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Effectiveness of Physical Activity Related to Food Addiction in Obese and Overweight Healthy Adults: A Systematic Review

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1. INTRODUCTION

Obesity or overweight is considered an important risk factor for mortality and morbidity from diabetes, cardiovascular disease, some types of cancers, metabolic syndrome, and musculoskeletal disorders, among others (Ezzati et al., 2002; González-Muniesa et al., 2017; Hruby & Hu, 2016; Whitlock et al., 2009). It is estimated that 39% of the population worldwide is obese or overweight, and it is believed that by 2030, at least 57.8% of adults will be overweight (González-Muniesa et al., 2017).

The latest increase in obesity coincides with a change in the environment, economic growth, the growing availability of energy-dense and tasty food (Young & Nestle, 2002), industrialisation, mechanised transport and urbanisation; altogether is known as "obesogenic environment" (González-Muniesa et al., 2017; Hruby & Hu, 2016). The impact that this environment has produced on lifestyle, consumption of hyperpalatable foods (HyPF), and sedentary lifestyle, are recognised as the primary causes of obesity for a large majority of the population (González-Muniesa et al., 2017; Hruby & Hu, 2016; Hu, 2007; Jauch-chara & Oltmanns, 2014; Morris, Beilharz, Maniam, Reichelt, & Westbrook, 2015; Peters, Wyatt, Donahoo, & Hill, 2002; Sellayah, Cagampang, & Cox, 2014). HyPF are a specific type of food (processed and ultra-processed foods and drinks) who override the body's and brain's natural satiation mechanism by sensory perception and promote excess consumption (Gibney, Forde, Mullally, & Gibney, 2017). Instead of the classic theory that considers the increase in adipose tissue as an imbalance between consumption and expenditure of calories, the aetiology of obesity is much more complex, being thus, the product of a set of genetic, biological, psychological, socioeconomic, and environmental factors (González-Muniesa et al., 2017; Hruby & Hu, 2016; Jauch-chara & Oltmanns, 2014; Sellayah et al., 2014).

Food addiction (FA) could be defined as a food-related behaviour expressed by a dysregulated consumption of HyPF (Imperatori et al., 2016). It has been gaining a lot of impact in the scientific community in the last years due to its proposal as a valid phenotype of obesity (Davis et al., 2011). There is broad evidence that supports FA existence and concludes that it could be important for the knowledge of patterns of overconsumption (Avena, Rada, & Hoebel, 2008; Blumenthal & Gold, 2010; Davis et al., 2011; Furlong, Jayaweera, Balleine, & Corbit, 2014; Gibney et al., 2017; Imperatori et al., 2016; Jauch-chara & Oltmanns, 2014; Kenny & Shaw, 2011; Morris et al., 2015; Murray, Tulloch, Gold, & Avena, 2014; Pedram et al., 2013; Volkow, Tomasi, & Baler, 2013).

The central control of food intake (FI) occurs within the brain, which receives information related to energy control, either inside the body or outside, where finally the perception of hunger and satiety is generated and where the decision regarding feeding is taken (H. b, Münzberg, & Morrison, 2017; Guyenet & Schwartz, 2012; Lenard & Berthoud, 2008; G J Morton, Cummings, Baskin, Barsh, & Schwartz, 2006; G J Morton, Meek, & Schwartz, 2015; Power & Schilkin, 2008; Saper, Chou, & Elmquist, 2002; Woods, 2013). In fact, the hypothalamus has significant relevance as an organ, where based on genomic studies, the vast majority of genes associated with body mass index are expressed in the central nervous system (CNS), and many in the hypothalamus (H. Berthoud et al., 2017). Other elements of the CNS involved in this process are the brainstem and parts of the cortex and the limbic system (Lenard & Berthoud, 2008).

Humans have evolved in a hostile context characterized by a food starvation, which has forced them to develop different systems that have generated representations and rewards for learning, and memory processes, provoking emotions that guarantee a minimum supply of food (Mela, 2006; Power & Schilkin, 2008; Sellayah et al., 2014). The increasing availability of HyPF, together with a globalised sedentary lifestyle, seems to be the reason for this imbalance in the physiological control of appetite and the homeostatic regulation of body weight. However, all the mechanisms that support this explanation are not yet known (Cardinal, Parkinson, Hall, & Everitt, 2002; Guyenet & Schwartz, 2012; Kelley et al., 2002; Lenard & Berthoud, 2008; Morris et al., 2015).

A dysfunction in the brain's reward system could induce an abnormal response to HyPF, altering the hedonic control of hunger (Robinson & Kent, 1993), resulting in eating-related addictive behaviour. The terms such as "liking", "wanting", and "craving" are highly used to explain this phenomenon, but its definition is often confused (Finlayson & Dalton, 2012; Mela, 2006; Pelchat, 2009). The term "liking" is the degree of sensory pleasure (Peciña, Smith, & Berridge, 2006). The term "wanting" refers to the motivation or desire through the release of dopamine prior to and during contact with food (Berridge, Ho, Richard, & Difeliceantonio, 2010), while the term "craving" would be related to a very strong desire (Hallam, Boswell, Devito, & Kober, 2016). Homeostatic and hedonic features work together to influence FI. It has already been shown that the homeostatic appetite system is coordinated by the hypothalamus, while the hedonic appetite system is coordinated by the brain's reward circuitry (Berridge et al., 2010; H. Berthoud et al., 2017; John E. Blundell & Finlayson, 2004; Finlayson & Dalton, 2012; Lutter & Nestler, 2009; Mela, 2006; Saper et al., 2002).

