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When winning is losing: A randomized controlled trial testing a video game to train food-specific inhibitory control

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ABSTRACT

Overweight and obesity are major causes of worldwide morbidity and mortality. A two-armed randomized controlled trial (n = 104) examined the effectiveness of *Hit n Run*, a video game based on the principles of Go/No-Go inhibition training, in young adults who reported disinhibited eating. Adults (aged 18 to 30) were randomly assigned to play *Hit n Run* or received an informative brochure (*Healthy Eating Step by Step*; HESbS). Prior to and directly following the intervention week general and food-specific inhibitory control, caloric intake, and perceived attractiveness of food pictures were assessed. Results revealed no improvements in food-specific inhibitory control or caloric intake in either intervention group. Similar improvements for general inhibitory control and similar decreases in perceived attractiveness of food-related stimuli were observed for both *Hit n Run* and HESbS. Future research should aim to clarify how video game design can implement working mechanisms of cognitive training tasks to facilitate the development of effective game-based interventions.

1. Introduction

Overweight and obesity are leading causes of preventable disease burden worldwide, contributing to cardiovascular diseases, diabetes and other health problems (Shaw, O'Rourke, Del Mar, & Kenardy, 2005; World Health Organization, 2009). The majority of the people who become overweight have an imbalance of caloric intake and energy expenditure, with excessive calories being converted into fat and weight gain (Houben & Jansen, 2015). Prevalence of overweight or obesity has increased steadily for decades (Ng et al., 2015; World Health Organization, 2000), currently affecting up to approximately 33,4% of Dutch young adults (aged 19 to 29; Volksgezondheidenzorg.info, 2016) with increased risk of overweight and obesity persisting in adulthood (Llewellyn, Simmonds, Owen, & Woolacott, 2016). Worldwide, the World Health Organization (2016) reports more than one-half of adults (51,5%; aged 18 and over) are overweight or obese. Although this is a pressing global problem, meta-analyses indicate that present intervention programs produce no or small effects (Stice, Shaw, & Marti, 2006; Vasques et al., 2014). Identifying effective intervention strategies is therefore of vital importance.

Hypersensitivity to food-rewards combined with deficits in inhibitory control (i.e., the ability to stop an automatic response) are key processes associated with the onset and maintenance of overweight and obesity (Adams, 2014; Jones et al., 2016; Stice, Lawrence, Kemps, & Veling, 2016). Calorie-dense food cues in an obesogenic environment may provoke automatic motor impulses towards these attractive foods, triggering impulsive consumption (Adams, 2014; Hofmann, Friese, & Strack, 2009; Papies, 2012). Thus, overeating and weight gain are facilitated in those with insufficient inhibitory control (Adams, 2014; Jones et al., 2016). Indeed, impaired inhibitory control has repeatedly been associated with overweight or obesity, with obese individuals having more difficulty controlling impulsive responding compared to individuals who maintain healthy weight (e.g., Nederkoorn, Smulders, Havermans, Roefs, & Jansen, 2006; Price, Lee, & Higgs, 2015). Moreover, strong food preferences combined with low inhibitory control have been found to precede excessive weight gain (Nederkoorn, Houben, Hofman, Roefs, & Jansen, 2010). Conversely, high levels of inhibitory control have been associated with self-regulating behaviors such as dieting (e.g., Hofmann, Adriaanse, & Baumeister, 2014; Pauli-Pott, Albayrak, Hebebrand, & Pott, 2010). Hence, inhibitory control processes will be one of the key targets for emerging interventions.

The most common procedure for inhibition control interventions is Go/No-Go training (Jones et al., 2016; Verbruggen & Logan, 2008), wherein participants are instructed to respond or withhold from responding to stimuli based on a cue that signifies behavioral inhibition (e.g., a colored Go vs. No-Go cue or high vs. low tone directly after

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presentation of a stimulus). In food-specific Go/No-Go training, participants are repeatedly trained to respond immediately to neutral stimuli, but inhibit their response upon presentation of food-related stimuli (Veling, Van Koningsbruggen, Aarts, & Stroebe, 2014). It is commonly believed that this type of training reinforces a top-down executive control process, directly increasing one's capacity to resist impulses toward calorie-dense food (e.g., Andrés, 2003). More recently, however, researchers have argued that consistent mapping of stimuli onto either stopping or going in food-specific Go/No-Go training fosters development of automatic motor inhibition through stimulus-stop associations, without strengthening general capacity for inhibition *per se* (e.g., Stice et al., 2016; Verbruggen & Logan, 2008).

Alternatively, Behavior Stimulus Interaction (BSI) theory (Chen, Veling, Dijksterhuis, & Holland, 2016; Veling, Holland, & Van Knippenberg, 2008; Veling, Lawrence, Chen, Van Koningsbruggen, & Holland, 2017) proposes that training decreases perceived attractiveness of No-Go food stimuli. When perceived attractiveness of calorie-dense food is lower, impulses toward these foods may be weakened, making individuals less prone to approach calorie-dense food and increasingly able to inhibit this response (Veling et al., 2008, 2014). Specifically, reduction through inhibition is argued to be specific to stimuli inherently associated with an approach orientation. In line with this reasoning, training should result in a larger decrease in attractiveness of appetitive No-Go stimuli than Go or neutral No-Go stimuli (i.e., devaluation effect). Several studies have indeed shown devaluation of attractive stimuli after repeated pairing with No-Go cues as measured with visual analogue scales (e.g., Chen et al., 2016; Lawrence et al., 2015; Veling et al., 2008; Serfas, Florack, Büttner, & Voegeding, 2017; however findings appear less robust when indirect measures of evaluation [e.g., IAT] are employed, see; Jones et al., 2016).

