "as any waking behaviour while in a sitting, reclining or lying posture with low energy expenditure" (WHO, 2022, p. 4). Apart from increased health risks, including higher mortality and chronic disease rates, physical inactivity carries an enormous economic burden. Based on the current physical inactivity levels this burden will have an estimated global cost of US$ 300 billion by 2030 (WHO, 2022).

Music as a tool in physical activity

Given its emotional potency to affect human beings, the use of music as a tool to enhance motivation in physical activity has gained increasing attention during the past decades (e.g., Terry et al., 2020). For instance, a recent meta-analysis (Clark et al., 2024) found that music listening interventions can lead to small increases in physical activity in older adults. Terry et al.'s (2020) meta-analysis highlighted the use of music across various physical activities to raise positive affective valence, boost physical performance, decrease perceived exertion, and enhance physiological efficiency.

To outline the theoretical underpinnings of music applications in this domain, a recent conceptual framework (Karageorghis, 2016) details the antecedents (musical factors), moderators (personal and situational factors), and consequences of music use (psychological, psychophysical, behavioural, psychophysiological). To further explain how music influences physical activity, previous research (e.g., Juslin et al., 2022; Karageorghis et al., 2021; Park et al., 2023) has typically focused on three salient types of underlying mechanisms: affect and emotions, dissociation of exertion, and rhythmic responses to music.

Regarding the first mechanism, music has been most frequently used in sports for its power to regulate, modulate or induce arousal and affective states or emotions (Terry et al., 2020). In addition, music might promote dissociation and distraction from pain and fatigue during physical activity (Karageorghis et al., 2021). According to the distraction hypothesis, music can divert attention away from the sensations of physical exertion, thereby reducing perceived effort and making exercise feel easier (Albert et al., 2022). This occurs as the afferent nervous system has a limited capacity to process information. When music is introduced, it can interfere with the body's physiological signals related to physical effort, further diminishing the perception of exertion (Terry et al., 2020).

Personalised Interactive Music Systems (PIMS) in physical activity

Recently, there has been significant efforts to develop personalised music systems aimed at enhancing health and physical activity outcomes (Agres et al., 2021; Danso, 2023). While music can assist physical activity in a multitude of ways (e.g., pre-task, in-task, and post-task; Karageorghis et al., 2021), the increased accessibility and use of smartphones and smart devices has initiated a rising development and adoption of Personalised Interactive Music Systems (PIMS) (Wijnalda et al., 2005). These systems leverage software and sensors to customise music according to the user's exercise routine, adjusting tempo, style, and musical timbre to align with the user's pace, intensity and/or duration of activity. PIMS typically use computer algorithms and are often integrated into smartphones or wearable devices to monitor movements. Use of these systems elicits a personalised music experience, helping users maintain motivation and adhere to physical activity (Wijnalda et al., 2005).

PIMS are designed for various contexts, leveraging intrinsic and extrinsic factors. For instance, the moBeat system (Van Der Vlist et al., 2011) used interactive music and biophysical signals to provide real-time feedback on pace and intensity during home aerobic exercises, boosting intrinsic factors such as motivation and attentional focus, and extrinsic factors such as training guidance. Similarly, a PIMS providing musical feedback for older adults' workout movements (Rehfeld et al., 2022) enhanced intrinsic factors like physical endurance, and extrinsic factors such as workout engagement, more than conventional workouts. As mobile interventions that include personalisation elements have demonstrated higher effectiveness in enhancing physical activity than those without such elements (Laranjo et al., 2021), PIMS offer vast potential in terms of health promotion and disease prevention.

Due to the relatively recent advancements in this field, there is little knowledge about the effectiveness of PIMS in increasing physical activity and reducing sedentary behaviours across diverse populations. This information is crucial, however, for the implementation, replication, and comparison of interventions aimed at promoting physical activity (Michie et al., 2013). While several reviews and meta-analytic reviews exploring music and physical activity have been published (e.g., Clark et al., 2024;

Terry et al., 2020), none of these reviews have focused on the effectiveness of PIMS across a variety of outcomes of interest affecting PIMS use (such as physical exertion, rate of perceived exertion, and affect). Given that our overarching goal is to contribute to empirical knowledge and provide practical implications for health promotion, our main research question is:

(1) How effective are PIMS in increasing physical activity and reducing sedentary behaviours?

For further exploration, the review also addresses a secondary research question:

(2) How have PIMS been used as an intervention for stimulating physical activity?

Methods

This systematic review and meta-analysis was designed based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol (Page et al., 2021). The full search strategy can be found in the review registration document (PROSPERO, registration reference CRD42023465941).

Eligibility Criteria

We included: (1) Studies that investigate the impact of Personalised Interactive Music Systems (PIMS) on exercise, physical activity, or adherence to non-sedentary behaviours; (2) Studies that include participants from various populations, with a focus on both sedentary and non-sedentary individuals; (3) Studies reporting quantitative or qualitative data related to the effects of PIMS on motivation, exercise intensity, adherence to physical activity, or related outcomes; (4) Studies involving testing a PIMS in relation to physical activity or exercise behaviour; (5) Articles in the English language; (6) Articles published from January 2010 to the present (to ensure relevance and up-to-date information); (7) Peer-reviewed journal articles and conference papers.

We excluded studies that were: (1) From non-peer-reviewed sources, books, dissertations, theses, and grey literature; (2) Studies written in languages other than English; (3) Not directly related to the impact of PIMS on exercise, physical activity, or adherence to non-sedentary behaviours; (4) Studies that use music for the management of specific conditions such as psychiatric disorders.

Information Sources

We searched the following databases: (1) Web of Science, (2) SPORTDiscus, (3) Medline, (4) Embase, (5) ACM Digital library databases, (6) Springer, (7) Google Scholar, (8) IEEE Xplore, and (9) Scopus. The database search was supplemented by a forward and backward snowball search. The reference list of all articles were scanned for potential sources. The snowball search continued until no sources could be identified.