In the literature, other paradigms are used to study the brain's reward system in the context of an eating-related addictive behaviour, which is correlated with reward elements. The attentional bias (AB) is a selective focus on personal relevant information over neutral information, and has been associated with levels of craving for various substances (Field, Mogg, & Bradley, 2005; Field, Mogg, Zetteler, & Bradley, 2004; Field, Munafo, & Franken, 2009), thus values of AB have been demonstrated as a useful instrument for predicting "wanting" (Finlayson & Dalton, 2012). The positive pleasure against sweet (i.e., sugar) or creamy (high-fat) has become a guarantee to energy intake (H. R. Berthoud, 2006) and that is the base for how preferences over sweet and creamy are related to obesity, even more, if both are taken together (Donaldson, Bennett, Baic, & Melichar, 2009). Finally, evidence from neural responses to food cues support the main idea of hyperactivation in specific brain areas to food cues in obese people (Val-laillet et al., 2015; Volkow, Wang, & Baler, 2012).

Physical activity (PA) and exercise performed over long periods reduce body weight (Donnelly et al., 2003; Jakicic, Marcus, Lang, Janney, & Forest, 2008; Ka, Hc, Rourke, & C, 2009). The benefits are not limited to weight loss; moderate PA also reduces the risk of developing some chronic diseases (González-Muniesa et al., 2017). However, the most important aims of this review are the effect of PA on the energy intake, by modulating the homeostatic and hedonic mechanisms (Beaulieu, Hopkins, Blundell, & Finlayson, 2016; Shook et al., 2015). According to the literature, sedentary behaviour promotes body weight gain by appetite deregulation and low energy expenditure (J E Blundell, 2011).

It is known that PA and exercise could modulate FI through different pathways. PA affects the sensitivity to insulin (Hawley & Lessard, 2008) and leptin (Dyck, 2005). Acute exercise reduce secretion of ghrelin and promotes the secretion of peptide YY (PYY), glucagon-like peptide-1 (GLP1), and pancreatic polypeptide (PP) (Schubert, Sabapathy, Leveritt, & Desbrow, 2013). Vigorous exercise may lead to a temporal suppression of appetite, known as "exercise-induced anorexia"(Bilski, 2009). Ultimately, "liking" and "wanting" values decrease in active people compared to inactive (Horner, Finlayson, Byrne, & King, 2016). Indeed, FI through exercise and PA continues to be a controversial topic (Bilski, 2009).

To date, no systematic review study has been found that focuses its objectives on the effects of PA, exercise, and SB management of eating-related addictive behaviour outcomes, linking FA to HyPF in the overweight or obese population. This review aims to disclose relevant information on the conservative treatment of food addiction.

The purpose of the present study is to determine the effectiveness of the physical activity, exercise, and sedentary behaviour management in attenuating the food addiction of HyPF in obese and overweight healthy adults.

Secondarily, the aim is to determine the effectiveness influenced by the intensity or type of PA, and whether the difference in the body composition or gender could alter the power of the intervention.

2. MATERIAL AND METHODS

This systematic review was guided according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) criteria (Moher, Liberati, Tetzlaff, Altman, & Group, 2009).

2.1. Selection criteria

Articles were selected based on the following inclusion criteria: 1) studies with participants included healthy, obese, or overweight adults (18–64 years) according to BMI, waist circumference, or waist-to-hip ratio; 2) participants were treated with acute and chronic interventions of PA or exercise; 3) Articles in English or Spanish language.

Exclusion criteria were: 1) studies with participants who suffer from binge eating, anorexia, or bulimia; 2) Psychiatric diagnosis and medications that could affect the FI; 3) studies which included interventions with pharmacological, dietary, and complementary therapies. Studies were not limited by race, sex, or community.

The primary outcomes were different kinds of eating-related addictive behaviours linked to FA: 1) The hedonic value of food, determined by the elements it is comprised of, such as the “liking” and “wanting”; 2) Appetite or desire to eat HyPF; 3) Food preference for HyPF; 4) Cognitive restraint of eating and disinhibition of control; 5) Attentional bias; 6) Fat and sweet taste perception; and 7) Craving mood. The secondary outcomes were neuronal responses to HyPF cues measured by neuroimaging, such as those described by Cornier M et al. (Cornier, Melanson, Salzberg, Bechtell, & Tregellas, 2012).

This review has not focused on lean people, so the outcomes of this group have been ignored. However, since different BMI groups did not show statistically significant differences, all the data were combined into one main group.

2.2. *Data sources*

The electronic databases that were used for the main purpose of this research included: MEDLINE, The Cochrane Central Register of Controlled Trials (CENTRAL), CINAHL, and PsycINFO. In addition, snowballing was used by searching reference lists of retrieved articles and published reviews on the topic.

2.3. *Literature search strategy*

The search strategy was designed to capture articles with research relevant to the following topics in the field: "Obesity/overweight", "Physical Activity", "Addiction", and "Hyperpalatable Food". The results were filtered to include papers that have studied humans, including adult (18–65 years) participant. Searches were limited to English and Spanish. No publication date restrictions were imposed. (see detailed research strategy of MEDLINE search strategy, the search was adapted for the other electronic databases; Table 1).

2.4. *Study selection*

Once the criteria were established, the search was conducted by two reviewers (DPP and CBN) to identify titles and abstracts of the references obtained as a result of the search strategies previously exposed to exclude irrelevant reports. Then, after the removal of duplicates, the full-text articles of the remaining references were screened by DPP and CBN to identify studies for inclusion and classify and record reasons for the exclusion of ineligible studies. Both reviewers resolved different opinions for eligibility by discussion, and when the review authors did not agree, a third reviewer (FRC) made an arbitrary decision. The selection process has been reported in a PRISMA flow diagram (Figure 1).

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2.5. Data extraction

Data was extracted from the admitted articles, and relevant information according to the established inclusion criteria was recorded on a data extraction form that has been developed for this review **(**see in appendices section; Table 2). Data extracted included the following items: authors, participants (including sample size, sex, age, and BMI), baseline status (including PA status, abstain status, and FA status), settings (including study design and details of intervention and control group), relevant outcomes, measurement tools, and adverse effects.