Though the psychological mechanisms through which Go/No-Go training changes behavior are still being debated, promising medium effect sizes were found for food-specific Go/No-Go training, with training reducing liking, choice and intake of No-Go foods (Allom, Mullan, & Hagger, 2016; Jones, Hardman, Lawrence, & Field, 2017; Turton, Bruidegom, Cardi & Hirsch, 2016). Indeed, Lawrence et al. (2015) demonstrated that four online sessions of food-specific Go/No-Go training resulted in improvements in a variety of self-reported health behaviors, including reduced daily caloric intake and weight loss. Moreover, a recent meta-analysis confirmed the effectiveness of training for short-term appetitive behavior change (Jones et al., 2016).

Nonetheless, Go/No-Go training shares common challenges with other weight loss interventions, including high rates of attrition, potential stigmatization, and limited accessibility (Forman et al., 2017; MacLean et al., 2009; Stice et al., 2006). We argue that these challenges can be addressed through the use of videogames (Granic, Lobel, & Engels, 2014; Johnson-Glenberg, Savio-Ramos, & Henry, 2014; Stice et al., 2006). Contrary to conventional Go/No-Go training, videogames have tremendous appeal, reflected by their worldwide popularity (Lenhart et al., 2008; Meeker, 2017). Videogames are able to evoke intrinsic motivation to engage people in treatment, facilitated by the artful use of motivating techniques when expert game developers design these games (Forman et al., 2017; Ryan, Rigby, & Przybylski, 2006). Moreover, video games can promote long-term training by incorporating repetitive actions that are compelling and fun, encouraging repetitive gameplay and practice of skills (Granic et al., 2014; Green & Bavelier, 2012). In addition, with little to no stigma attached to gameplay and immense potential for scalability, videogames can reach those who might otherwise not seek help (Granic et al., 2014).

Hence, the current two-armed Randomized Controlled Trial (RCT) examined the effects of *Hit n Run*, a video game based on principles of Go/No-Go training, in young adults who reported disinhibited eating. An informative brochure *Healthy Eating Step by Step* (Nutrition Information Center, 2013) was selected as the active control group because this brochure incorporated no evidence based training components specifically directed at inhibitory control (Adams, Lawrence, Verbruggen, & Chambers, 2017), while still being a common intervention for the promotion of healthy eating. Potential mechanisms of change were also examined. Specifically, we aimed to investigate claims that Go/No-Go training (a) strengthens food-specific and/or general inhibitory control and/or (b) weakens attractiveness of food cues. Furthermore, to assess potential distal behavioral effects of our interventions, laboratory food intake was recorded. We expected that young adults who played *Hit n Run* would show improved levels of food-specific (automatic) inhibition, decreased attractiveness ratings for appetitive food stimuli, and decreased caloric intake of unhealthy food post-intervention, relative to young adults in the control condition. No specific hypotheses were put forth about intervention effects on general (top-down) inhibition or caloric intake of healthy food.

2. Materials and methods

2.1. Participants

Young adults, recruited through online advertisements and flyers distributed around the campus of the Radboud University in the Netherlands, were screened for susceptibility to overeating and being overweight using the Three Factor Eating Questionnaire Disinhibition scale (TFEQ-D; Stunkard & Messick, 1985) and Body Mass Index (BMI; determined from self-reported height and weight). Inclusion criteria were: (1) aged 18 to 30, (2) motivated to eat healthier within 6-months or less (contemplation stage; Prochaska et al., 1994), (3) BMI ≥ 25 and/or elevated eating disinhibition (TFEQ-D score ≥ 5; Lawrence et al., 2015). Exclusion criteria were: (1) BMI < 18.5 (underweight), (2) taking psychotropic drugs, (3) receiving psychosocial care, and (4) intolerance for food included during test procedures. Eligible participants were invited into the study, whereby priority was given to those with a BMI ≥ 25. Based on a priori power analysis using G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007) sample size was set at 98 participants (Repeated Measures ANOVA, between subjects design; $f = 0.25$, $\alpha = 0.05$, power = 0.80, correlation among repeated measures = 0.50).

In total, 104 young adults were enrolled with a mean age of 21 (M_{age} = 20.95 years ± 2.42) and a majority of females (89.4% females; see Fig. 1 for flowchart), thereby allowing for 5–10% attrition. The sample included 70.2% healthy weight (18.5 ≤ BMI < 25), 24.0% overweight (25 ≤ BMI < 30) and 0.8% obese participants (BMI > 30) with a mean BMI of 24.07 ± 2.99 across the sample. Participants showed moderately high scores on disinhibited eating (M_{TFEQ-D} = 9.81 ± 2.70; Lawrence et al., 2015), restraint eating (Restraint Scale [RS; Polivy, Herman, & Warsh, 1978], M_{RS} = 20.79 ± 4.48; Nguyen & Polivy, 2014) and symptoms of food addiction (Yale Food Addiction Scale [YFAS; Gearhardt, Corbin, & Brownell, 2009], M_{YFAS} = 2.51 ± 1.52; Pursey, Stanwell, Gearhardt, Collins, & Burrows, 2014), and had normative scores on general impulsivity (M_{TFEQ-D} = 62.85 ± 9.17; Barratt Impulsivity Scale [BIS; Patton, Stanford, & Barratt, 1995]; Davis et al., 2011). In addition, 23.1% of participants indicated not playing video games at all in their leisure time, with an additional 3.8% playing less than an hour in an average week. Yet, almost two thirds of participants were more active video game players (46.2% 1 ≤ hours ≤ 2, and 16.3% 2 < hours ≤ 7) and 10.6% indicated playing more than 7 hours a week.