Search Strategy

A literature search was performed using terminology related to the use of PIMS to reduce sedentary behaviour or stimulate physical activity, ("Personalised Interactive Music System" OR "Music Recommendation Algorithm" OR "Music Recommendation System" OR "Streaming" OR "MP3" OR "Digital Music" OR "Machine Learning") AND ("Physical Activity" OR "Exercise" OR "Recovery" OR "Recuperation" OR "Sedentary Behav*" OR "Inactive" OR "Sitting").

Selection Process and Data Collection Process

The citations of all retrieved articles were imported into Zotero and all duplicates were removed. Study title and abstract were then screened by two authors (AD, TK) using ASREVIEW (Van de Schoot et al., 2021) and Rayyan (Ouzzani et al., 2016). If the article could not be excluded on the basis of the title or abstract, full-text articles were retrieved. The retrieved full-text articles were then assessed for inclusion by two authors (AD, TK) in pairs independently. At each stage, disagreements were discussed with a third author (KK) used if a consensus could not be achieved.

Data Extraction

The studies' information was extracted to a spreadsheet, including study characteristics, such as the type of PIMS, the study design, PIMS measurement, the target effect/behaviour of the PIMS, physical activity results, and non-sedentary behaviour results (Table 1). Where available, quantitative data suitable for meta-analysis were extracted. This was done for the pre-registered outcome of physical activity level, as well as for physical activity related affect, rate of perceived exertion (RPE), and physical exertion, which were not pre-registered as outcomes. The decision to extract data on these additional outcomes was taken because of the close relationships between these variables and physical activity participation, their prevalence as outcomes in the included studies, and the limited number of studies reporting data on physical activity behaviour. In cases where effect sizes could not be readily calculated based on the published articles, authors were contacted at least two times requesting this additional data.

Study Risk of Bias Assessment

The quality of the studies was assessed by two authors (AD, TK) using the Joanna Briggs Institute (JBI) critical appraisal checklist, including tools for Quasi-Experimental Appraisal, Qualitative Research Appraisal, and the Revised Checklist for Randomised Controlled Trials.

Data Synthesis and Analysis Methods

We conducted a narrative synthesis based on study design (experimental studies or proof of concept and user testing studies). Randomised experimental design, experimental design, quasi-experimental design, within-subjects crossover design, pilot study, and within-subject experiments were considered experimental studies. Proof of concept and user testing designs were placed into another single category. We produced a preliminary synthesis by adopting the methodological framework of Campbell et al. (2020) and identified trends within and between the two study groups (experimental/proof concept and user testing studies). Within all the studies, we subdivided them based on their focus of PIMS affecting physical activity levels, physical exertion, RPE, and affect.

To allow for quantitative synthesis, Hedges' g effect sizes and standard errors were calculated using the tool by David B. Wilson (2023). These data were input to SPSS (v28), where separate random-effects meta-analyses using the inverse variance weighting method were conducted for the outcome's physical activity level, physical activity related affect, RPE, and physical exertion. Forest plots and funnel plots were created to summarise the data and investigate possible publication bias, respectively. Data and syntax files for these analyses are available as supplementary files (OSF, https://osf.io/jpy5k/).

To examine the effectiveness of PIMS aimed at improving physical activity outcomes, a meta-analysis based on the outcome of interest (physical activity, exercise behaviour or reducing sedentary behaviour) in eligible studies was conducted[1]. In the context of the present meta-analysis, physical activity refers to any kind of physical activity (e.g., walking, running, weight training, cycling, housework, gardening) or exercise behaviour (e.g., e.g., a behaviour that is a planned and uses structured movement of the body that is designed with the goal of enhancing physical fitness). Outcomes outside the area of interest of the analysis were excluded (e.g., studies

1 Eligible studies included a control group and intervention arm targeting the outcome of interest.

measuring subjective feasibility of their PIMS). Six studies (with 17 total intervention arms) reported data on at least one outcome of interest, from which an effect size could be calculated. Due to the small number of studies eligible for meta-analysis, sensitivity analyses were not performed. This underpins the exploratory and preliminary focus of the review.

Results

Study Selection

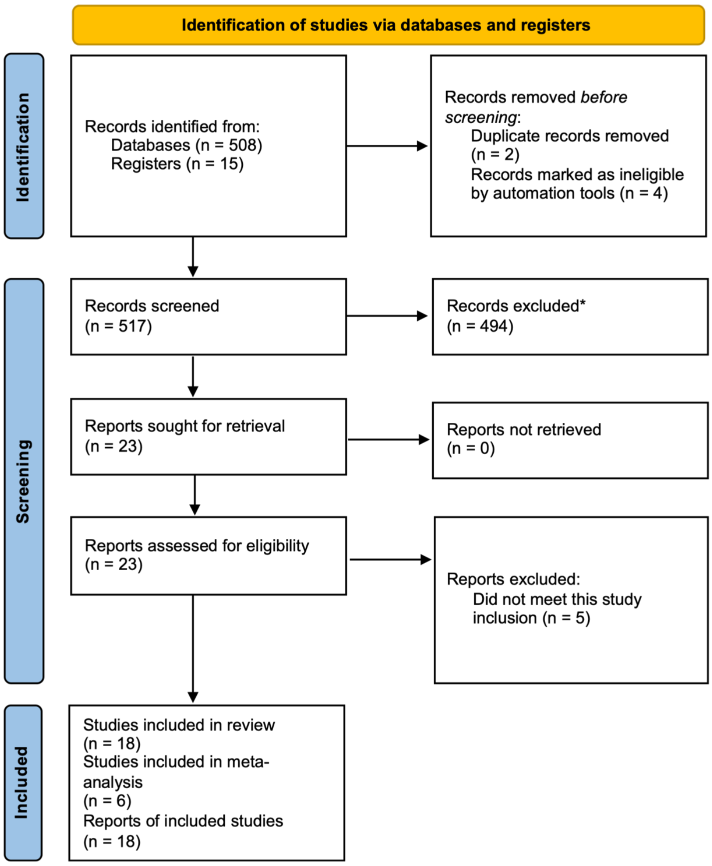

Figure 1. PRISMA information flow describing the screening process[2] *All records excluded by ASReview (Van de Schoot et al., 2021) and Rayyan (Ouzzani et al., 2016).