2.6. Risk of bias assessment

The risk of bias was assessed using the criteria outlined in the Cochrane Handbook for Systematic Reviews of Interventions (Higgins, 2011). The risk of bias was graded for each domain as high, low, or unclear. Unclear means there is a risk of bias, but not enough information is available to determine whether an important risk of bias is present, or there is a lack of clarity whether an identified problem will introduce bias. The high risk was determined when there was at least one important risk of bias for a domain.

3. RESULTS

Two-hundred and ninety-five potentially relevant articles were identified from the database search and other sources. After the removal of duplicates, a total of 258 (87.5%) were screened on the basis of their titles and abstracts. The full text was retrieved for 25 (8.5%, from the total) articles, 18 were excluded for the following reasons: results not posted (n = 3), not the population of interest (n = 3), not the intervention of physical activity (n = 6), not the study design of interest (n = 6). Finally, seven articles were included in the qualitative synthesis. Figure 1 illustrates the PRISMA flow diagram of the data collection process.

3.1. Risk of bias

The risk of bias from the included studies was presented descriptively (see figure 3). All the following items showed an unclear risk of bias: 1) Random sequence generation; 2) Allocation concealment; 3) Blinding of participants and personnel; 4) Blinding of outcome assessment; 5) Selective outcome reporting. Finally, the item “Selective outcome reporting” had a low risk of bias, and no other bias were detected. According the nature of studies, the main bias was the information of allocation concealment and random sequence which was missed in the main of studies. Also, the blinding of participants and personnel were not possible too due to knowledge of which intervention a participant received. However, the selective outcome reporting had a low risk of bias in all studies except Alkahtani (Alkahtani, Byrne, Hills, & King, 2014b).

3.2. Participants

The sample size for the included studies ranged from 12 to 58 (n = 137). To assess obesity and overweight, all the included studies used BMI. No participants were underweight. Three articles conducted the study with both genders (Ledochowski, Ruedl, Taylor, & Kopp, 2015; Martins et al., 2015), the other two articles included just females (Oh & Taylor, 2013) or males (Westerterp-Plantenga, Verwegen, Ijedema, Wijckmans, & Saris, 1997). Together, all the studies included 43 males and 94 females. Even so, no studies investigated the difference between genders.

Three articles (Martins et al., 2015; Oh & Taylor, 2013; Westerterp-Plantenga et al., 1997) classified their participants as inactive, untrained or sedentary. Only one paper did not report any information on their PA (Ledochowski et al., 2015). Finally, two studies (Oh & Taylor, 2013; Westerterp-Plantenga et al., 1997) included different groups according to their BMI, and both reported no significant differences between groups; therefore, all the data were combined.

Authors	Participants	Randomization	Intervention group versus control	Relevant outcome	Results	Measurement tools	Effect adverse
Oh, H. and Taylor, A. H. (2013) (Oh & Taylor, 2013)	**n=58 ♀ (18-45 yr)** Healthy participants who ate at least 100 gr of chocolate per day	**Normal Weight (n=20).** age =23.90 [6.87], BMI =22.44 [1,88] **Obese (n=21).** age=38.14[11.56], BMI=30.62[4.38] **Lent** religious period when many abstain from snack food. **(n=17).** (12 NW and 5 OW), age=25.88 [9.67], BMI =22.68 [2.88]	**-moderate intensity**: 2 min warm-up and 15 min semi self-paced brisk walk on treadmill between 11 (fairly light) and 13 (somewhat hard) according to RPE scale. One intervention only **-Passive**: Rest for 15 min. No access to reading materials	IAB of passive group at post-treatment in comparison with exercise was greater t =2,78, p<0.01 Craving was significant lower after exercise compared with rest at post-treatment t=3,67, p<0.001, at 5 min t=3,76, p<0.001 and 10 min after t=4,15, p<0.001	No significant interaction effect between groups and condition per time. Therefore, data was assessed for all 3 groups combined. **AB:** Significant effect of condition per time for IAB and MAB. IAB was significantly greater in the passive control, compared with the exercise condition at post-treatment. **Craving:** Significant effect of condition per time for craving. Craving for exercise was significantly lower compared with rest at all assessments post-treatment	-modified visual dot probe task with chocolate-related pictures. -VAS for chocolate craving -Heart Rate Exercice -Exercise Rating of Perceived Exertion	**No**
Westerterp-Plantenga, M. S. *et al.* (1997) (Westerterp-Plantenga et al., 1997)	**n=30 ♂ (19-35 yr).** Healthy participants untrainted.	**Non-OB (n=20).** 10 at first protocol and 10 at second one. age=25 [7], BMI=22.8 [1.6] **OB (n=10)**. age =25 [6], BMI =28.5 [1.9]	**First protocol:** 2 h of submaximal exercise on a bicycle at 60% W_{max} versus rest. Once a week during 8 weeks **Second protocol:** Sauna versus rest for 2h.	After cycling, rate of taste perception of the 50 g/litter sucrose solution was significantly increased compared to after rest F(3,76)=110.18 p=0.0001. After sauna was also increased F(3,36)=44.9, p=0.0001. After cycling, rate of taste perceptcion for bitter was increased compared with rest F(3,76)=102.34, p=0.0001.	No significant interaction effect between groups on comfortability, taste perception and hedonic value. In single taste drinks, after cycling and sauna, perception for sweet of one concentration was significantly increased compared to after rest in the same group. In the mixture drink, after cycling, only rate of taste perception for bitter in the mixture was significantly increased compared to after rest	VAS of Taste perception and Hedonic value	**No**

