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Exergaming Characteristics in Interventions Addressing Physical Activity and Nutrition: A Systematic Literature Review

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Abstract

INTRODUCTION: The increasing popularity of exergames to promote the adoption of physical activity and healthy nutrition among different population groups is well established. However, due to the use of various types of exergames, their effectiveness in addressing specific behaviours varies.
OBJECTIVES: This systematic review aims to identify, classify exergaming elements, and examine their efficacy in enhancing physical activity levels, improve nutrition habits, or a combination of both, across various populations.
METHODS: A systematic search was conducted to identify relevant publications. Data on study characteristics pertaining to types of exergames, purpose, focus, target population, technologies used, and the theoretical framework were extracted. A classification scheme of exergaming components and characteristics has been developed to facilitate this systematic review.
RESULTS: A total of 34 studies were included and n=21 of them were experimental. Most studies (n=31) were focused on Physical Activity using exergames, whereas n=9 studies addressed both Physical Activity and Nutrition simultaneously.
CONCLUSION: All of the studies reported positive behavioural outcomes, although, prolonged and sustained engagement with exergames were not consistently reported.

Keywords: Exergames, Digital Behaviour Change Interventions, Physical Exercise, Nutrition

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1. Introduction

Exergames, which is a sub-category of Serious Games (SGs), have emerged as promising technological solutions to reduce sedentary behaviours and promote healthy habits, such as Physical Activity and Nutrition (PAN), among different populations[1]-[3]. While SGs deal with aspects of physical, mental and social well-being, Exergames are more focused on incorporating physical activities and healthy eating habits into gameplay. They require players to engage in body movements and record their intake of healthy food as game interactions to progress onwards. Exergaming aims to dismantle the barriers that exist in performing physical activities and eating healthy food, to create a motivational environment that engages a number of participants concurrently across different age groups and locations. Exergaming enables both individual and group-based physical activity and food tracking, with feedback on performance being shareable, thus offering social functions.

Over the past decade, a number of devices have been developed and used to deploy exergames, including Commercial-Off-The-Shelf (COTS) console-based exergames [4] such as the Nintendo Wii and Switch alongside specific peripherals such as the Balance Board and the Ring-

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con [5]. Exergames devised as mobile applications running on tablets and smartphones [6], and those which can be used with specialised equipment (such as dance pads, elliptical trainers and stationary bikes) have also gained attention [7].

Thus, the aim of the current review is to provide a classification of the different types of exergames with respect to the different characteristics and components used in them. This review included exergames which focused on promoting PAN and excluded those that only targeted cognitive training. This is intended to facilitate future research in incorporating the most appropriate components when developing exergames targeting PAN.

2. Methods

The review was conducted and reported in reference to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methods. Systematic searches were carried out between November 2019 and February 2020 in the following six databases: Web of Science, ACM Digital Library, CINAHL, PsychInfo, SPORTDiscus and PubMed.

The search was restricted to publications in the English language, between the years 2005 and 2020, due to the unlikelihood of having interventions using mobile-based applications before the introduction of smartphones around the years 2006-2007. Additional articles were identified through manual searches from reference lists of relevant articles. Search categories included exergaming, health behaviours, interventions and population, where the search strategy comprised a combination of keywords (see Appendix A.1.)

2.1. Study selection and inclusion criteria

Studies were considered for this review and included if they met the following criteria: (1) a specific exergame, through a mobile application, a video-game console or specialised equipment, or a combination, was used in an intervention to bring about changes in at least one of the targeted behaviours - physical activity and/or nutrition; (2) targeted children and/or adolescents and/or adults (which also included the senior population); (3) attention given to prevention and/or treatment and/or management of diseases; (4) focused on rehabilitation purposes after strokes or physical injuries. Other outcomes deemed relevant to have an influence on health behaviours and have the potential for behavioural changes, such as BMI, general health and wellness relating to improved quality of life, were also included. Studies were also accepted despite the variation in reporting measurement types (calorie counts, step counts, energy expenditure, MET-minutes etc). Studies were excluded from this review if they were not (1) experimental (2) peer-reviewed; (3) published in the English language; (4) Used exergaming only for cognitive training.

2.2. Data extraction

Data extraction was conducted using a shareable Google spreadsheet template developed for this review, adapted from the one used in [8]. For all included studies, data were extracted for author, year, country, exergame title, study design, population/sample size, Focus (PA/Nutrition/Both), duration, theoretical perspectives, social components, strengths and limitations and the main findings. The primary outcome measures were physical activity and healthy eating habits. Other relevant outcome measures were behaviours related to fitness, sedentary behaviour and quality of life. For each study included in this review, two independent reviewers (BSE and RE) extracted data simultaneously to maximise inter-rater reliability. Both reviewers agreed on the data extraction in over 70% of the studies. Discrepancies were then resolved through discussion between the reviewers.

2.3. Quality assessment and risk of bias

The quality of included studies were assessed using the fundamental mechanisms of the AMSTAR checklist [9]. Some adaptations were made since the original checklist is mainly used for critically appraising systematic reviews of RCTs while our selection also included published experimental studies. For the purpose of this review, bespoke categories were added and included: use of existing exergame apps or exergame equipment or custom-developed exergames; inclusion of social components and use of wearable devices amongst others. The items used for rating are presented in an additional file. The series of questions resulted in an overall rating of high, moderate or low quality. The reviewers (BSE and RE) compared their assessments and any mismatch between the ratings for the included studies was resolved through consensus. Only reviews that had a high rating ($\geq$7) were included. Studies that were rated ($\leq$6) (low/moderate quality) were excluded to avoid unreliable conclusions. The adapted-AMSTAR checklist and the corresponding rating of the included articles are presented in Appendix A.2.