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2 Page et al (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

A total of 508 articles were found in the initial strategic search using the mentioned keywords. Thereafter, two duplicated articles were excluded as well as four articles marked ineligible. After screening based on the title and abstract, 494 articles were excluded whose topic did not match the inclusion criteria. Twenty-three full articles that matched the defined topic of interest were evaluated based on the inclusion and exclusion criteria. We considered other articles (n = 5) for evaluation with similar details based on the defined topic of interest. However, the five articles were excluded, as they did not evaluate the desired effect and outcome. In total, 18 articles were eligible to be included in this review study (Figure 1).

Study Characteristics

The study characteristics (Table 1) encompass a diverse range of studies conducted across various countries, including Canada, Spain, Germany, Taiwan, Singapore, Denmark, Finland, Belgium, Switzerland, the Czech Republic, the Netherlands, Norway, and locations not specified. These studies, conducted between 2010 and 2024, provide a broad age range among participants, with some studies focusing on specific groups such as the elderly, patients with cardiovascular disease, students, non-athletes and office workers. The PIMS used in these studies vary in their design and objectives, ranging from personalised music audio-playlists to interactive music systems linked to fitness devices and smart cushions. These systems are utilised in different settings and for various purposes, including motivating physical activity, enhancing exercise experience, and rehabilitation.

Table 1. Characteristics of included studies.

Authors	Country	Age, y	Sample Size, N	Population	Type of PIMS	Study Design	PIMS Measurement	Target Behaviour/Target Physical Activity	Physical Activity Results	Non-sedentary Behaviour Results
Alter et al. (2015)	Canada	47.3 – 79.2 [a]	34	Patients with cardiovascular disease	Personalised music audio-playlists	Randomised Experimental Design	Tri-axial accelerometer	Adherence	Improved PA volumes (*p < 0.001*)	N/A
Alvarez et al. (2020)	Spain	N/A	N/A	N/A	Personalised music recommendation system	Proof of Concept	Sensors [b]	Motivation/performance enhancement	N/A	N/A
Carôt et al. (2023)	Germany	N/A	1	Elderly participant	Music feedback for rehabilitation	Proof of Concept	Accelerometer	Rehabilitation	N/A	N/A
Chen et al. (2023)	Taiwan	21.56 ± 1.04	10 female and 26 male	Participants from the National Yang Ming Chiao Tung University	Exercise system for middle-distance running	User Testing Design	Smartphone's built-in tri-axial accelerometer	Adapting music selection to user's pace during walking	N/A	Higher emotional responses during exercise (*p* <0.05). Significantly improves mood (p <0.001)
Chen et al. (2014)	Taiwan	N/A	N/A	N/A	Music to motivate exercise	Quasi-Experimental Design	Tri-axial accelerometer	Physiological, perceptual, affective responses	N/A	N/A
Fang et al. (2017)	Singapore	N/A	60	Students	A music recommendation system	Within-subjects Crossover Design	Music recommendation ratings	Motivation	N/A	N/A
Fritz et al. (2013)	N/A	N/A	45	Non-athletes, non-body builders, non-musicians	Jymmin® – Sensor attached to fitness devices to provide musical feedback	Experimental Design	Movement sensor [c]	Workout	N/A	Positive mood during workout (*P = <0.05)*
Jun, Rew & Hwang (2015)	N/A	N/A	27	N/A	Runner's Jukebox (RJ) – music tempo matching the user's pace during exercise	User Testing Design	Smartphone app to recognise user pace/adjust music tempo	Walking/running pace monitor [d]	N/A	Improve performance of SWPM
Maculewicz & Serafin (2015)	Denmark	N/A	N/A	N/A	Music clips with dynamic BPM ranging from 110 – 170	Proof of Concept	Sensors [e]	Cycling	N/A	N/A

Maes et al. (2019)	Switzerland	18–45	7 females, 8 males	Cyclists	SoundBike – Musical sonification to improve spontaneous synchronisation of cyclists.	Experimental	Sensors	Cycling	Enhanced cyclist synchronisation to external music	N/A
Mendoza et al. (2022)	Finland	N/A	2	Elderly participants	Processing accelerometry data to create musical sonifications of physical activity	Proof of Concept	Sonification of PA data [f]	Awareness of PA	N/A	N/A
Moens et al. (2010)	Belgium	N/A	33	Participants from public event	DSaT algorithm for music selection and real-time adaptation [g]	Pilot Study	Tri-axial accelerometer	Synchronisation to beat of music	Majority (56.79%) synchronised steps with music	N/A
Moens et al. (2014)	Belgium, Czech Republic	21.9 ± 12.9 20.2 ± 0.8 21.2 ± 1.7 23 +- 3 SD	82 male, 68 female 56 male, 44 female 12 female 6 female, 4 male	N/A	Synchronise music with the participant' movements	Case Study	Recordings of footfalls & music alignment strategies [h]	Synchronisation to beat of music	Improved entrainment	N/A
Ospina-Bohorquez et al. (2021)	N/A	N/A	N/A	N/A	Context-aware recommender system (CAMRS)	Mixed-method Design [i]	Automatic learning algorithm	Motivate users to complete PA	N/A	N/A
Rehfeld et al. (2022)	Germany	70.6 (SD ± 3.9)	11 females 5 males	Non-physically active	Jymmin® – Sensor attached to fitness devices to provide musical feedback	Within-subjects Design	Movement sensor [j]	Strength-endurance exercises	N/A	Strength-endurance duration increases during musical feedback (p = 0.001)
Ren et al. (2017)	Netherlands	18 – 25	24	Office workers	Smart cushion providing musical feedback	Within-subjects Design	Movement sensor-pad	Posture changes	No effect breaking sedentary behaviour	N/A