Authors	Participants	Randomization	Intervention group versus control	Relevant outcome	Results	Measurement tools	Effect adverse
Martins, C. *et al.* (2015) (Martins et al., 2015)	**n=12 (5 ♂, 7 ♀)** **OW/OB.** Age=33.4 [10.0], BMI =32.3[2.7]		**Control:** Rest. participants remained seated. **MICC**: Cycling at 70% HR_{max}. (until 250 kcal). **HIIC**: Bouts of 8-s sprinting and 12-s slowly. Cycling at 85%–90% HR_{max}. (until 250 kcal). **S-HIIC**: was half of the HIIC (until 125 kcal).	AG plasma levels were significantly reduced in the MICC and HIIC conditions ($p<0.05$) compared with control. Desire to eat ratings decreased immediately after breakfast consumption and afterwards and were lower in the exercise conditions.	The high or intensity exercise lead to a similar appetite response.	Insulin, AG, PYY, GLP-1 LFPQ measures of Explicit liking (EL), implicit wanting (IW), and relative food preference.	**No**
Ledochowski L *et al*. (2015) (Ledochowski et al., 2015)	**n=47 (18 ♂, 29 ♀)** **OB.** Age =28.11 [9.55], BMI =27.63 [2.62] consume at least 100gr of high caloric sugary snacks		**Control:** Rest. Sitting quietly in the laboratory for 15 minute. **Exercise:** (moderate intensity) 15-min brisk walk.	FCQ-S showed between condition differences in self-reported sugary snack craving at mid and post treatment ($p<0.01$) In same condition, FAS and FS revealed a significant differences in self-reported activation and affective valence at mid and post treatment ($p<0.01$)	Significant between condition differences on craving at mid treatment and post treatment. Significant differences at mid treatment and post treatment for Feeling Scale and Felt Arousal Scale for same condition.	FCQ-S adapted for sugary snacks. FS Affective valence FAS Perceived activation (Felt Arousal Scale). SBP and DBP systolic and diastolic blood pressure	**No**

Authors	Participants	Randomization	Intervention group versus control	Relevant outcome	Results	Measurement tools	Effect adverse
Martins, C. *et al. (2017)*(Martins et al., 2017)	**n=46** (**16** ♂, **30** ♀) **OW/OB.** Age =34.4 [8.8], BMI= 33.3[2.9]		**MICT**: Cycling at 70% HR_{max}. (until 250 kcal). **HIIT**: Bouts of 8-s sprinting and 12-s slowly. Cycling at 85%–90% HR_{max}. (until 250 kcal). **1/2-HIIT**: was half of the HIIC (until 125 kcal). During 12 weeks	There was significant increase in fasting subjective feelings of hunger with exercise within group (p=0.01). Also of tAUC for hunger after the 12 wk exercise program (P=0.048). More else, a significant effect of smapling time (p<0.001) was observed for GLP-1 plasma levels.	The effect of chronic MICT versus HIIT on appetite, in obese previously sedentary individuals, does not seem to differ.Neither exercise modality seems to induce meaningful changes in either subjective or objective appetite measures or food hedonics.	Insulin, AG, PYY, GLP-1 LFPQ measures of Explicit liking (EL), implicit wanting (IW), and relative food preference.	**No**
Alkahtani, S *et al.* (2014)(Alkahtani, Byrne, Hills, & King, 2014a)	**n=12** (♂) Age =29 [4.1] BMI =29.1 [2.4]		3 exercise sessions: First. initial graded exercise test Second. MIIT: cycling for 5 min repetitions of alternade 20%below and 20% above max fat oxidation Third. HIIT: cycling alternate bouts 15 s at 85% VO_{2max} and 15 s unloaded recovery.	There was a significant effect of time on explicit liking for all food categories, highest p<0.001 except the HFNS foods. The interaction between intensity and time was not significant.	Two different intensities of interval exercise exerted similar effects on appetite sensations and Liking and Wanting. The results showed that HIIT provides an appropriate weight-loss option without increasing hunger.	Rating of perceived exertion (RPE), Expired breaths and HR, Visual Analogue Scale, Liking and wanting	**No**

Authors	Participants	Randomization	Intervention group versus control	Relevant outcome	Results	Measurement tools	Effect adverse
Alkahtani, S *et al.* (2014)(Alkahtani et al., 2014b)	**n=10** (♂) Age=29[3.7] BMI=30.7[3.4]		two 4-week training intervention consisting of 12 cycling sessions in each intervention (MIIT or HIIT) separated by a 6-week detraining wash-out. Being MIIT and HIIT at 45 and 90%VO_2 peak respectively.	The interaction between intensity and time on delta Medium term-Ex approached significance for desire to eat (p=0.07), also for delta Medium term- Ex explicit liking for HFNS food (p=0.09). The same interaction on fat intake approached significance was (p=0.07).There was an interaction between time and fat oxidation (p=0.04)	HIIT seems a better strategy than MIIT to minimize the compensation of eating behaviour during interval training among males.	Expiratory gas exchange, Visual Analogue Scale, Liking and wanting, libidum test meal	**No**

Abbreviations: AG, Acylated ghrelin; **7-PAR**, Seven-day Physical Activity Recall Questionnaire; **AB**, Attentional bias; **BMI**, Body Mass Index; **DBP,** diastolic blood pressure; **FAS**, Felt Arousal Scale; **FAT_{max},** Intensity that elicits maximal fat oxidation; **FCQ-S,** The State Food Craving Questionnaire; **FS**, Feeding State; **GLP-1,** Glucagon-like peptide; **HFNS,** High-fat nonsweet; **HIIT**, High-intensity interval training; **HR_{max},** Maximum heart rate; **LFPQ**, Leeds Food Preference Questionnaire; **MICT**, moderate-intensity continuous training; **MIIT**, Moderate-intensity interval training; **NR**, not reported; **NW**, Normal weight; **PYY,** Polipeptide YY; **OB**, Obese; **OW**, Overweight; **RPE**, Rating of Perceived Exertion; **SBP,** systolic blood pressure; **SD**, Standard deviation; **TFEQ,** The Three-Factor Eating Questionnaire; **VAS**, Visual analogue scale; **VO^2_{peak},**, peak oxygen uptake; **wk**, week.