2.2. Procedure

Data were collected in the Behavioral Science Institute Laboratory of the Radboud University. Participants provided informed consent and were randomized into either the experimental (n = 51) or control (n = 53) group. Randomization was performed by an independent researcher using random number generation and was stratified by sex. Test procedures prior to and directly following the one-week intervention lasted approximately 90 min including (respectively): general

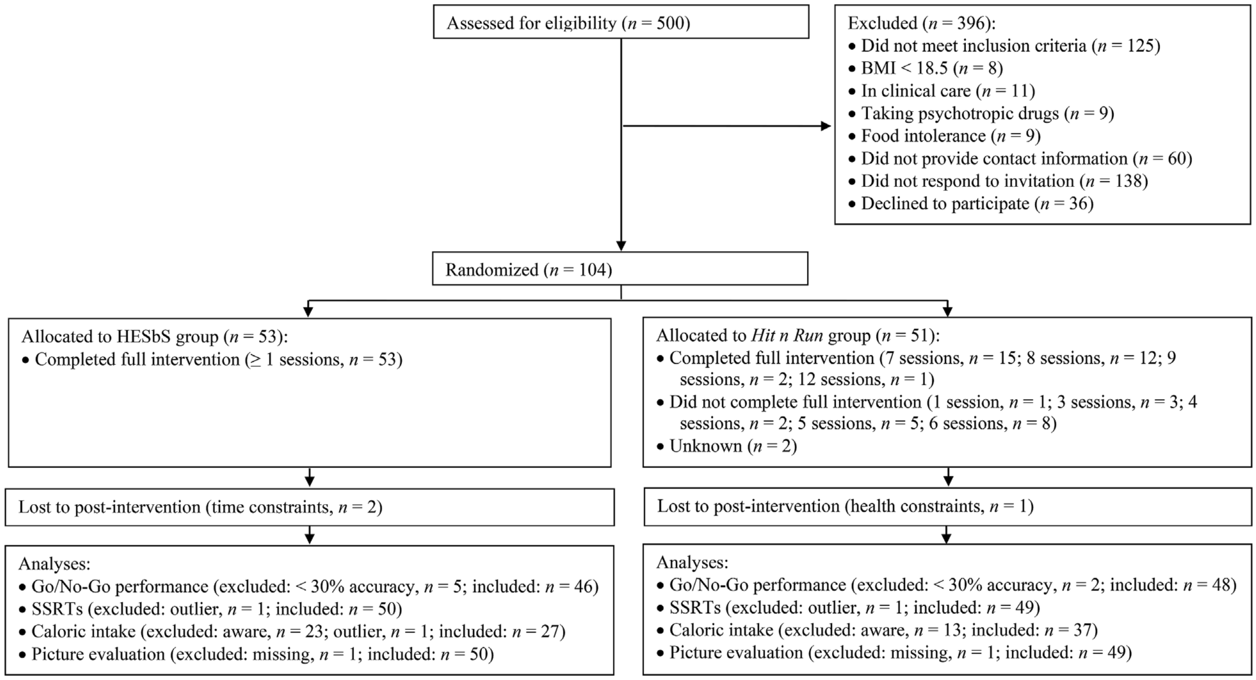

Fig. 1. Flow chart participant inclusion from screening to post-intervention.

inhibitory control, food-specific inhibitory control, caloric intake, and picture evaluation. The first intervention session, which either consisted of a first gameplay session or reading of the informative brochure in the lab, was administered immediately following pre-intervention test procedures. After that, picture evaluation was repeated. During the remainder of the intervention week, participants were instructed to complete either six more daily sessions of game play at home or were given the brochure for further reading and/or browsing of websites listed within. Halfway through the intervention week all participants were reminded to engage with their assigned intervention (to play *Hit n Run* daily or to (re-)read HESbS and visit recommended websites) via a personalized email. Participants received course credits or a €25 gift certificate for their participation. The current study was approved by the ethical committee of the Faculty of Social Sciences at Radboud University (ECSW2016-1403-378) and registered at the Dutch Trial Register (No. NTR5793).

2.3. Interventions

2.3.1. Hit n run

The infinite runner game *Hit n Run*, based on principles of Go/No-Go training (Lawrence et al., 2015; Veling et al., 2014), was co-developed with Embodied Games LLC and the Games for Emotional and Mental Health (GEMH) Lab. The general premise of infinite runners is simple: players control an avatar that is running forward non-stop with the objective to direct the avatar from left to right or in an up-and-down motion to collect points along the way (Parkin, 2013). Commercially-available infinite runners are extremely popular (e.g., Temple Run; Parkin, 2013) and they are particularly well-suited for training inhibitory control because they require continuous quick and accurate responses.

Hit n Run is a PC game (Fig. 2) that places players in a city filled with billboards on which pictorial stimuli are displayed for 1000 ms. Stimuli consisted of neutral household items (n = 120) and energy rich foods (n = 40) photographed for the purpose of the current study and selected based on highest palatability rating in an independent sample (n = 19). To ensure training effects were not due to specific pictures, three game versions with different pictures sets (selected from 140 neutral and 60 food pictures) were constructed and randomly assigned to participants.

Players were instructed to press a button as fast and accurately as possible in order to hit billboards (Go trial) or to withhold their response (No-Go trial) based on billboard border color which appeared 100 ms after stimuli onset (Go and No-Go borders were blue and yellow respectively). Stimuli of household items were consistently paired with Go trials, whereas energy rich food items were paired with No-Go trials. Settings were manipulated such that 25% of trials in each gameplay session were No-Go trials, to ensure that players were set to respond to billboards and had to actively inhibit responses on No-Go trials (Chen et al., 2016). Trials (Go versus No-Go) were presented in a quasi-randomized order such that at most five No-Go billboards were presented consecutively.