Rosseland (2016)	Norway	N/A	3 – 6[k]	Seniors with early-stage Alzheimer's disease	Interactive music system	Qualitative Research Design	Sensor-pad	Stimulate/motivate PA	N/A	Entrainment and synchronisation
Vlist et al. (2011)	Netherlands	23 – 51	26	Philips employees	MoBeat – Interactive music system	Within-Subject Experiment	Cadence sensor, heart-rate	Motivation	N/A	Significant effects on fun/enjoyment (p = <0.001), perceived competence (p = 0.05), value/usefulness (p = 0.029), dissociation (p = 0.001), distress (p = 0.266)

Notes:

[a]= Lowest lower bound: 47.3 years (from the second subgroup). Highest upper bound: 79.2 years (from the first subgroup). The estimated entire age range for all three groups combined would be from approximately 47.3 years to 79.2 years.

[b]= Galvanic Skin Response, oxygen saturation sensor, pulse sensor.

[c] = Jymmin® – The movement of the sensor-equipped fitness device is mapped to musical parameters, creating an acoustic feedback signal.

[d] = Swings Per Minute (SWPM).

[e] = Monitor cycling pace and & heart rate, influencing audio feedback (soundscape sounds) in real-time.

[f] = Accelerometry data.

[g] = Dynamic Song and Tempo (DSaT).

[h] = The methodology involved recording footfalls and various music alignment strategies to synchronise music with participants' walking or running movements.

[i]= Includes elements of a proof of concept design and an experimental design.

[j] = Jymmin® – The movement of the sensor-equipped fitness device is mapped to musical parameters, creating an acoustic feedback signal.

[k] = Exact numbers are not specified, but a mention of a group size of 3 to 6 participants.

Risk of Bias in Studies

Following the assessment of the study quality using the JBI critical appraisal checklist tools, the nine criteria were adapted to the five risk of bias domains found in the McGuiness et al. (2021) R package for risk-of-bias assessments. This assessment/tool tests the risk of bias resulting from the randomisation process (D1), deviations from intended intervention (D2), missing outcome data (D3), measurement of the outcome (D4), and selection of the reported result (D5). Each domain is assessed with a judgement scale indicating a high risk of bias (red cross), some concerns (yellow circle), low risk of bias (green plus) and No Information (blue question mark) (Figure 2).

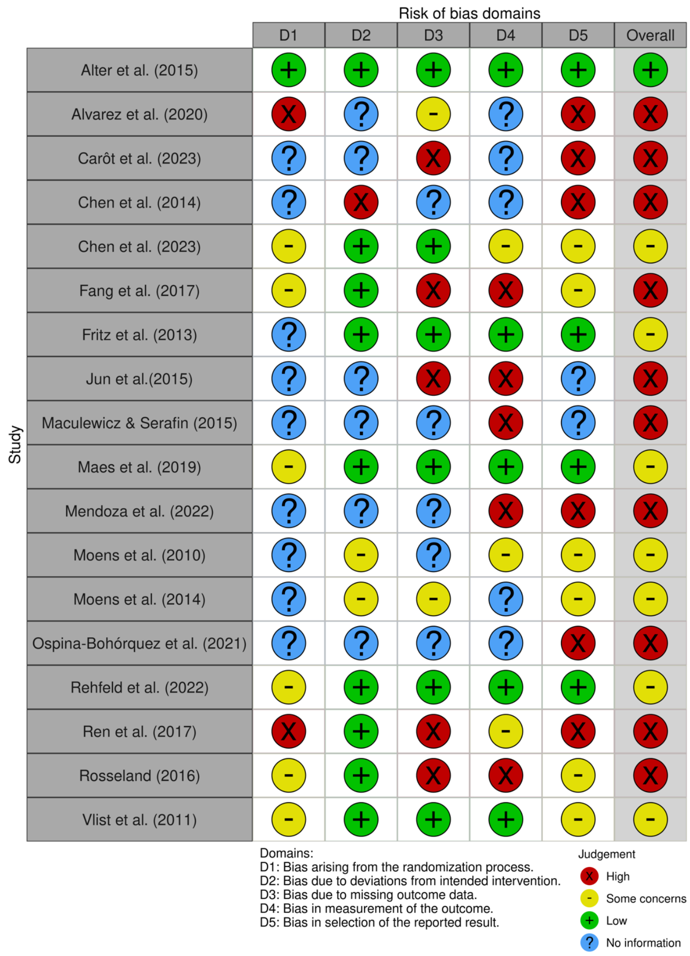

Figure 2. Evaluation of bias risk in selected studies, categorised across five domains from D1 to D5. An overall bias risk assessment for each study is also provided, summarising the findings across all domains.[3]

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3 McGuinness, L. A., & Higgins, J. P. T. (2021). Risk-of-bias VISualization (robvis): An R package and Shiny web app for visualizing risk-of-bias assessments. Res Syn Meth. 2020; 1-7. https://doi.org/10.1002/jrsm.1411

We included all 18 studies in the review regardless of their quality rating. Of the 18 studies, one randomised experimental design study (Alter et al., 2015) was rated for low risk of bias. Seven studies received a moderate (some concerns) rating in risk of bias, and 10 were rated for a high risk of bias.