3. Results

3.1 Study selection and study characteristics

The study selection process is presented in Figure 1.

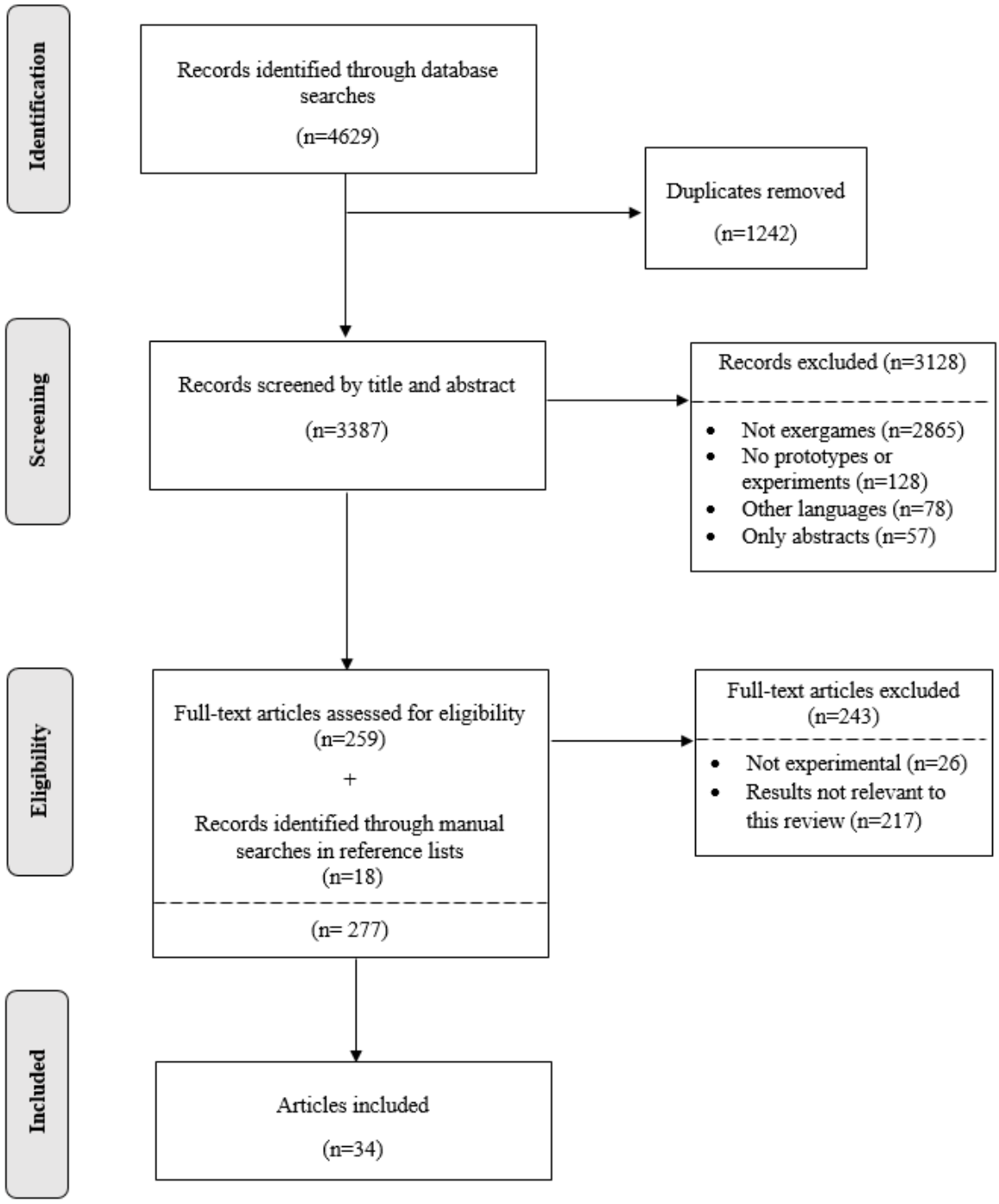

Figure 1. Articles selection using PRISMA flow diagram

A total of n=4629 publications were identified from the database search. Following duplicates elimination, n=3387 publication titles and abstracts were screened, and n=259 full-text articles were considered potentially eligible for inclusion. Out of these, n=34 articles reporting on exergames and their effectiveness in increasing physical activity levels and improving nutrition habits were included in this review. The extracted characteristics of included studies are reported in Annex B.

3.1 Extracted properties

A summarised overview of the extracted properties data is provided below. For detailed breakdowns, see the Extracted Review Data made available for download from synapse.org (https://doi.org/10.7303/syn32152553).

Country

It was found that the majority of the selected articles (n=11) reported on studies conducted in the United States of America (USA).The remaining studies were as follows: n=5 in South Korea, n=6 in Canada, n=5 in the United Kingdom (UK), n=5 in Europe and n=1 in Thailand. n=2 studies from the same researchers in South Korea collaborated with other researchers from the USA and from China respectively.

Study design

n=21 studies were experimental, n=4 of them were user-studies, n=2 studies consisted of field trials, and n=7 studies did not report on their research design, or not applicable.

Duration

The duration of experiments ranged from 1 to 27 weeks and the majority (n=18) did not adequately report on the exact duration of their experiments.