To provide participants with feedback on performance, billboards turned green or red after each correct or incorrect Go response, respectively. Additionally, for each correct Go response players were rewarded with 100 points and a one-tenth increase of the point multiplier, adding bonus points for consecutive correct responses. Players received no points for correct No-Go responses as this could potentially confound training effects by strengthening associations of reward with No-Go food cues. The point multiplier was set back to 1.0 at each incorrect Go or No-Go response of the player. Moreover, consecutive correct or incorrect Go/No-Go responses allowed players to move up or down, respectively, between the three levels contained in the game (a sewer-, street-, and rooftop-level). Difficulty increased with each level, with higher levels allowing for fewer incorrect responses, while higher levels were also designed to be more rewarding using more audio-visual input (e.g., upbeat music). To make game play more challenging and engaging players' running speed was dynamically adjusted, increasing over time in the street- and rooftop-level, and decreasing with each incorrect Go response in the sewer-level. In addition, space between billboards was randomly varied. Participants were instructed to complete at least seven, daily 10-min sessions of game play. On average participants played the game 6.55 times (SD = 1.85; including sessions with a minimum 80 trials, similar to training sessions in Veling et al., 2008).

2.3.2. Healthy eating step by step (HESbS)

The freely available self-help brochure *Gezonder Eten Stap voor Stap*

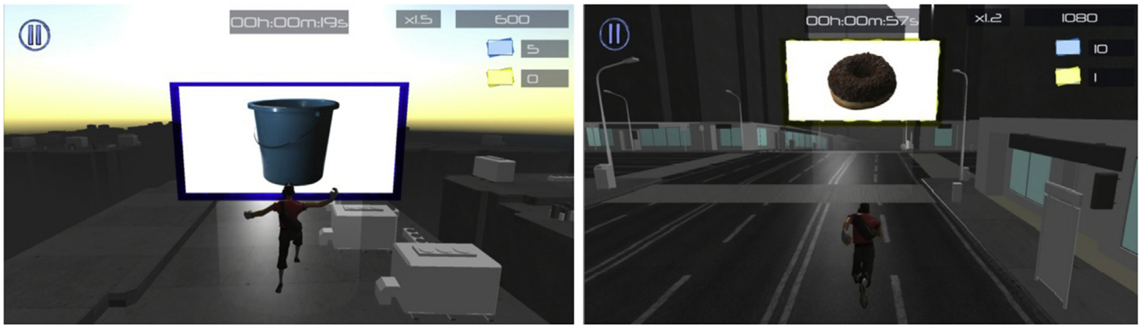

Fig. 2. Screenshots of *Hit n Run.*

(*Healthy Eating Step by Step*; HESbS) by the Nutrition Information Centre (2013) from Belgium, aimed at the general public, was provided to participants in the control group. The brochure addresses benefits of a healthy and balanced diet, describes strategies for improving eating habits, includes example recipes and contains references to specialist support and websites on healthy nutrition. Participants received a paper version of this 8-page brochure to read at least once during a 10-min time period in the lab. In addition, participants were provided with the opportunity to browse websites recommended in the brochure. After the pre-intervention test participants were given the brochure and encouraged to read through the brochure and listed websites at home. On average participants indicated at post-intervention reading the brochure a total of 2.78 times ($SD = 1.90$) throughout the entire intervention week.

2.4. Instruments

2.4.1. Expectations

Expectations for the effectiveness of each intervention were assessed at pre-intervention. This to ensure that differential expectations did not account for potential group differences on outcome measures and instead could be attributed to the strength of interventions (Boot, Simons, Stothart, & Stutts, 2013; Crum & Phillips, 2015). Participants were presented with brief descriptions of each intervention emphasizing their promise for strengthening control in order to prime equal and positive expectations. Participants then indicated on a 6-point scale ranging from 1 (*not at all*) to 6 (*very much*) to what extent they thought that HESbS and *Hit n Run* would make them (1) "eat healthier," (2) "eat less impulsive," (3) "have more control over their eating behavior," and (4) "be more motivated to eat healthier." Sum scores were calculated for expectations relating to participants' assigned intervention.

2.4.2. Food-specific inhibitory control

A modified version of the Go/No-Go task designed by Luijten, Little and Franken (2011) was used to assess inhibition of pre-potent responses to energy rich foods. Participants were presented with food-related ($n = 75$) and neutral pictures ($n = 75$), all selected from the food-pics database (Blechert, Meule, Busch, & Ohla, 2014) and therefore different from the pictures included in *Hit n Run*. Food-related pictures depicted a wide range of energy rich foods such as pizza and chocolate, whereas neutral pictures displayed household items including a stapler and clock. Participants were instructed to respond to stimuli, quickly and accurately, by pressing a spacebar (Go trials) or withhold from responding (No-Go trials) based on frame color. The frame color (purple versus turquois) assigned to Go versus No-Go trials was counterbalanced across participants.

Participants completed one practice block, followed by four test blocks of 150 trials each. Of the 600 trials 25% were No-Go trials. Throughout assessment, each pictorial stimulus was presented four times for 200 ms: once as a No-Go stimulus, and three times as a Go stimulus. Trials were presented in a quasi-random order with the restriction that no more than four Go trials and two No-Go trials followed each other. Trials were separated by a black screen for a random duration varying unpredictably between 1020 ms and 1220 ms. Mean accuracy on No-Go trials and mean reaction time on Go trials were calculated per picture type (food vs. neutral).