3.3. Interventions

All of studies founded focused their interventions on the acute effects of a single bout of different types and doses of exercise. There wasn't any article that analysed the effect of exercise or physical activity management follow up on time. All studies (Alkahtani et al., 2014b, 2014a; Ledochowski et al., 2015; Martins et al., 2017, 2015; Oh & Taylor, 2013; Westerterp-Plantenga et al., 1997) conducted their intervention at moderate intensity, and four studies (Alkahtani et al., 2014b, 2014a, Martins et al., 2017, 2015) included two conditions based on high intensity (HIIT). The modality of physical activity were brisk walk in two studies (Ledochowski et al., 2015; Oh & Taylor, 2013) and cycling in the rest. According of variable used in the studies, the intensity of HIIT were between 85-90% of HR_{max} (until 250kcal) or 85-90% VO_{2max}. On the other hand, MIIT were between 70% HR_{max} or 40% VO_{2max}, also 20% below and 20% above max fat oxidation were measured to determinate the intensity. The duration and frequency varied between studies.

3.4. Outcomes

The included articles showed different eating-related addictive behaviour outcomes linked to FA: attentional bias (Oh & Taylor, 2013), craving (Ledochowski et al., 2015; Oh & Taylor, 2013), sweet taste perception (STP) (Westerterp-Plantenga et al., 1997), and hedonic and reward value of food (Alkahtani et al., 2014a, 2014b, Martins et al., 2017, 2015; Westerterp-Plantenga et al., 1997). Table 2 summarises the information related to all the outcomes included.

3.5. Acute effects of Physical Activity on Food Addiction

Six included studies were focused on the effect of a single bout of exercise and one of them studied four week training intervention (Alkahtani et al., 2014b). None of the included studies reported or measured sedentary behaviour management. No significant differences between groups of intervention were reported; therefore, all the data were taken together, as described above.

The Leeds Food Preference Questionnaire were used to measure the hedonic value of food using a 100-mm visual analogue scale (VAS) (Martins et al., 2017, 2015) and the reward value. Two studies with 32 participants, 25 males and 7 females, found that there were no significant differences in the hedonic value per conditions, groups, and time to different types of drinks and concentrations of sweet taste (Westerterp-Plantenga et al., 1997, Martins et al. 2017), buffet styles, and the same for the reward value of high-fat foods relative to low-fat for all intensities (Martins et al., 2015).

A modified visual dot-probe task with chocolate-related pictures were used in one study (Oh & Taylor, 2013) of 58 female participants in order to measure AB (Oh & Taylor, 2013). Each trial began with a central black fixation cross on a white background for 1000 ms, followed by a pair of images, which were presented for either 200 ms or 1000 ms, to capture initial attentional bias (IAB) and maintained attentional bias (MAB) respectively. Both IAB and MAB presented a significant interaction between condition and time. IAB was significantly greater in the passive control, compared with the exercise condition at post-treatment.

The STP test was assessed in one study of 20 female participants (Westerterp-Plantenga et al., 1997). The exercise condition was significantly greater when compared to the rest condition, affecting the taste perception in only one of the concentrations of the drink; the 50 g/litre. The individual perception of sweet taste in the mixture did not differ significantly between rest and exercise. The rate of taste perception for sweet in the sports drink increased from before to after cycling when compared to after rest.

Craving was assessed using the State Food Craving Questionnaire in two studies with 105 participants, 18 males and 87 females (Ledochowski et al., 2015; Oh & Taylor, 2013). Both studies revealed a significant difference in the effect of conditions on craving over time. The exercise significantly decreased the value of the craving compared to rest at all the assessments post-treatment. Craving was significantly lower at all assessments post-baseline in the exercise condition compared to the baseline. Finally, there were no changes from baseline to any follow-up assessment for the passive condition.

The variable “linking” and “wanting” were assessed by 4 studies (Alkahtani et al., 2014a, 2014b, Martins et al., 2017, 2015). Only in the Alkahtani study there was a significant effect on explicit liking for all food categories except high fats nonsweet (Alkahtani et al., 2014a).

4. DISCUSSION

This systematic review tried to determine the influence of exercise doses in relation to eating-related addictive behaviour, craving, or neural activation to HyPF linked to FA in overweight or obese people.

Obese are more prone to show preferences for sweet and fatty flavours (Donaldson et al., 2009) and they also show greater neuronal activation to food cues (Val-laillet et al., 2015; Volkow et al., 2012). Two studies (Oh & Taylor, 2013; Westerterp-Plantenga et al., 1997) that included different groups according to their BMI did not show differences in the results to the STP (Westerterp-Plantenga et al., 1997), the hedonic value (Westerterp-Plantenga et al., 1997), the AB (Oh & Taylor, 2013), or neither of the craving values (Oh & Taylor, 2013). Castellanos et al. (Castellanos et al., 2009) did not show a difference in AB between obese and normal-weight subjects who were in a state of hunger. In contrast, when the participants had eaten, the obese showed a higher AB value. This could be the reason why the subjects did not show differences, since none of the two studies submitted the subjects to a period of abstinence, with the exception of one study where the subjects were restrained only to one type of food (chocolate snacks) (Oh & Taylor, 2013). The inclusion criteria for this review may have also influenced the lack of differences between the BMI groups. In addition, these results allow hypothesising whether the cause of FA is actually obesity per se, or the baseline level of the PA, where all the groups of both studies (Oh & Taylor, 2013; Westerterp-Plantenga et al., 1997) were considered inactive. The evidence is still ambiguous and cannot reach a firm conclusion. Moreover, two of the studies included subjects of both genders (Ledochowski et al., 2015; Martins et al., 2015), but none analysed the differences between them and rather included all the subjects of the same data which could give a wrong view of the results considering that men and women have different behaviours and responses related to craving (Hallam et al., 2016) and food addiction (Pursey, Stanwell, Gearhardt, Collins, & Burrows, 2014), with women being most affected. This might be an effect that could be correlated with higher levels of overweight in this gender (World Health Organization, 2018). Furthermore, it is known that menstrual phases affect the energy intake and food reward (Mcneil, 2012; Mcneil, Cameron, Finlayson, Blundell, & Doucet, 2013).