Target population

Nineteen studies targeted adults, n=8 of them involved children and adolescents, n=2 studies included both adults and children in terms of parent-child relationships; and n=9 studies did not report on the target population. The total number of participants across studies was 447 adults and 249 children. The majority of studies reported more male participants in exergames (n=139) compared to female participants (n=82).

Target activities

Most studies did not address nutrition and physical activities simultaneously, except for n=3 included studies, where they promoted healthy eating through earning points for the consumption of seasonal fruits, vegetables and water, while encouraging physical activity among participants. Thirty-one out of n=34 included studies focused solely on physical activity.

Out of the n=34 selected studies, n=16 focused on walking, n=10 studies considered running. Other studies included activities such as swimming, cycling and a combination of several physical exercise such as squats, jumps and other different workout routines as shown in Table 1.

Table 1. Targeted physical activities

Physical Activity Focus	Paper Reference
Walking (n=16)	P4-P7; P9; P11; P12; P15; P17-P20; P24; P26; P29; P33
Running (n=10)	P3; P10; P14; P18; P19; P23; P24; P26; P29; P30
Cycling (n=5)	P8; P13; P20; P21; P25
Swimming (n=2)	P1; P2
Dance (n=2)	P22
Various physical activities [includes walking and running, jogging, squatting, jumping, swinging, spinning, sit-ups, hang-ups, dips, table-up, glute bridge, Bulgarian squats, hanging le raises, pistol squats, arm circles, dodges, stretches] (n=17)	P5-P7; P9; P12; P15; P16; P18; P19; P23; P26; P27; P29-P32; P34

Devices, tools & technologies

Research confirms that the most common devices and technologies used with exergames include smartphones equipped with accelerometer and GPS sensors. These sensors are used primarily to estimate distance rather than for tracking player location, although some form of exergames require the location of players to move onwards in the game [19], [29], [44]. In the current review several of the included studies have used commercially available wrist-worn wearables such as the Xiaomi Mi Band 2, the Microsoft Band, and a less common sock-type wearable device, the Sensoria Fitness Sock. Although numerous other health monitoring devices with built-in sensors are available, they have not been used in the selected studies mainly because they are typically seen in medical settings, for instance, EEG, ECG, EMG and electrodermographs (EDG).

Presence of social components

Twenty out of n=34 studies included a combination of different social components in their exergames such as: sharing achievements; players communicating among each other via chat systems; and trading game elements on social networking sites, as presented in Table 2. Other types of social interaction reported were the creation of communities around a particular exergame - where players communicate in online forums, Facebook groups and pages to discuss matters related to the exergame.

Table 2. Social components types included in exergames

Social Component	Paper Reference
Support and Communication (n=10)	P1; P2; P4; P7; P9; P11; P23; P30-P32
Interaction and Sharing (n=15)	P1-P3; P5; P6; P8; P9; P11; P14; P20; P24; P25; P27; P29; P30
Comparison and Pressure (n=9)	P1-P3; P7; P8; P16; P18; P19; P33
No social element (n=10)	P10; P12; P13; P15; P17; P21; P22; P26; P28; P34

Theoretical framework

In the reviewed articles, 16 out of 34 studies were theoretically driven. This information is presented in Table 3. The most commonly applied were the Self-Determination Theory (SDT), Transtheoretical Model (TTM) and Dual Flow Theory. These behaviour change theories and models used in the design and implementation of behaviour change interventions that use exergames will be further discussed in the next sections. It has been observed that multidisciplinary research was based on theories, compared to single research areas.

Table 3. Theoretical Frameworks Used

Theoretical Framework	Paper Reference
Self-Determination Theory [SDT] (n=4)	P7; P23; P30; P34
Dual Flow Theory (n=3)	P6; P8; P10
Transtheoretical Model [TTM] (n=3)	P9; P28; P29
Social Behaviour Change Theory (n=4)	P11; P32; P33; P29
Game Theory (n=1)	P22
Learning Theories (n=2)	P31; P32
El-Hilly Framework [45] (n=1)	P16
No theories or models (n=18)	P1-P5; P12-P15; P17-P21; P24-P27

Main characteristics of exergames to encourage Physical Activities and Nutrition (PAN)

The characteristics of different types of exergames to encourage PAN can be illustrated using a classification scheme developed to support this review (see Figure. 2).

Exergames are classified through (1) their development type, (2) the platform on which they are deployed and played, (3) their purpose, (4) their genre and, (5) their type of interaction modes. Each of these nodes have different characteristics, which are described in the subsequent section. Part of the classification was drawn upon existing published works[45]–[47]. This enhanced classification is expected to be used as a solid foundation for further research work in the exergaming area for enhanced adaptation to various targeted behaviours.