2.4.3. General inhibitory control

To assess general inhibitory control (i.e., inhibition that was not contingent on stimuli type such as food), a Stop Signal task was used (Chen, Veling, Dijksterhuis, & Holland, 2017). In this task, participants were presented with left- or right-pointing arrow stimuli. Participants were instructed to respond to stimuli by indicating arrow direction (Go trials) unless a Stop Signal (beep) was provided after a variable delay (Stop trials). The initial Stop Signal delay of 250 ms was dynamically adjusted after each successful or failed inhibition response, increasing or decreasing by 50 ms, respectively, ranging from 0 ms to 1000 ms (Logan, Schachar, & Tannock, 1997). Arrow stimuli were visible for 1000 ms on each trial, with the inter-trial interval randomly varying between 100 ms and 200 ms. The Stop Signal Task consisted of one practice block and three test blocks of 80 trials. The 240 trials were presented in quasi-random order with 25% of the trials ($n = 80$) containing a Stop Signal. Participants were instructed to respond both quickly and accurately. Stop Signal reaction times (SSRT) were estimated using the quantile method, subtracting the average Stop Signal delay from the quantile Go reaction time that corresponded to the proportion of failed inhibition attempts (for more information see Congdon et al., 2012 or Verbruggen, Chambers, & Logan, 2013).

2.4.4. Picture evaluation

All participants were instructed to rate pictures of food ($n = 60$) and household items ($n = 60$) on a continuous scale ranging from −100 (*negative*) to 100 (*positive*; Chen et al., 2016; Chen et al., 2017). For participants in the *Hit n Run* group, 80 of these pictures were trained during intervention, that is, these pictures were included in *Hit n Run* (40 neutral and 40 food, labelled 'trained pictures'). The remaining 40 pictures were novel pictures, exclusively presented in the evaluation task (20 neutral and 20 food, hereafter 'untrained pictures'), thereby we were able to evaluate whether changes in picture evaluation compared to an untrained baseline (Veling et al., 2008). For participants in the HESbS group all pictures (60 neutral and 60 food) were considered untrained, as these pictures were not included in the brochure.

Pictures were rated at three time points: at pre-intervention (i.e., before the first intervention session of playing the game or reading the brochure in the lab on the first intervention day; T1), straight after the first intervention session in the lab (T2), and again at post-intervention (i.e., following the one-week intervention period [7–11 days later, $M = 7.51$, $SD = 0.88$]; T3). Mean scores were calculated for each picture type per training status. That is, mean scores for untrained food and neutral pictures scores were calculated for all participants and additional mean scores for trained food and neutral pictures were calculated for the *Hit n Run* group specifically.

2.4.5. Caloric intake

In a bogus taste test (e.g., Blackburne, Rodriguez, & Johnstone, 2016; Guerrieri, Nederkoorn, & Jansen, 2012; Houben & Jansen., 2011; Robinson et al., 2017) participants were presented three glass bowls (500 ml) containing chocolate M&M's, salted potato chips, and white grapes. Participants were instructed to consume as much or little of each product as desired (with a minimum of a single bite) under the guise of evaluating the products' smell, flavor and texture. Participants received 8 min to complete this task in private. The products were then removed and weighted out of sight. The amount of kilograms consumed were converted into kilocalories (kcal) for each product, then scores were averaged for healthy (i.e., grapes[1]) and unhealthy food (i.e., M&M's and chips).

2.5. Statistical analyses

Prior to analyses, we checked for outliers (± 3IQR; Walfish, 2006), poor accuracy on No-Go trials (< 30%), and awareness of the true nature of the Bogus Taste test (i.e., measuring food intake). Accordingly, participants were excluded from analyses of Go/No-Go task performance (excluded $n = 7$), Stop Signal reaction times (excluded $n = 2$), and caloric intake (excluded $n = 37$; see Fig. 1).

Behavioral accuracy on No-Go trials and reaction times on Go trials of the food-specific Go/No-Go task were tested with a Group (HESbS vs. *Hit n Run*) × Picture type (food vs. neutral) × Time (pre-vs. post-intervention) Repeated Measures Analyses of Variance (RM-ANOVA). Similarly, a Group × Time RM-ANOVA compared group differences for Stop Signal reaction times, and a Group × Product type × Time compared group differences for caloric intake. Picture evaluations were analyzed with two separate RM-ANOVAs; A Group (HESbS vs. *Hit n Run*) × Picture type (food vs. object) × Time (T1 vs. T2 vs. T3) RM-ANOVA compared evaluations of untrained pictures between groups. Furthermore, a Picture type (food vs. object) × Training (trained vs. untrained) × Time (T1 vs. T2 vs. T3) within-subjects RM-ANOVA for participants in the *Hit n Run* group compared effects between trained and untrained pictures. Greenhouse-Geisser corrections were employed when sphericity was violated. Significant interaction effects were further examined using follow-up pairwise comparison of estimated marginal means with a Bonferroni correction.

In the supplementary materials we report on additional Bayesian RM-ANOVAs, which were carried out to inform interpretation of null findings. In addition, results of latent growth curve analyses on mean accuracy scores for No-Go billboards recorded during *Hit n Run* gameplay (hereafter 'game performance') are reported. These growth curve analyses were conducted to explore whether growth patterns in game performance across gaming sessions were correlated with intervention effects. Growth curve models were estimated using performance data from the second to the seventh gameplay session (≥80 trials) to warrant optimal accuracy while retaining the vast majority of data (≥65%; see supplementary materials for further details). Finally, means and standard deviations on participants' satisfaction with *Hit n Run* and HESbS at post-intervention can be found in supplementary materials.

3. Results

3.1. Participant characteristics

Table 1 presents descriptive statistics of participant characteristics and outcome variables per group at pre-intervention. Participants in the HESbS group had higher expectations for their assigned intervention and higher average caloric intake prior to start of intervention than participants in the *Hit n Run* group. In order to account for variances in expectations between groups we included pre-intervention expectations as a covariate in subsequent analyses (see Table 2 for results). Moreover, the RM-ANOVA on caloric intake adjusted for differences on food intake at pre-intervention. No further group differences were observed prior to the intervention.