Key Findings of Experimental Studies

For the eight studies using PIMS in an experimental design, Alter et al. (2015), Chen et al. (2014), Fang et al. (2017) and Maes et al. (2019) report outcomes in enhanced jogging experience, motivation for exercise, enhanced cyclist synchronisation, and engagement in physical activities. Whereas, studies by Fritz et al. (2013), Moens et al. (2014), Rehfeld et al. (2022), Ren et al. (2017) and Van Der Vlist et al. (2011) provide findings in enhanced mood, increased motivation for exercise, reduced RPE, and longer physical endurance without increased RPE. These studies used PIMS in a variety of ways (see Table 2 in the supplementary information for a description of the PIMS used in the experimental studies). Objective measures such as step detection algorithms, physiological data (e.g., heart rate measurement), musical parameters (e.g., tempo), exercise duration, number of repetitions, RPE and mood state questionnaires were reported.

Key Findings of Proof of Concept and User Testing Studies

The nine studies using PIMS in a proof of concept and user testing design used a real-time, personalised approach to adapt music or provide audio feedback based on the participant's physical activity. They also included the testing of interactive music systems in relation to their impact on physical activity and exercise behaviour. The studies' outcomes report consistent entrainment and synchronisation to music, improved physical performance, improved mood, enjoyment of the physical activity, improved recovery times, increased motivation, and increased engagement to physical activity after using the PIMS. Objective measures were reported such as heart rate, RPE, pace, repetitive bodily movements, feeling and arousal scales. In addition, system interactions were described (see Table 3 in the supplementary information for a description of the PIMS used in the proof of concept and user testing studies).

Summary of studies

Most studies provide evidence for the effectiveness of PIMS in improving physical activity and exercise behaviour. This is compared to control conditions using either passive music listening or conventional workouts, albeit at varying levels of support. For instance, Rehfeld et al. (2022) report longer exercise durations using Jymmin® as compared to performing exercise routines while passively listening to music, without a significant increase in RPE. Similarly, Alter et al. (2015) report increased weekly physical activity volumes among cardiovascular disease patients using personalised Rhythmic Auditory Stimulation (RAS)-enhanced playlists. Furthermore, some qualitative evidence by Ren et al. (2017) suggests PIMS were appropriate motivators for reducing sedentary behaviours (i.e., PIMS reduces sitting time in the office).

Music Recommenders

Álvarez et al. (2020), Fang et al. (2017), Jun et al. (2015) and Ospina-Bohórquez et al. (2021) created mobile applications using novel music recommendation techniques. The principal aim was to provide personalised playlists for participants during exercise to increase their level of physical activity (e.g., to train for longer durations of time). Fang et al. (2017) report a significant increase in willingness to use the application as compared to a music recommendation system not using their user profiling approach. (Jun et al., 2015) found that controlled music fixed to BPM and pace matching improved exercise performance (i.e., improved swings per minute, SWPM, indicating how fast the user walks or runs). Overall, Álvarez et al. (2020), Jun et al. (2015) and Ospina-Bohórquez et al. (2021) studies report positive impacts of music recommender systems on physical activity output.

The majority of the literature suggests an indirect association for the effectiveness of PIMS on physical activity and exercise behaviour. They find PIMS enhance the experience of physical activity measured by ratings of increased participant mood, motivation and lower instances of RPE (Carôt et al., 2023; Fritz et al., 2013; Moens et al., 2010; 2014; Rosseland, 2016; Van Der Vlist et al., 2011). Furthermore, intrinsic motivation and attentional focus during exercise were increased using PIMS (moBeat; Van Der Vlist et al., 2011).

Music-Movement Synchrony

Synchronising music with movement was also measured across three studies (Moens et al., 2010; 2014 and Maes et al., 2019). All three studies found increased synchronisation using PIMS. Specifically, Moens et al. (2010; 2014) report that movement was better synchronised with a playlist in the synchronised condition, compared to a random playlist condition. Maes et al. (2019) report that musical sonification of cyclists' motor rhythm significantly increased their tendency to spontaneously synchronise their pedal cadence with external music, compared to having no sonification. This was however, without a direct evaluation on physical activity or exercise outcomes. In addition, several studies used PIMS tempo adjustment to stimulate physical activity (Chen et al., 2014; Maculewicz & Serafin, 2015; Rosseland et al., 2016). In these studies, music tempo was adjusted (or proposed to be adjusted) to heart rate, step frequency, biking pace, walking/running speed, or body movements. Music tempo was adjusted to either match the participants' current exercise speed (Chen et al., 2014; Rosseland et al., 2016) or to guide participants to exercise at a more optimal pace (Maculewicz & Serafin, 2015; Chen et al., 2014; Van Der Vlist et al. 2011). Jun et al. (2015) report significant increases in step frequency count (SWPM), finding enhanced user synchronisation between music tempo and user pace in the studied PIMS.

Quantitative Meta-Analysis

A single overall meta-analysis of the studies was not achievable due to heterogeneity across datasets and outcomes. Therefore, we clustered the data into several outcomes of interest. The outcomes included (1) physical activity levels, (2) physical exertion, (3) rate of perceived exertion (RPE), and (4) affect. Physical activity levels refers to the PIMS eliciting an effect of the volume of physical activity or volume of exercise in participants. Physical exertion was associated with the PIMS stimulating an effect on the measured physiology of participants (e.g., heart rate) during physical activity or exercise behaviour. RPE refers to the PIMS eliciting an effect on participants' ratings of perceived exertion. Affect refers to the emotional value associated with music, and how it influences the emotions of the listener.

To quantify the magnitude of the impact of PIMS across different research settings, effect sizes were calculated and synthesised. The following meta-analysis of the outcomes of interest associated with PIMS within the studies takes into account variations in study design, sample size, and measurement of outcomes. A random-effects model was used due to potential heterogeneity among the included studies. Effect sizes are reported as Hedges' g.