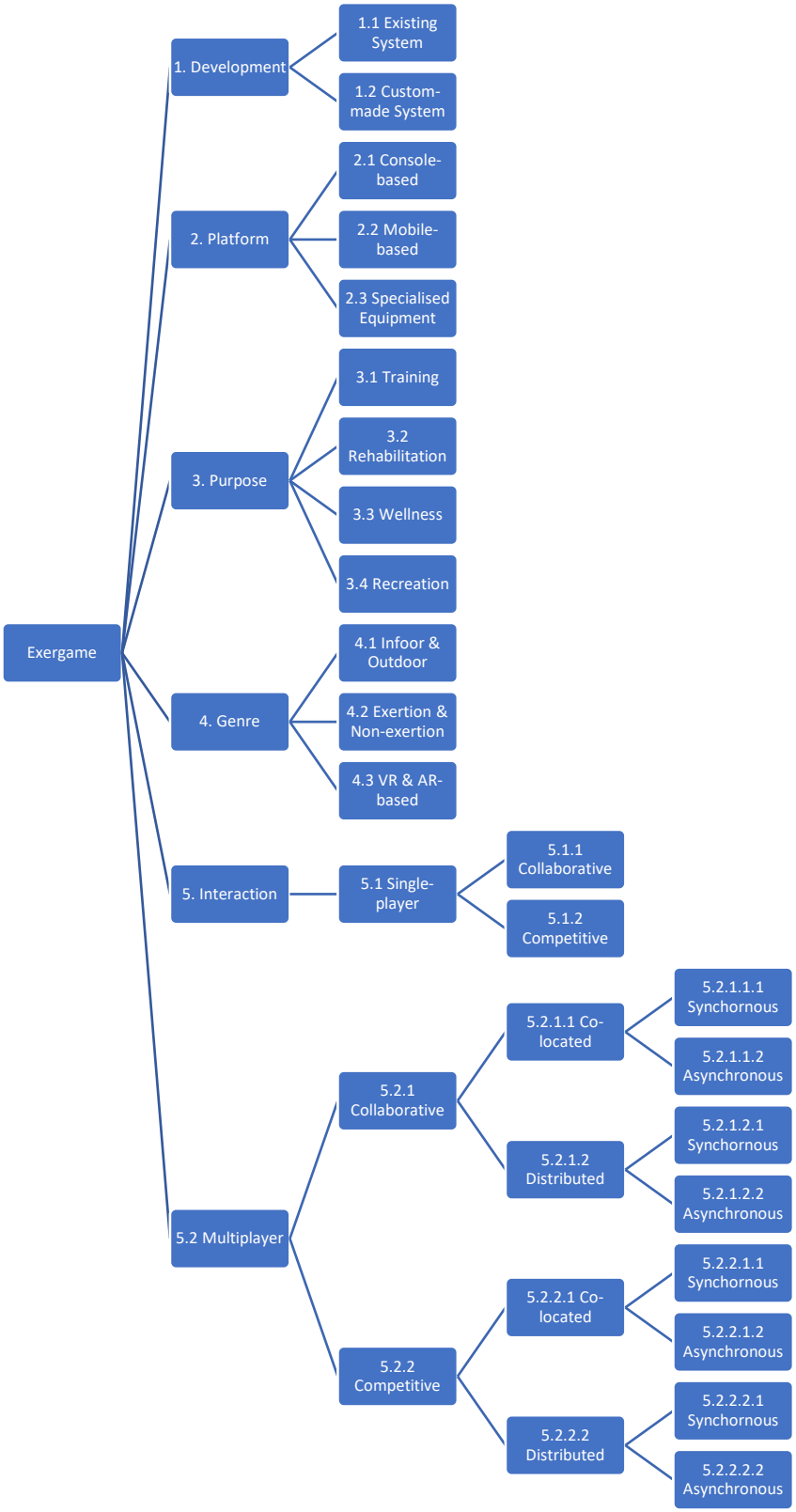

Figure 2. Classification scheme for exergaming characteristics

Description of Classification Nodes

While most of the nodes are self-descriptive, a brief definition is provided in Table 4. to ensure unambiguity.

Table 4. Classification nodes description

1. Development	This Development branch relates to how/whether an exergame has been developed for a particular context. 1.1 Existing System: Exergames may use already developed and generic systems/applications which can be considered as off-the-shelf. 1.2 Custom-made System: This refers to a one-off/tailor-made system or prototype developed for specific situation; thus, considering its contextual requirements.
2. Platform	The Platform branch relates to the type of hardware and/or software ecosystem through which users can engage with the exergame. 1.3 Console-based: These refer to exergames developed for commercial console such as the Microsoft X-Box, Sony PlayStation, Nintendo's WII, etc. The exergames may require the use of additional sensory accessories. 1.4 Mobile-based: Exergames developed as mobile phone applications can be easily installed by users on their smartphones. The use of phone-embedded sensors further enhances the exergames' user-tracking capabilities. 1.5 Specialised Equipment: The use of specialised hardware equipment to engage with exergames include the Dance Pads, Elliptical trainers, stationary bikes, pedometers, smartwatches etc. These equipment are mostly used in conjunction with 2.1 and 2.2 rather than as stand-alone components.
3. Purpose	Exergames are developed with goals and objectives for the targeted user-group. To achieve them, designers have to identify and incorporate suitable components adapted to the specific context. Often, exergames have a combination of two or more purposes rather than just a single one. 1.6 Training: Exergames developed for user-training purposes focus mostly on physical exercises and tend to include competitive components (5.1.2 & 5.2.2) 1.7 Rehabilitation: Such exergames target users who have had (or are undergoing) medical treatments for physical or mental conditions. The exergames aim to facilitate their transition to a regular lifestyle. 1.8 Wellness: These exergames strive to enhance/maintain healthy lifestyles among users and tend to focus on more sustainable activities that ensure continuous and regular engagement over a longer period of time. 1.9 Recreation: The exergames attempt to boost the well-being of users through a gamified exercising program.
4. Genre	Exergames can be based on a particular genre or a combination of multiple genres. 1.10 Indoor & Outdoor: Some exergames are designed for an indoor environment, such as those using gaming consoles, whereas others are predominantly meant for outdoors, such as mobile-based exergames. 1.11 Exertion & Non-Exertion: Exergames, specially designed for purposes of Training (3.1) and Rehabilitation (3.2), tend to focus on exertional & non-exertional elements.