3.2. Main analyses

Statistics for the main RM-ANOVAs are reported in Table 2. Overall, the main analyses showed increases for reaction times on Go trials, and decreases for accuracy No-Go trials, Stop Signal Reaction Times and evaluation of food pictures in both intervention groups. No differences between intervention groups were observed (see details below).

3.2.1. Food-specific inhibitory control: no-go accuracy

To compare intervention effects on inhibition of responses to food cues, behavioral performance on the Go/No-Go task was compared across groups first for No-Go accuracy and below for Go reaction times. The Group × Picture type × Time RM-ANOVA on No-Go accuracy showed a main effect of Picture type, indicating that participants were generally less accurate on inhibiting a response for food-related No-Go trials than for neutral No-Go trials (64.1% versus 66.3%, respectively). No effects were found for Time, Group, Picture type × Time, Picture type × Group, Time × Group, or Picture type × Time × Group. These results show that the ability to inhibit responses in No-Go trials for both food and neutral pictures remained the same in both groups. Thus, although participants were less accurate on food-related No-Go trials, this did not improve over time, nor were there any group differences.

3.2.2. Food-specific inhibitory control: go reaction times

Results from the Group × Picture type × Time RM-ANOVA on Go reaction times revealed a main effect of Time, with participants responding faster at post- than pre-intervention ($M_{\text{post-intervention}} = 256.93$ ms versus $M_{\text{pre-intervention}} = 274.27$ ms). However, there were no effects for Group, Picture type, Picture type × Time, Picture type × Group, Time × Group, or Picture type × Time × Group. Thus, while participants' responses on Go trials became faster over time, again no group differences were found.

3.2.3. General inhibitory control

To compare intervention effects on inhibitory control that was not contingent on stimuli type, behavioral performance on the Stop Signal task was compared across groups. Group × Time RM-ANOVA on Stop Signal reaction times revealed a main effect of Time, showing participants inhibited their response on Stop trials faster at post-than pre-intervention ($M_{\text{post-intervention}} = 265.65$ ms versus $M_{\text{pre-intervention}} = 271.78$ ms). No other effects were observed for Group or Time × Group. Hence, results suggested equal improvements in general inhibitory control for both intervention groups.

3.2.4. Picture evaluation: trained versus untrained pictures in the hit n run group

To examine whether food picture evaluation decreased for trained pictures included in *Hit n Run,* and novel, untrained pictures a Training × Picture type × Time RM-ANOVA on picture evaluation for the *Hit n Run* group was conducted. A main effect of Picture type was found, indicating participants in the *Hit n Run* group rated food pictures more positively than neutral pictures ($M_{\text{neutral}} = 7.13$ versus $M_{\text{food}} = 21.50$). There was also a main effect of Time, with follow-up tests indicating picture evaluation decreased significantly over time from T1 to T2, T2 to T3, and T1 to T3 (see Table 3).

More importantly, a Picture type × Time interaction was found; Follow-up tests showed that evaluations of food pictures again decreased significantly over time from T1 to T2, T2 to T3, and T1 to T3. In contrast, however, evaluations of neutral pictures remained constant

[1] While grapes are still high in calories they contain natural sugar and are uncompressed, thus here grapes are considered the healthier choice (Blackburne et al., 2016).

Table 1
Participant characteristics and outcomes per group at pre-intervention Means and Standard Deviations or Percentages and χ2 or t-values.

	Total		HESbS		*Hit n Run*		χ^2 1, 104	*t*-value	*p*-value
Sex									
n %									
Male	11.00	10.60	6.00	11.30	5.00	0.80			
Female	104.00	89.40	47.00	88.70	46.00	90.20	0.06		.801
Age									
Mean SD	20.95	2.42	21.13	2.55	20.76	2.29		0.77	.441
Gameplay [hrs p/w]									
Mean SD	5.21	16.21	2.78	4.13	7.74	22.61		−1.54	.129
Expectations									
Mean SD	11.65	4.87	14.62	3.73	8.57	3.91		8.07	< .001***
Motivation for change									
Mean SD	1.31	0.59	1.38	0.66	1.24	0.51		1.23	.221
BMI									
Mean SD	24.07	2.99	24.00	2.98	24.13	3.02		−0.23	.822
TFEQ-D									
Mean SD	9.81	2.70	9.83	2.79	9.78	2.63		0.09	.931
RS									
Mean SD	20.79	4.48	20.83	4.94	20.75	4.00		0.10	.923
YFAS									
Mean SD	2.51	1.52	2.26	1.46	2.76	1.56		−1.69	.093
BIS									
Mean SD	62.85	9.17	63.06	9.80	62.63	8.56		0.24	.813
No-Go accuracy									
Mean SD									
Food pictures	0.65	0.15	0.63	0.15	0.67	0.15		−1.43	.155
Neutral pictures	0.67	0.15	0.65	0.15	0.68	0.14		−0.95	.345
Go reaction time									
Mean SD									
Food pictures	273.29	41.50	266.36	38.01	280.08	43.99		−1.64	.104
Neutral pictures	273.95	42.61	267.30	39.14	280.45	45.21		−1.53	.129
SSRT									
Mean SD	271.73	0.04	265.08	0.04	278.65	0.05		−1.62	.109
Caloric intake									
Mean SD									
Healthy food	27.79	25.18	37.32	32.87	20.84	14.53		2.44	.020*
Unhealthy food	51.46	52.02	61.33	56.65	44.25	47.86		1.31	.197
Evaluation scores									
Mean SD									
Untrained food pictures	32.13	24.62	1.31	0.24	1.33	0.25		−0.29	.755
Untrained neutral pictures	7.96	13.59	1.07	0.15	1.09	0.12		−0.69	.490

Note. *p < .05; ***p < .001.

over time (see Table 3). Moreover, additional follow-up tests revealed food pictures were rated more positively than neutral pictures at T1 and T2, but at T3, after the decrease in evaluation for food pictures from T1 to T3, evaluations for food and neutral pictures no longer differed (see Table 3).