The effectiveness of different intensities of exercise related to different mechanisms in FI behaviour is not clear; studies have been contradictory with those who have reported significant differences in energy intake for obese adolescents (Thivel, Isacco, Montaurier, Boirie, & Duche, 2012) and satiety for overweight men (Rosenkilde et al., 2013), and those who have not been able to observe any difference in the effect on appetite, "liking" and "wanting" in overweight males (Alkahtani et al., 2014a) with different intensities. This lack of clarity is also represented in the articles selected, where the only study (Martins et al., 2015) that compared several intensities with a rest control group did not observe any effect on the reward value assessed with the Leeds Food Preference Questionnaire (LFPQ). Furthermore, this study also saw no effect of exercise on hunger and satiety through all the conditions, an unexpected result according to a large amount of evidence on the topic (Alkahtani et al., 2014a; Beaulieu et al., 2016; Martins, Robertson, & Morgan, 2008; Shook et al., 2015; Sim, Wallman, Fairchild, & Guelfi, 2013). On the other hand, Alkahtani (Alkahtani et al., 2014a) study revealed exercise not increase the hunger in Liking and Wanting analogue Scale. The other studies (Ledochowski et al., 2015; Martins et al., 2015; Oh & Taylor, 2013; Westerterp-Plantenga et al., 1997) only evaluated the levels of moderate-intensity where the effects, compared to the control rest condition, were seen in specific outcomes such as AB (Oh & Taylor, 2013), taste perception (Westerterp-Plantenga et al., 1997), or craving (Ledochowski et al., 2015; Oh & Taylor, 2013), but not on the hedonic value (Westerterp-Plantenga et al., 1997), which was measured with a 100-mm VAS, nor with the reward value of food (Martins et al., 2015), assessed with the LFPQ. The results seem to be unclear, but this may be a result of the lack of standardisation of measurement tools and the interventions applied, all of which are different in intensity and duration. The exercise effect could be based on implicit pleasure and feelings of enjoyment and wellbeing (Ekkekakis, Parfitt, & Petruzzello, 2011) and the subsequent reduction of desire over other substances through their replacement, supporting the theory of self-determination (SDT) (Heather & Geoffrey C, 2012). This theory sustains that individuals who exercise for self-determined or autonomous reasons did not favour the consumption of HyPF than those who did it for more controlled reasons (Beer, Dimmock, Jackson, & Guelfi, 2017; West, Guelfi, Dimmock, & Jackson, 2017). Therefore, self-selection of the intensities, participation in activities that subjects enjoy, and also the assessment of the acute affective responses to interventions could be a good idea to keep in mind. This hypothesis could explain why subjects who underwent sessions of the same intensity (moderate intensity) and duration, but continuously or intermittently, showed a reduction in appetite and an increase in satiety for the second condition, compared to those who did it continuously (Holmstrup, Fairchild, Keslacy, Weinstock, & Kanaley, 2013), where it was less demanding for them, less stressful, and more enjoyable.

This study provides relevant information that seems to indicate that some eating-related addictive behavioural outcomes are influenced by several elements that take part in the term called food addiction, after a single bout of exercise, at moderate intensities in obese or overweight healthy subjects. One of the most studied cases has been the AB, where Oh and Taylor (Oh & Taylor, 2014) noted that after short sessions of moderate and high-intense exercise, there was a reduction in the initial AB in response to the images of cigarettes and HyPF, instead of only the high-intensity exercise having an effect on the maintained AB. Then, any exercise would have an effect in reducing the attention to such images, but only the high-intensity exercises had an effect in maintaining the gaze and interest from drifting towards the salient images of cigarettes and snack food. In this review, we have included an article (Oh & Taylor, 2013) that corroborates part of the results, observing that moderate-intensity exercises have a great effect in the IAB, and a lesser effect in MAB, although being significant with respect to the resting control group. Moreover, although not enough to reach a definitive conclusion, it seems to indicate that single bouts of exercise can have an effect in the first phases when those substances that cause craving are perceived. AB values have also been associated with craving in different studies in variate substances (Field et al., 2005, 2004, 2009). The studies included in this review provide relevant information that seem to indicate that the craving values for HyPF are reduced after a single bout of exercise at moderate intensity in obese or overweight subjects (Ledochowski et al., 2015; Oh & Taylor, 2013, Alkahtani et al., 2014a), results that would be in accordance with those presented on AB. This effect becomes more solid after observing how it can be seen against other substances, such as craving in cigarettes (Taylor, Ussher, & Faulkner, 2007; Thayer, Peters, & Takahashi, 1993) and alcohol (Ussher et al., 2004) with large investigations supporting them. Several studies (Taylor & Oliver, 2009; Thayer et al., 1993) also observed how an exercise session reduced craving in non-obese subjects to certain types of food.

In a recent review (Coltell et al., 2019), the relationship between taste perception and body weight, BMI, and waist circumference in older patients was studied, indicating an inverse association. Only a single article (Westerterp-Plantenga et al., 1997) was found that analysed the perception of sweet taste after applying a moderate exercise session and observed an increase in the perception of sweet taste, compared to the control group at lower concentrations of sucrose in a simple solution, in a mixture, and in a sports drink after exercise compared to after rest, although this change did not occur at other concentrations.

These findings suggest that those subjects who do not feel the taste that much, need more doses to achieve the same pleasure (Donaldson et al., 2009).