1.12 Virtual Reality (VR) & Augmented-Reality (AR) based: VR is deployed through specialised devices while AR can be experienced through smartphones. Exergames from this genre provide users with a more immersive experience and interaction techniques.

5. Interaction — All exergames require that users interact with the system and these interactions differ based on the platforms used, the purpose and the genre. Interaction is also impacted by the single-player mode or multi-player mode.

1.13 Single-Player: A user will engage with the exergame without interacting other participants. Although there might be elements of collaboration (5.1.1) or competition (5.1.2), these would be mostly with/against one-self or some kind of Artificial Intelligence (AI) system or 'Non-player characters' (NPCs)

1.14 Multiplayer: Groups of users can participate in an exergaming session. This enables collaborative/team-based activities (5.2.1) and also provide users with the opportunity to compare/compete (5.2.2) against one another.

5.2.1.1 & 5.2.2.1 Co-located: The group of participants in an exergaming session are physically present in a particular place (e.g., within a room, on a playground), usually in close proximity to enable direct and physical peer-to-peer communication.
5.2.1.2 & 5.2.2.2 Distributed: The participants in the exergaming session are mostly in different geographical locations and communicate mostly digitally (Internet, Mobile Phone, SMS, etc) or via radio.

5.2.1.1.1, 5.2.1.2.1, 5.2.2.1.1, 5.2.2.2.1 Synchronous: Communication among participants occurs in a synchronous way; for example, a participant asking a peer for advice and the later receives the message and responds in real-time.

5.2.1.1.2, 5.2.1.2.2, 5.2.2.1.2, 5.2.2.2.2 Asynchronous: Communication among participants happens in an asynchronous way; for example, a participant asking a peer for advice through a recorded audio or text message and the recipient receive a notification about the message when he/she logs back into the system. The recipient can then listen/read the message and respond back at the time of his/her own choosing.

4. Discussion

This paper systematically reviewed studies addressing the use of exergames in health promotion. A classification of the different types and characteristics of exergames was developed. This was intended to facilitate the assessment of exergames and their effectiveness in changing behaviours on the long-term compared to traditional physical activity and food intake tracking methods. In addition, it was important to investigate whether types of exergames impact population groups differently.

This systematic review identified 34 studies making use of exergames to promote physical activity, healthy eating habits, or a combination of both, albeit the last one is rather scarce and warrants more research to examine the combination of both physical activity and nutrition. Indeed, most studies did not address nutrition and physical activity simultaneously, except for *Alien Health*, *My Plate Picks* and *GameMyHealth*. They promoted healthy eating by earning points for the consumption of seasonal fruits, vegetables and water, while encouraging physical activity and teamwork among participants in educational settings. Since diet and physical activity are often interlinked, it would be judicious to research

the complementary relationships between diet and physical activity, especially in the context of exergames and technological tools for health promotion. It would enable the design of more effective interventions which can in turn inform health policies.

The majority of studies were from the US. There are two plausible possibilities: the USA have been among the first country to encounter the obesity epidemic and research was needed to promote healthier lifestyles. At the same time, the USA experienced technological advancements, which enabled the use of technology for health, and most specifically the development of exergame research in physical activity and nutrition. Given that obesity is taking epidemic proportion worldwide, other countries will have to address the challenges faced by fast food habits combined with hectic work patterns and sedentary lifestyles [48]. Simultaneously, less developed countries will also have to bridge the technological gap [49]. Indeed, researchers from other countries can benefit from the experiences and learn from advances featured in developed countries; while research collaboration between different countries allows for different perspectives to become evident, leading to interesting health findings across different populations and cultures.

Demographic factors such as age and gender have also been able to influence engagement with exergames, whereby higher app usage has been reported among the female youth population and those displaying positive attitudes towards technology usage [45]. These gender difference can help to identify factors for adherence to exergames and remedy disengagement among male and female participants. The lower number of studies involving children could be attributed to the lengthy ethics procedures required when using children as research subjects.

Walking is recognised as the most popular type of physical activity across the different age groups and between males and females. This is in line with a large-scale study carried out by [50], using data from Fitocracy recorded over a period of 4 years from February 2011 to January 2015. Walking is less intensive compared to running, especially for those suffering from joint pains or knee problems and those who are overweight, and it can be done for longer periods of time. Walking was the preferred exercise for participants as it improves fitness, heart and mental health, prevents weight gain and other diseases associated with lack of physical activity, irrespective of age and gender.