No effects for Training × Picture type, Training × Time, or Training × Picture type × Time were found, suggesting similar trajectories for trained and untrained pictures over time. Together results showed evaluations of both trained and untrained food pictures in the *Hit n Run* group decreased, whereas evaluations of neutral pictures remained the same (see Fig. 3).

3.2.5. *Picture evaluation: untrained pictures across intervention groups*

To compare changes in evaluation of untrained pictures across groups a Group × Picture type × Time RM-ANOVA was performed for evaluations of untrained pictures. Similar to the effects found in the *Hit n Run* group only, a main effect of Picture type was found, indicating participants in both groups rated untrained food pictures more positively than untrained neutral pictures ($M_{\text{food}} = 20.90$ versus $M_{\text{neutral}} = 5.76$). This appears to reflect an explicit bias toward high-caloric food, with participants attributing high hedonic value to food-related stimuli in particular. Moreover, a Picture type × Time interaction was found. Unlike earlier results in the *Hit n Run* group only, follow-up tests revealed that both untrained food *and* neutral pictures decreased significantly over time from T1 to T2, and T1 to T3 (see Table 3). A significant decrease was also found from T2 to T3 for untrained food pictures, but not for untrained neutral pictures. Thus, evaluation trajectories differed with untrained food pictures being rated lower after both the first intervention session and even lower after the extended intervention period, while the untrained neutral pictures were rated lower after the first intervention session but evaluation showed no further decline after the extended intervention period. Despite the steady decline in evaluation of untrained food pictures for both groups, additional follow-up tests (see Table 3) revealed untrained food pictures were rated more positively than untrained neutral pictures at all points in time.

Furthermore, no effects for Group, Time, Group × Picture type, Group × Time, or Group × Picture type × Time were found. Thus, results of the current analysis indicated that both groups showed similar decreases in evaluation of untrained food and neutral pictures respectively, with food pictures showing a continued decrease after the extended intervention period (see Fig. 3).

Taken together, the two RM-ANOVAs on picture evaluation show a robust decrease in perceived attractiveness of food pictures in *both* intervention groups for both untrained and trained pictures (data for trained pictures is only available in the *Hit n Run* group).

3.2.6. *Caloric intake*[2]

The Group × Product type × Time RM-ANOVA on caloric intake

[2] Participants rated their hunger on a 100 mm VAS (0 = *not at all*; 100 = *very*

Table 2
RM-ANOVA results: F-values for main and interaction effects on outcome variables.

	F-value	*df*	*p*-value	η_p^2
Food-specific inhibitory control				
No-Go accuracy				
Group	2.03	1.00	.158	.02
Picture type	6.11	1.00	.015*	.06
Time	0.29	1.00	.593	< .01
Expectations	1.21	1.00	.275	.01
Group × Picture type	3.46	1.00	.066	.04
Group × Time	< 0.01	1.00	.950	< .01
Picture type × Time	0.09	1.00	.771	< .01
Picture type × Expectations	1.33	1.00	.252	.01
Time × Expectations	0.01	1.00	.909	< .01
Group × Picture type × Time	0.40	1.00	.531	< .01
Picture type × Time × Expectations	0.29	1.00	.594	< .01
Go reaction times				
Group	0.75	1.00	.390	< .01
Picture type	0.15	1.00	.700	< .01
Time	4.60	1.00	.035*	.05
Expectations	0.03	1.00	.855	< .01
Group × Picture type	0.27	1.00	.610	< .01
Group × Time	0.01	1.00	.922	< .01
Picture type × Time	0.87	1.00	.354	.01
Picture type × Expectations	0.11	1.00	.743	< .01
Time × Expectations	0.65	1.00	.424	< .01
Group × Picture type × Time	2.37	1.00	.127	.03
Picture type × Time × Expectations	1.60	1.00	.209	.02
General inhibitory control				
Group	3.56	1.00	.062	.04
Time	5.19	1.00	.025*	.05
Expectations	1.11	1.00	.295	.01
Group × Time	0.16	1.00	.693	< .01
Time × Expectations	3.85	1.00	.053	.04
Picture evaluation				
Hit n Run group				
Training	1.38	1.00	.246	.03
Picture type	9.58	1.00	.003**	.17
Time	6.14	1.54	.007**	.12
Expectations	1.98	1.00	.166	.04
Training × Picture type	0.30	1.00	.590	< .01
Training × Time	0.90	2.00	.412	.02
Training × Expectations	3.16	1.00	.082	.06
Picture type × Time	4.19	1.83	.011*	.10
Picture type × Expectations	1.62	1.00	.209	.03
Time × Expectations	1.47	1.54	.236	.03
Training × Picture type × Time	0.04	1.60	.935	< .01
Training × Picture type × Expectations	1.01	1.00	.321	.02
Training × Time × Expectations	2.14	2.00	.124	.04
Picture type × Time × Expectations	0.48	1.83	.602	.01
Training × Picture type × Time × Expectations	0.13	1.60	.836	< .01
Total sample				
Group	0.10	1.00	.748	< .01
Picture type	5.85	1.00	.017*	.06
Time	2.13	1.76	.128	.02
Expectations	0.52	1.00	.472	< .01
Group × Picture type	0.91	1.00	.342	.01
Group × Time	1.36	1.75	.260	.01
Picture type × Time	6.11	1.87	.003**	.06
Picture type × Expectations	0.66	1.00	.417	< .01
Time × Expectations	1.78	1.75	.176	.02
Group × Picture type × Time	0.22	1.87	.789	< .01
Picture type × Time × Expectations	0.80	1.87	.446	< .01
Caloric intake				
Group	2.28	1.00	.136	.04
Product type	2.62	1.00	.111	.04
Time	0.12	1.00	.914	.01
Expectations	0.02	1.00	.884	< .01
Group × Product type	< 0.01	1.00	.954	< .01
Group × Time	1.15	1.00	.287	.02
Product type × Time	0.21	1.00	.650	< .01
Product type × Expectations	< 0.01	1.00	.999	< .01
Time × Expectations	0.20	1.00	.659	< .01
Group × Product type × Time	0.32	1.00	.575	< .01
Product type × Time × Expectations	0.86	1.00	.358	.01