Results for Physical Activity Level

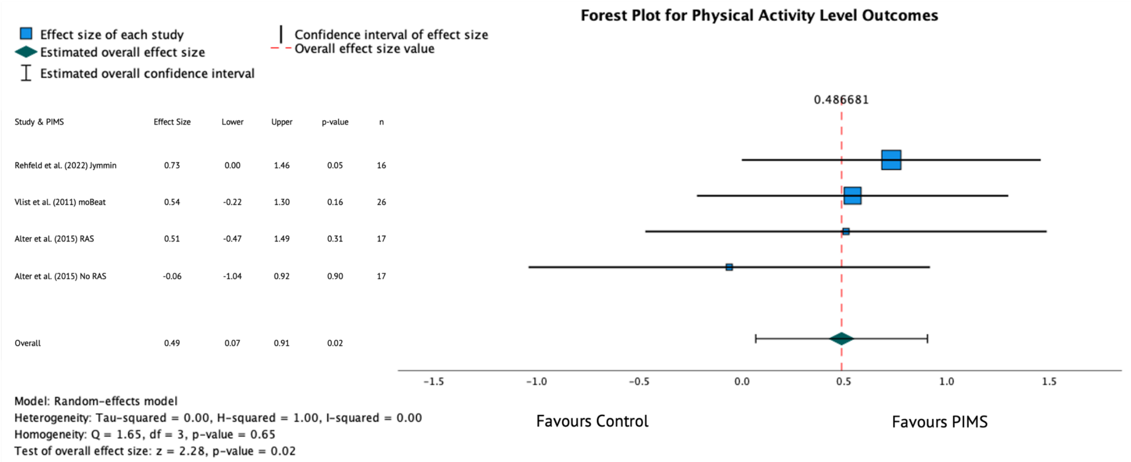

Figure 3. Forest plot of effect sizes for physical activity level outcomes associated with PIMS.

The overall effect size is 0.49 with a CI of 0.07 to 0.91, and a p-value of 0.02 ($k = 4$, $n = 76$). This indicates that the results are statistically significant, supporting the effectiveness of PIMS in improving physical activity level outcomes. The random-effects model indicates low heterogeneity (I-squared = 0%, Tau-squared = 0.00) between the studies, suggesting the variance between studies is negligible.

Results for Physical Exertion

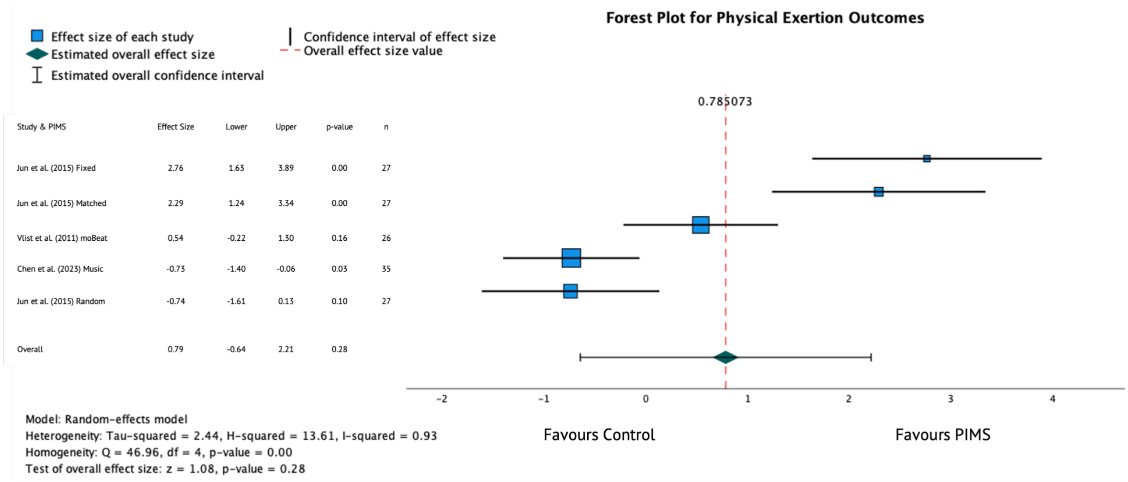

Figure 4. Forest plot of effect sizes for physical exertion outcomes associated with PIMS.

The overall effect size is 0.79 with a CI of -0.64 to 2.1, and a p-value of 0.28 (k = 5, n = 142), indicating that the results are not statistically significant, and do not support the effectiveness of PIMS in improving physical exertion outcomes. The random-effects model indicates high heterogeneity (I-squared = 93%, Tau-squared = 2.44) between the studies, suggesting the variability between studies is substantial.

Results for Rate of Perceived Exertion

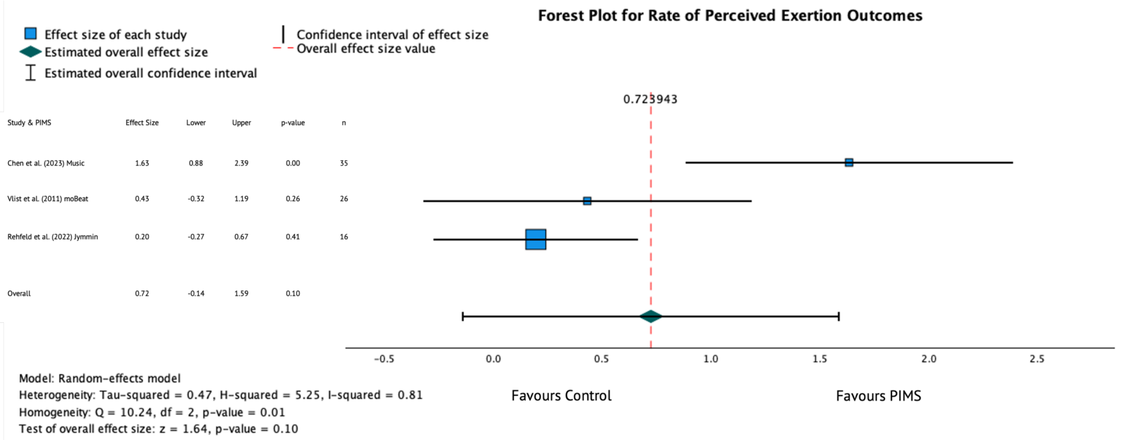

Figure 5. Forest plot of effect sizes for rate of perceived exertion outcomes associated with PIMS.