The majority of studies in this systematic review were not theoretically driven. As a matter of fact, only 16 out of 34 studies drew on a theoretical background: mainly Self-Determination Theory (SDT), the Transtheoretical Model (TTM) and Dual Flow Theory. This finding is surprising since it is well established that the use of theories in the design and implementation of interventions improve their effectiveness [51]. Moreover, there is mounting empirical evidence on the barriers and motivators of health behaviour change [52]. This is particularly true in physical activity promotion and nutrition. Four of the most commonly used theories in health behaviour research [53] and physical activity promotion [54] are the transtheoretical model [55], social cognitive theory [56], the Health-Belief Model [57], and the theory of planned behaviour/ reasoned action [58], [59]. All four theories use an individual approach to motivate healthy behaviour; they focus largely on the abilities and capacities of individuals as individuals (such as self-efficacy, attitudes, predispositions) to explain exercise behaviour. More recently, a social approach to health and physical activity has been proposed[60]–[62]. Indeed, researchers have shown the importance of social identities, group memberships, in shaping beliefs and health behaviours[63]. It would be thus important to apply these findings in exergames and other digital interventions. We argue for the importance of interdisciplinary collaboration. It would allow for better perspectives and improve research practice. A model of behaviour change to assess the promotion and maintenance of positive health habits using exergames is essentially missing. There is a need for a model that allows intervention participants to be in control of their behaviour changes using digital means. Intervention participants need to understand the purpose of the intervention and have the ability to measure the impact of their progress on their behaviour so as to take the required actions. At present, theories and models of health behaviour change are often used in isolation, or even when used in conjunction, consist of fundamental overlaps or are overly intricate. There is a need to synthesise and integrate the different aspects of behaviour change into a unified model [64], to change physical activities and nutrition behaviours when using technology (in our case, exergames).

5. Conclusion

Having proper nutrition, keeping fit and overcoming a sedentary lifestyle is a major struggle for people irrespective of their age, gender, health, profession and social status. The findings of this systematic review are consistent across studies and show that exergames generally contribute to positive effects when game elements have been carefully taken into consideration in the design. The novelty factor associated with exergames makes it popular at the beginning, but after some time, players lose interest and the enthusiasm fades. A number of strategies have been used to increase the retention rate through sustained motivation and engagement with exergames. These include avatars, goal-setting, rewards, progression, timely feedback and delivering persuasive messages to actively engage players in changing their health behaviours, each of which have varying degrees of success when targeting different behaviours. There seem to be limited research in the exergame domain for group-specific motivational elements that would appeal the most and/or be more impactful with respect to age, gender and player type. Similarly, only a few experimental studies which made use of control groups were undertaken in that area.

5.1 Implications for research using exergames and future directions

Some types of exergames are inherently apt for a post–COVID-19 pandemic society where being socially distanced is highly encouraged. Despite the fact these studies did not set out to directly address this issue, the types of exergames available can be useful in engaging people in adopting healthier lifestyles in the comfort of their homes, especially in challenging times when physical and mental health issues are on the rise.

Notwithstanding the entertainment value generally conferred by exergames and their associated benefits for increased physical activity and healthy food intake, there is insufficient evidence to support the health-enhancing ability of exergames. It is challenging to evaluate whether exergames have significant health benefits, mainly because exergames tend to provide moderate-to-low intensity levels of exercise, and do not consider the need for vigorous-intensity exercise. Additionally, nutrition education studies using exergames have not tested their results over extended periods of time. In order to have significant health improvements, whereby exergaming can then be suggested for PAN promotion, exergames should be used in conjunction with other methods of promoting health benefits, such as opting for incidental activities in daily routines and reducing sedentary behaviour. We recommend that future research focus on the design and development of exergames that are tailored to the players, taking into consideration the different personalities and abilities. Prolonged interventions involving thorough methods of research design, such as RCTs, are needed to assess the effectiveness of exergames in comparison with other ways of performing physical activities, for instance, traditional physical exercise without any technology use or some level of technological integration. Details about the purpose of the exergame, gameplay and the rules by which they are governed, the type of research design and the theoretical framework underpinning the research on particular types of exergames should be systematically reported. This way future research would be in a better position to create meaningful links with the types of interventions to investigate relevant physical and behavioural outcomes.

Appendix A. Methods

A.1. Search strategy

Topic Category	Search Term
Exergaming	"exergam*" **OR** "active video gam*" **OR** "serious gam*" **OR** "application*" **OR** "app*" **OR** "mobile gam*" **OR** "smart phon*" **OR** "smartphon*" **OR** "tablet*" **OR** "consol*" **OR** "console-based" **OR** "health gam*"
	AND
Health Behaviours	"physical activit*" **OR** "physical exercis*" **OR** "physical fitness" **OR** "physical education" **OR** "physical training" **OR** "training equipment" **OR** "leisure activit*" **OR** "motor activit*" **OR** "exertion" **OR** "sedentary lifestyl*" **OR** "sedentary behaviour*" **OR** "sedentary behavior*" **OR** "sitting" **OR** "reclining" **OR** "screen time" **OR** "inactiv*" **OR** "diet*" **OR** "nutrition*" **OR** "healthy eating" **OR** "food*" **OR** "fruit*" **OR** "vegetable*" **OR** "snack*")
	AND
Interventions	"behaviour change intervention*" **OR** "digital behaviour*" **OR** "change interventio*" **OR** "health interventio* **OR** "health promotio*" **OR** "health programm*" **OR** "trial*" **OR** "rehabilitation" **OR** "prevention" **OR** "treatmen1*"
	AND
Population	"child*" **OR** "youth" **OR** "adolescen*" **OR** "adul*" **OR** "elderly" **OR** "senior adul*" **OR** "older adul*" **OR** "geriatric*"

A.2. AMSTAR quality assessment ratings of included studies

Paper Reference	Rating items										Rating
	1	2	3	4	5	6	7	8	9	10	
P1	1	1	1	0.5	1	1	1	0	1	0	7.5
P2	1	1	1	0.5	1	1	1	0	1	0	7.5
P3	0.5	0.5	0.5	0.5	1	1	1	0.5	1	0.5	7
P4	1	1	1	0.5	1	1	1	0	1	0	7.5
P5	0.5	0.5	1	1	1	1	1	0	1	0	7
P6	0.5	1	1	0	1	1	1	1	1	0	7.5