The results found on the hedonic value (Westerterp-Plantenga et al., 1997) and the food reward (Martins et al., 2015), indicated no acute effect of a single bout of exercise on these outcomes. These findings are not in accordance with what has been described in the literature, where a reduction in the neural response was observed to visual stimuli in non-obese adults in principal cerebral areas, related to reward after a bout of exercise (Evero, Hackett, Clark, Phelan, & Hagobian, 2012). It was also observed after the chronic application of exercise in overweight/obese subjects (Luo, O'Connor, Belcher, & Page, 2018). In another study (Luo et al., 2018), a correlation between greater time in moderate to vigorous physical activity (MVPA) and lower in SB time and decreased brain responses to HyPF was observed in obese and normal-weight adult subjects. The lack of results may lie in the type of population used for the studies, the interventions, or more probably, the difference in the evaluation methods between the studies.

As it has been discussed, the mechanisms behind the effect of PA and exercise on FA are still not well understood; therefore, generic aspects, such as energy consumption or macronutrients, appetite, hunger, satiety and satiation, combined with more specific elements to homeostatic components (i.e., hormones), and those for food addiction (i.e., craving, homeostatic hunger, "liking", "wanting", taste perception, AB and food reward), even neuroimaging studies, could help to identify those aspects where it is most useful.

4.1. Limitations

The systematic review is under a set of limitations due to the structure of the methodology itself. All included studies were based on a cross-over design, this methodology is considered as a type of randomised controlled trial, with particular characteristics where the subjects receive several treatments consecutively, this limits long-term conditions analysis, and the effects could be transferred to the following interventions; nevertheless, it allows to obtain a larger sample (Sibbald & Roberts, 1998).

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4.2. Implications for current practice

The PA and exercise have been described as essential components for weight loss and maintenance programs (Donnelly et al., 2003; Jakicic et al., 2008; Ka et al., 2009; Murray et al., 2014), especially in combination with healthy eating habits (González-Muniesa et al., 2017). The current knowledge also could associate a partial effect in the reduction of food intake (Beaulieu et al., 2016; J E Blundell, 2011; Shook et al., 2015), and as described before, could be by several elements of eating-related addictive behaviour. This knowledge gives those professionals, who deal with patients suffering from obesity/overweight, a useful conservative tool to help them.

5. Conclusion

The literature seems to indicate that the acute effects of PA at moderate intensity may be useful as a complement to other therapies to help control the levels of addiction to HyPF.

Further research is needed to determine the effect of chronic interventions, different doses and types of PA applications. It is also unknown if only obese/overweight subjects could benefit from this effect since there does not seem to be much difference between body composition, which means that it could serve as a preventive treatment. The unknown pathways and mechanisms on the topic open many lines to research.

Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

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Author Contributions

The authors declare contribution to the development of article in the following actions, David Piñol-Piñol realized the search and wrote discussion section, Francesc Rubí-Carnacea developed the research, methodology and quality analysis of articles, Silvia Solé providing language support and Cristina Bravo assessed the focus of review and performed the supervision of whole process. Finally, all authors have approved the final article.

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Appendices

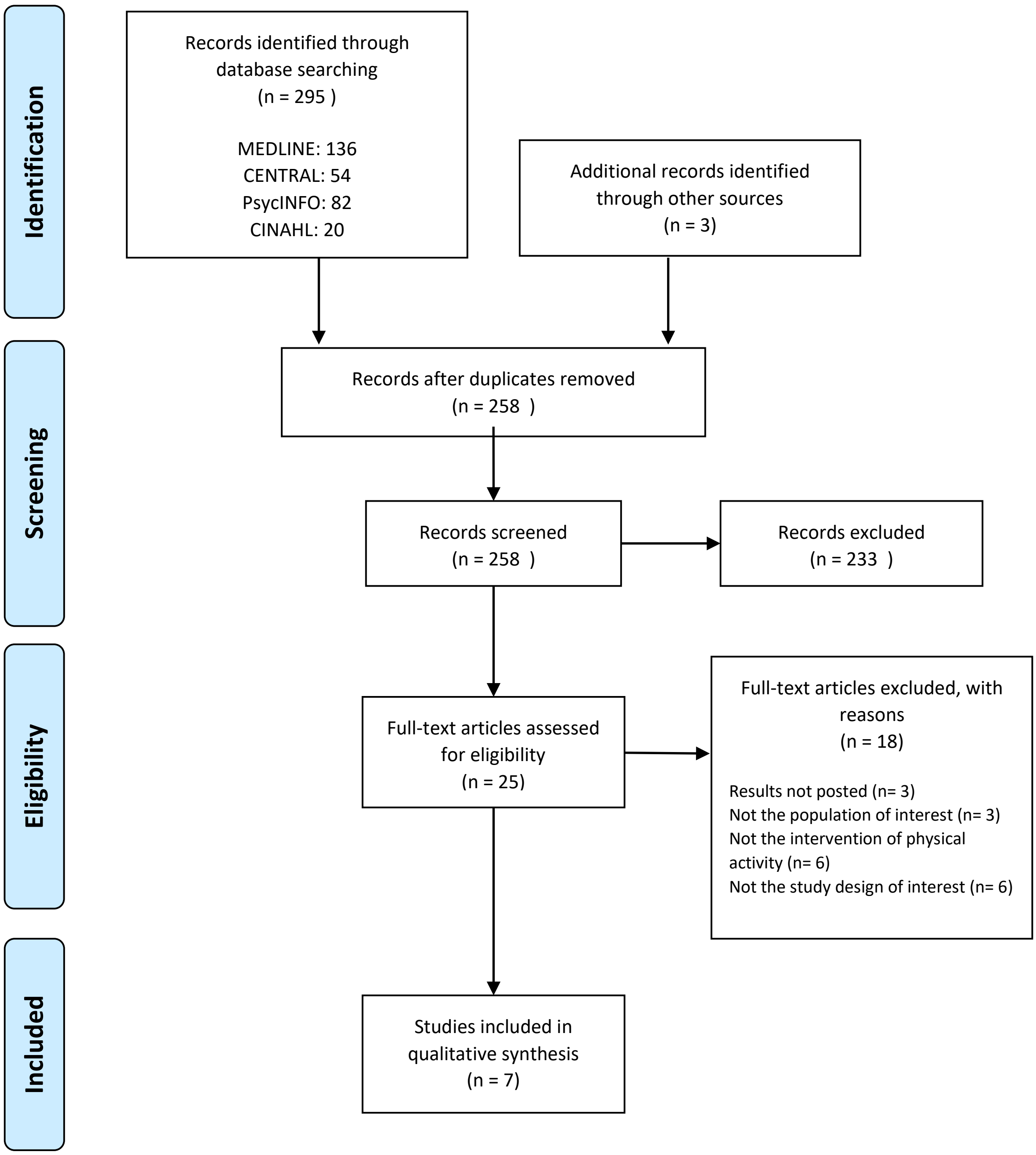

Figure 1. PRISMA flow diagram of literature search.