The overall effect size is 0.72 with a CI of -0.14 to 1.59, and a p-value of 0.10 (k = 3, n = 77), indicating that the results are not statistically significant, and do not conclusively support the effectiveness of PIMS in improving RPE outcomes. The random-effects model indicates high heterogeneity (I-squared = 81%, Tau-squared = 0.47) between the studies, suggesting substantial levels of variability between studies.

Results for Affect

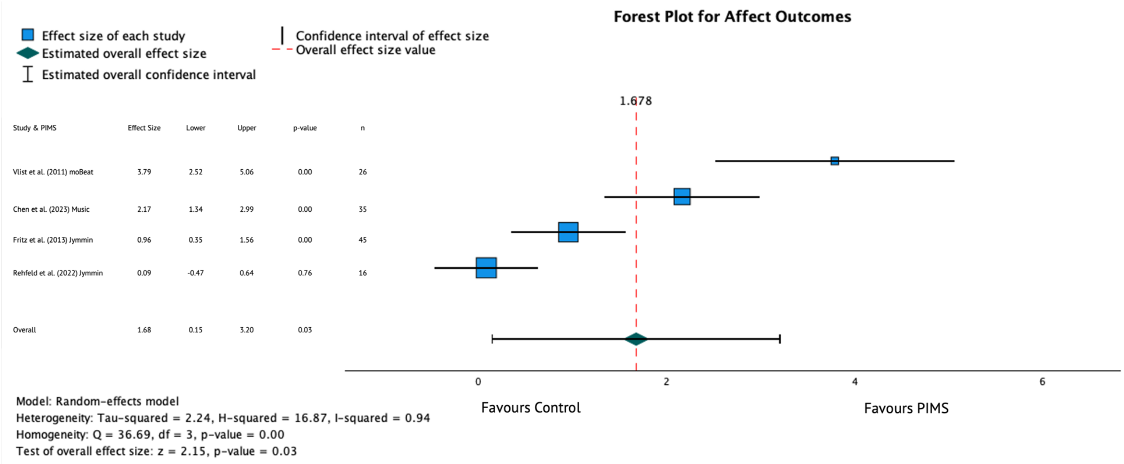

Figure 6. Forest plot of effect sizes for affect outcomes associated with PIMS.

The overall effect size is 1.68 with a CI of 0.15 to 3.20, and a p-value of 0.03 (k = 4, n = 122), indicating that the results are statistically significant, and support the effectiveness of PIMS in improving affect outcomes. The random-effects model indicates substantial heterogeneity (I-squared = 94%, Tau-squared = 2.24) between the studies, suggesting the variability between studies is substantial.

Discussion

The goal of this systematic review was to assess for the first time whether PIMS are effective at increasing physical activity and reducing sedentary behaviours. This review included 18 studies between January 2010 to February 2024, featuring 597 participants. Our findings highlight that favourable results can be identified across outcomes of interest associated with physical activity.

The key finding emerging from our (separate random effects) meta-analysis is that the effect size estimates are in line with previously estimated effects of music listening on physical activity levels (Clark et al., 2024). Our meta-analysis shows modest evidence that PIMS significantly influence physical activity levels and positively impact affect in physical activity and exercise contexts. Specifically, PIMS are shown to have a favourable effect on physical activity levels (g = 0.49, p = 0.02) and affect (g = 1.68, p = 0.03), but do not show a favourable effect on physical exertion (g = 0.79, p = 0.28). PIMS do not conclusively support the effectiveness in improving RPE (g = 0.72, p = 0.10) outcomes. Taken together, outside of our findings for RPE, this evidence supports previous meta-analytic findings regarding the effects of music listening in exercise and physical activity domains (Clark et al., 2024; Terry et al., 2020).

Even though PIMS were found to have a positive impact on various physical activity outcomes, there is insufficient evidence to definitively conclude whether PIMS are effective at increasing physical activity and reducing sedentary behaviours. This is due to the wide variety of results reported, methods used, contextual differences across the studies, and potential biases within the studies. Accordingly, the results of the reviewed studies present a mixed picture regarding the review's main research question. For instance, Alter et al. (2015) and Chen et al. (2023) report significant improvements in physical activity levels and positive affect due to PIMS interventions. In contrast, Rehfeld et al. (2022) Van Der Vlist et al. (2011) did not observe a significant reduction in RPE, although there were improvements in mood and motivation. These discrepancies suggest that the impact of PIMS may vary depending on the specific context and design of the intervention. In addition, there is a significant risk of bias concern identified across the studies. However, we discuss the moderate evidence of the beneficial effects of PIMS on several key aspects, as these findings may have implications for future music-based interventions to support physical activity and exercise behaviours.