P7	1	1	1	0.5	0.5	0.5	1	1	1	1	8.5
P8	0.5	1	1	1	1	1	1	1	1	0	8.5
P9	0.5	1	1	1	1	1	1	1	1	0	8.5
P10	1	1	1	1	1	1	0	1	1	0	8
P11	1	1	0.5	1	1	1	1	1	1	0	8.5
P12	1	1	1	1	1	1	0	0	1	0	7
P13	0.5	0.5	0.5	0.5	1	1	1	0.5	1	0.5	7
P14	1	1	1	0	1	1	1	0	1	0	7
P15	1	1	1	1	1	1	0	0	1	0	7
P16	0.5	1	0.5	1	1	1	1	0.5	1	0	7.5
P17	1	1	0.5	1	1	1	0	0.5	1	0	7
P18	1	1	0.5	0.5	1	1	1	0	1	0	7
P19	1	1	1	1	1	1	1	0	1	0	8
P20	1	1	1	1	1	1	1	0	1	0	8
P21	1	1	1	1	1	1	0	0	1	0	7
P22	1	0.5	0.5	1	1	1	0	1	1	0	7
P23	1	1	1	1	1	1	1	1	1	0	9
P24	0.5	1	0.5	1	1	1	1	0	1	0	7
P25	1	1	1	1	1	1	1	0	1	0	8

P26	1	1	1	1	1	1	0	0	1	0	7
P27	1	1	1	1	1	1	1	0	1	0	8
P28	1	1	1	1	1	1	0	1	1	0	8
P29	1	1	1	1	1	1	1	1	1	0	9
P30	1	0.5	0.5	0.5	1	1	1	1	1	0.5	8
P31	1	0.5	0.5	0.5	1	1	0.5	1	1	1	8
P32	1	1	1	1	1	1	0.5	1	1	1	9.5
P33	1	1	1	1	1	1	1	1	1	1	10
P34	1	1	1	0	1	1	0	1	1	1	8

Adapted-AMSTAR Checklist
Yes – 1; No – 0; Partially – 0.5; Not Applicable – 0.5

Rating Items

1. Was the target population clearly defined?
2. Was the research design described in detail?
3. Was the sample size, including gender ratio, described in detail?
4. Was the duration of the study/experiment reported?
5. Did it include existing or custom-developed exergame?
6. Did it include information about technologies and devices used?
7. Did it include social components?
8. Did it include a theoretical framework?
9. Did it have clear findings and recommendations?
10. Was a control group used?

Appendix B. The second appendix

Paper Reference	Exergame & Reference	Country	Target Population --- Study Design	Target Physical Activities	Devices, Tools & Technologies	Presence of Social components	Theoretical Framework
P1	SwimTrain[10]	South Korea; China	Adult swimmers (beginner to expert levels) --- Case Study & Experimental Study	Swimming	Waterproof smartphones and earphones; accelerometer, a gyroscope, a magnetometer, and a barometer.	True-collaborative interactive and group fitness	None
P2	MobyDick[11]	Daejeon, South Korea; Michigan, USA	Swimming club communities --- Experimental Study	Swimming	Waterproof off-the-shelf Android smartphones	True - multi-player game	None
P3	SmartRabbit[12]	Salvador, Brazil	Not reported --- Technical report with app architecture	Running	Android smartphone with GPS;	True – players compete with friends	None
P4	PiNiZoRo[13]	Saskatchewan, Canada	Families (parents and children) --- Experimental study	Walking	Smartphone with GPS	True - family-friendly	None
P5	Exercise[14]	Turku, Finland	Voluntary participants --- Experimental study	Various physical activities	VR equipment like headset; controllers; XBOX 360 controllers	True -co-located multiplayer	None
P6	Exermon[15]	Trondheim, Norway	Voluntary participants --- Experimental study	Various physical activities	Smartphone's proximity and accelerometer sensors	True - social network to compare exermon with characteristics of friends' exermon	Gameflow framework and Dual Flow Theory
P7	Spirit50[16]	Toronto; Oshawa; Waterloo, Canada	Participants above 50 years old --- Experimental study– 8 weeks	Various physical activities	Website - Spirit50.com; pedometers	True - exercise in group; competition with other people	Self-Determination Theory

P8	PedalTanks[17]	San Jose, USA	University students --- Experimental study – 3 days	Cycling	Stationary bicycle enhanced with hardware components; black and white patterns for use with optical sensors; Arduino microcontroller	True - co-located multiplayer game; team-based and competitive	Gameflow framework and Dual Flow Theory
P9	Fish 'N' Steps[18]	Princeton, USA	Staff of Siemens Corporate Research --- Experimental study – 14 weeks	Various physical activities	Pedometers Sportline 330	True – team condition the players' fish tanks included other players' fish; Individuals within teams can see each other's progress; anonymous chat application	Transtheoretical Model (TTM)
P10	iFitQuest[19]	Edinburgh, UK	Adolescents aged 12 – 15 years --- Experimental study – 2 distinct 3-hour sessions	Running	GPS; compass data; iPhone, Google Maps	False	Flow Theory
P11	StepStream[20]	Atlanta, USA	US middle school students --- Experimental study – 4 weeks	Walking	Pedometers; game website	True - Social network site for middle school students to share and encourage everyday lifestyle activity. single-player game but students could choose to play the 'with' up to three friends (asynchronously).	Social Behaviour Change Theory