Table 1. Search strategy used in MEDLINE (PubMed) on April 15, 2019

Search ID	Search/ MeSH Terms and text words	Hits
1	Obesity/physiopathology OR Obesity/psychology OR Overweight/physiopathology OR Overweight/psychology OR Obes*[TIAB] OR overweight*[TIAB]	63020
2	Exercise OR Sedentary Behavior OR Exercise therapy OR Exercise Movement Techniques OR sports OR Physical Exertion/physiology OR Walking/physiology OR walking/psychology OR Exercise*[TIAB] OR physic* activ*[TIAB] OR physic* fit*[TIAB] OR “Physical exercise”[TIAB] OR sedentary*[TIAB] OR “Sedentary Lifestyle”[TIAB] OR Physic* inact*[TIAB] OR inactivity[TIAB]	130055
3	Reward OR Cues OR Food addiction OR Craving OR Food Preferences/drug effects OR Food Preferences/physiology OR Food Preferences/psychology OR Arousal/physiology OR Motivation/physiology OR Brain/physiology OR Taste/drug effects OR Taste/physiology OR neuronal response*[TIAB] OR Brain Response*[TIAB] OR “wanting”[TIAB] OR “liking”[TIAB] OR “visual food stimuli”[TIAB] OR reward* value[TIAB] OR "drive to eat"[TIAB] OR “emotional eating” [TIAB]	133199
4	Food OR “fast foods”[TIAB] OR “high-calorie food” [TIAB] OR “Sugar-sweetened carbonated beverage”[TIAB] OR sweet*[TIAB] OR “soft drink”[TIAB] OR “high-fat foods”[TIAB] OR “high-energy food”[TIAB] OR sugar[TIAB] OR "palatable food"[TIAB]	90175
	1 AND 2 AND 3 AND 4	136

Notes: Filters activated: Clinical Trial, Controlled Clinical Trial, Randomized Controlled Trial, Research Support, American Recovery and Reinvestment Act, Research Support, N.I.H., Extramural, Research Support, N.I.H., Intramural, Research Support, Non-U.S. Gov't, Research Support, U.S. Gov't, Non-P.H.S., Research Support, U.S. Gov't, P.H.S., Research Support, U.S. Government, Humans, MEDLINE, Adult: 19+ years.

Abbreviations: [TIAB], text word restrict to title or abstract.

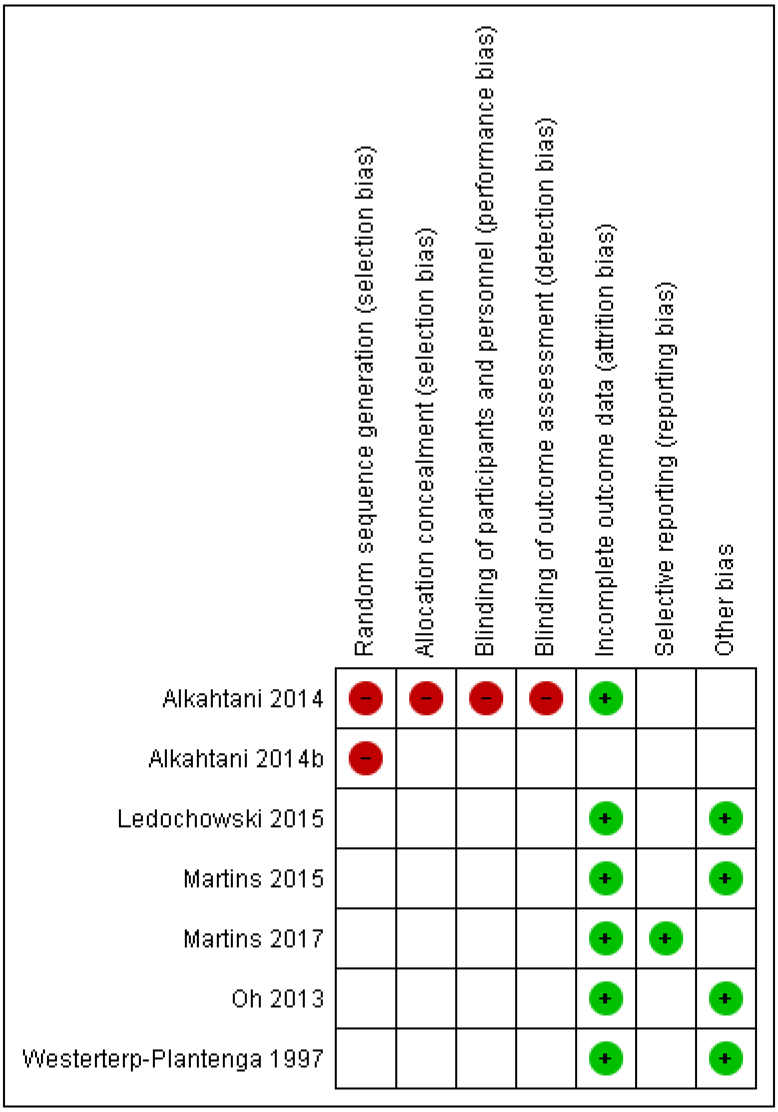

Figure 2. Risk of bias summary of results