Aspects of PIMS Effectiveness: Perceived Exertion and Affect

The PIMS examined for RPE were not shown to have a significant effect in terms of reducing perceived exertion (Figure 5); however, the near-significant effect size estimate ($g = 0.72$, $p = 0.10$) warrants discussion. This meta-analytic cluster included three studies, but only Chen et al. (2023) reported a significant effect of PIMS on reducing RPE. Both Rehfeld et al. (2022) and Van Der Vlist et al. (2011) did not report significant effects on RPE when compared to control conditions. Van Der Vlist et al. (2011) reported participants' RPE as lower using moBeat compared to a reference system; however, this was not a statistically significant result. Chen et al. (2023) reported significant effects of their PIMS on RPE across several time points (0, 2, 6, 8, 10 minutes), and was the only study to monitor RPE across time. The study found considerable differences in RPE starting from the two-minute time point. The fact that users could self-select their music in the study may substantiate the large effect on RPE among participants. Including these studies that measured RPE across a variety of PIMS adds ecological validity to our results. Chen et al. (2023) findings are in line with previous works, suggesting that self-selected music has a significant bearing on RPE, principally explained by music functioning as a distractor from unpleasant emotions and fatigue-related sensations during submaximal exercise (Terry et al., 2020).

The large effect size estimate found in favour of affect ($g = 1.68$, $p = 0.03$) suggests PIMS are associated with positive affect in physical activity and exercise domains. In general, this supports the notion that music enhances participant enjoyment, as well as overall physical activity and exercise adherence (see e.g., Terry et al., 2020). However, this estimate is reported, for the most part, due to one study by Van Der Vlist et al. (2011) who used the moBeat system. In this cluster, an additional study by Chen et al. (2023) was also favourable, although a smaller effect size estimate was reported. Both Van Der Vlist et al. (2011) and Chen et al. (2023) used a control condition of no music, which may cause an overestimate of the overall effect.

Aspects of PIMS Effectiveness: Tempo Adjustments

PIMS that use tempo adjustments to encourage physical activity produced supporting results for the primary research question. Chen et al. (2023) report a positive effect of PIMS on physical activity associated with the use of musical tempo: using real-time music tempo adaptation according to heart rate led to reduced RPE (e.g., Figure 5, Chen et al., 2023, $g = 1.63$, $p < .00$) and enhanced affect (e.g.., Figure 6, Chen et al., 2023, $g = 2.17$, $p < .00$), compared to the non-music exercise group. In addition, we found Alter et al. (2015) report positive effects for RAS music playlists on physical activity levels (Figure 3). Both studies associate music tempo adjustment in physical activity behaviour differently. First, Chen et al. (2023) associate adjusted musical tempi and heart rate with affect, indicating that music allowed participants to dissociate from internal sensory signals, focusing on enjoyable aspects of the exercise behaviour similar to previous findings (e.g., Terry et al., 2020). Second, Alter et al. (2015) associate RAS-enhanced playlists to support overall physical activity adherence. Their results are partially in line with Clark et al.'s (2016) conceptual framework illustrating how music listening supports and modulates physical activity levels.

However, the evidence remains unclear regarding PIMS use of tempo for overall effectiveness to increase physical activity. For instance, in four studies (Chen et al., 2014; Jun et al., 2015; Maculewicz & Serafin, 2015; Rosseland et al., 2016), music tempo was included as a design feature. Yet, no statistical outcomes were reported on its use (as all but one of these studies were proof of concept and user testing designs). The interactive music system used by Rosseland (2016) reported positively on the effects of adjusted tempo to stimulate physical activity in elderly populations. However, the results were based on the subjective observation of participants. Thus, despite these studies providing insight as to how PIMS have been used as an adjunct tool to stimulate physical activity, there is a paucity of evidence as to their overall effect.

Limitations

There are several challenges with interpreting the body of evidence of this review. First, variations in study methodologies such as sample sizes, ranging from small pilot studies to larger randomised trials present mixed results. For example, the robust findings of Alter et al. (2015) were derived from a well-powered randomised design, whereas the non-significant findings of Rehfeld et al. (2022) stemmed from a smaller within-subjects study. Furthermore, the types of PIMS used varied widely, from music recommendation systems to real-time music feedback during exercise, each potentially influencing the outcomes differently.

Second, several limitations are recurrent among the reviewed studies. Small sample sizes, as seen in Mendoza et al. (2022), limit the statistical power and generalisability of the findings. Short intervention durations, typical of pilot studies like those by Maculewicz & Serafin (2015), did not capture the long-term effects of PIMS. In addition, many studies lacked rigorous control conditions, such as a no-intervention or placebo control group, which are essential for establishing causality.

Practical Applications and Future Studies

The music recommender systems examined by Álvarez et al. (2020), Fang et al. (2017) and context-aware recommender system (CAMRS) by Ospina-Bohórquez et al. (2021) may provide a key development route for future PIMS. This is due to the studies demonstrating integration with current music playlist and streaming services (e.g., Spotify) appearing feasible. In addition, the studies find promising results in user feedback, as well as willingness to use the systems in physical activity and exercise contexts. Overall, studies by Álvarez et al. (2020), Fang et al. (2017) and Ospina-Bohórquez et al. (2021) suggest PIMS may support physical activity through enhanced personalisation and provide working systems for future hypothesis testing.

Conclusions

Due to the small number of studies reviewed, results suggest uncertainty as to whether PIMS are effective at increasing physical activity and exercise behaviours. However, the majority of evidence suggests that PIMS are promising in relation to supporting physical activity and exercise behaviours. Results from this review's meta-analysis suggest PIMS increase physical activity levels and positive affect. Subjective evidence suggests PIMS may improve the experience of physical activity and exercise behaviour, although this appears to be heterogeneous with variability across different populations. While our review highlights a significant gap in the current evidence and indicates the need for fully powered trials examining the use of music listening alongside more focused behaviour change interventions in adult populations across the lifespan, PIMS show potential as easily implementable, evidence-based interventions to promote physical activity.

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Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials accessed here: OSF, https://osf.io/jpy5k/

Disclosure statement

No potential conflict of interest is reported by the authors(s).

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