P12	World of Workout[21]	Texas, USA	Undergraduate students --- User study	Various physical activities	Mobile phone; web page; smartphone sensors - accelerometer and GPS	False	None
P13	PaperDude[22]	Toronto, Canada	Not reported --- Technical report with exergame implementation	Cycling	Oculus Rift VR headset, a Trek FX bicycle attached to a Wahoo Kickr power trainer, and a Microsoft Kinect camera, iPhone,	False	None
P14	Geoboids[23]	Christchurch, New Zealand	General public --- User study	Running	Smartphone, Craig Reynolds' OpenSteer code ported to the Google Android platform; motion and location sensors;	True - trading GeoBoids through social networking sites	None
P15	Health Defender[24]	Lancaster, UK	Not reported --- Experimental study	Various physical activities	Alive Technologies HRM Chest Strap; mobile phone; Bluetooth; GPS;	False	None
P16	GameMyHealth [25]	Sevilla; Vigo, Spain	University students and lecturer --- Experimental study – 8 weeks	Various physical activities & Food intake monitoring	Wearable sensors; Food Frequency Questionnaire	True - dynamically rank individual/group user progress and achievements as compared to their peers.	El-Hilly's theoretical framework (2016)
P17	LocoSnake[26]	Udine, Italy	Not reported --- User study	Walking	GPS (location-based); iPhones	False	None
P18	Calory Battle AR[27]	Suwon, South Korea	Not reported --- Not reported	Walking, Running, Jumping	Android platform; smartphone; Google Maps; wearable sensors such as smartwatch; Heart Rate Monitor (HRM)	True – upon game completion, players can upload score to a hall of fame website where they can be	None

						compared to other players' scores	
P19	Running Othello 2[28]	Suwon, South Korea	Korean 3rd grade elementary school students --- Experimental study – 1 week	Running, Jumping, Swinging, Spinning	Inertial sensors and HRM; Near-field Communication (NFC), accelerometer, magnetometer, heart rate monitor; Microsoft Band devices and Samsung Galaxy SIII smartphones	True - compete with friends	None
P20	Google's Ingress[29]	California, USA	Not applicable --- Not applicable	Walking; Cycling	Smartphone with GPS	True – compete with players across the world	None
P21	Play 'N' Ride[30]	Toulouse, France	170 Fan Park visitors --- User study – 3 days	Cycling	Bicycle with sensors	False	None
P22	Dance Exergame System[31]	Seoul, South Korea	Not reported --- Not reported	Dance	Smartphone, Sensoria fitness sock - sock-type wearable device, motion sensor, pedometer, gyroscope	False	Game Theory
P23	Storywell[32]	Boston, USA	18 adults; 18 children --- Experimental study – 3 months	Various physical activities	Android smartphone; MiBand 2 wristband	True – social rewards in the form of storybooks	Self-Determination Theory
P24	Go Run Go[33]	Bangkok, Thailand	10 voluntary participants --- Experimental study	Walking, Running	Android smartphone, accelerometer	True -allows the user to share results on a social network web site	None

P25	Calorie Cruncher[34]	New York, USA	16 participants --- Experimental study – 6 months	Cycling	Wizard of Oz prototype; stationary bicycles	True – multiplayer; social interaction through competition	None
P26	GrabApple[35]	Saskatchewan, Canada	8 university students --- Experimental study – 2 days	Various physical activities	Microsoft Kinect Sensor	False	None
P27	Gemini[36]	Saskatchewan, Canada	8 participants --- Experimental study – 5 days	Various physical activities	Wireless mote with accelerometers, light, and temperature sensors; smartphone with built in camera, accelerometer, Bluetooth.	True - social and competitive elements	None
P28	UbiFit Garden[37]	Seattle, USA	12 participants --- Field trial – 3 weeks	Various physical activities	Mobile Sensing Platform (MSP) with humidity, visible and infrared light, temperature, microphone, and compass, mobile phone, barometer, accelerometer, Bluetooth	False	None
P29	Walk2Build[38]	Glasgow, UK	Not applicable --- Not applicable	Walking	GPS; Android phone; web app	True - published on Facebook to exploit social networking in supporting users.	None
P30	Zombies, Run![39]	Redditch, UK	Not applicable --- Not applicable	Various physical activities	GPS; accelerometer	True - results are shared with friends and find out who can make the brightest future for “humanity”.	None

P31	Alien Health Game[40]	Arizona, USA	20 participants - 6th-7th grade students ---------- Experimental study – 2 weeks	Physical activities and nutrition	Microsoft Kinect	Partially – (non-digital)	Learning Theories
P32	My Plate Picks[41]	Chicago, USA	48 participants – 7-13 year olds ---------- Experimental study – 8 weeks	Physical activities and nutrition	Outsourced to external development company Circle 1 Network	Partially – (non-digital)	Social Cognitive Theory; Behaviour Change Theory; Learning Theory
P33	TreeCare[42]	Halifax, Canada	103 responses from participants - older than 18 years ---------- Field trial – 3 weeks	Various physical activities	Android devices ;Unity framework; Android Studio. 3 Google Fit APIs (i.e., Sensors API, Recording API, and History API); Activity Recognition API	Yes – challenger mode and tournament mode	Behaviour Change – Goal Setting Theory
P34	vEngage Project[43]	London, UK	31 Adolescents 13-17 years semi-structured interview (18 female, 13 male) and 511 participants responded to quantitative survey	Various Physical activities	Unity platform and Steam VR; tested on HTC Vive hardware with 2 hand controllers	No	Self-Determination Theory

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