Note. *p < .05; **p < .01.

revealed no main or interaction effects of Group, Product type, or Time. Hence, results indicated caloric intake of both healthy and unhealthy food remained constant over time in both groups.

4. Discussion

4.1. Mechanisms of change and distant behavioral effects

The current two-armed RCT tested the effects of the video game intervention *Hit n Run* in young adults with elevated levels of disinhibited eating. Potential mechanisms of the video game intervention were examined as well as more distal behavioral effects. Contrary to our expectation, Go/No-Go task performance revealed no improvement in inhibitory control of food No-Go cues after the intervention week, suggesting that food-specific inhibitory control was not strengthened in either intervention group. Nevertheless, an improvement was observed in reaction time on Go trials for both groups, with participants responding faster to both neutral and food cues after intervention. Though arguably these reduced reaction times may reflect facilitated motor learning, researchers have recently argued that, with Go responses speeding up, the relative strength of inhibitory control must increase to avoid mistakes on No-Go trials (Benikos, Johnstone, & Roodenrys, 2013; Smith, Johnstone, & Barry, 2006). Hence, our findings can also be understood as maintenance of accuracy over time regardless of decreases in reaction times, suggesting more efficient inhibition of response to both food and neutral stimuli after both interventions. A similar result was found for Stop Signal Task performance, with both intervention groups showing equal improvements for general inhibitory control scores over time. It is important to bear in mind, however, that suggested increases in inhibitory control efficiency are not specific for *Hit n Run*, and therefore effects for both food-specific and general inhibitory control likely reflect learning processes due to repeated measurements (e.g., Ghuntla, Mehta, Gokhale, & Shah, 2014).

Indeed, very few prior studies have used a comparative before-and-after assessment of inhibitory capacity to study effectiveness of inhibition training (e.g., bib_Blackburne_et_al_2016Blackburne et al., 2016; Houben, Havermans, Nederkoorn, & Jansen, 2012; Johnstone, Roodenrys, Phillips, Watt, & Mantz, 2010). Moreover, existing studies differ in design, training procedure and measure for assessment, and as a result little has been concluded about whether inhibitory training actually strengthens inhibitory capacity. Some researchers suggest training effects such as reduced food intake may not truly result from inhibitory improvements, but rather result from changes in the subjective evaluation of the to-be-inhibited stimuli (Veling et al., 2008).

In the current study, a robust decrease in perceived attractiveness of pictures of energy-rich foods was observed in both groups. That is, participants rated food pictures less positively directly after the first intervention session and even more so after the extended intervention period. This continuous decrease in perceived attractiveness of food stimuli occurred for both trained pictures, which were consistently mapped onto No-Go cues in *Hit n Run*, and novel, untrained pictures. Yet once again, no advantageous effect of *Hit n Run* was observed, with

(*footnote continued*)
much) at start of pre- and post-intervention test procedures (i.e., directly following the Stop Signal Task). No group differences were observed (pre-intervention: t(102) = 0.91, p = .364; post-intervention: t(99) = 1.26, p = .212), hence we did not include hunger scores when analyzing caloric intake.

Table 3
Follow-up tests: interaction effects on picture evaluation (Means and Standard Deviations) and F-values for the *Hit n Run* group and the total sample.

	T1		T2		T3		T1 vs. T2	T2 vs. T3	T1 vs. T3	Neutral vs. Food T1	Neutral vs. Food T2	Neutral vs. Food T3
	M	*SD*	*M*	*SD*	*M*	*SD*	*p*-value	*p*-value	*p*-value	*p*-value	*p*-value	*p*-value
Hit n Run group										< .001***	< .001***	.119
Total pics	19.55	2.10	13.48	2.04	9.90	2.08	< .001***	.022*	< .001***			
Neutral pics	7.58	1.43	6.86	1.84	6.94	1.64	1.000	1.000	1.000			
Food pics	31.52	3.48	20.10	3.19	12.87	3.60	< .001***	.007**	< .001***			
Total sample										< .001***	< .001***	.003**
Neutral pics	7.71	1.39	5.17	1.70	4.41	1.59	.014*	1.000	.011*			
Food pics	31.60	2.45	17.33	2.68	13.77	2.53	< .001***	.046*	< .001***			

Note. *p < .05; **p < .01; ***p < .001.

results demonstrating an equal decrease for food stimuli in both intervention groups. Similar results were found in a recent meta-analysis (Jones et al., 2016), showing that, for studies predominantly using implicit evaluation measures, stimulus devaluation did not differ between experimental and control groups.

However, other work does suggest evidence for a devaluation through inhibition. That is, No-Go foods are consistently devalued more than untrained foods in explicit evaluation measures (Chen et al., 2016). The discrepancy between current results (i.e., evaluations of untrained foods showing equal decreases as trained foods) and those of Chen et al. (2016), may stem from food items never being paired with Go trials in *Hit n Run.* Whereas Chen et al. (2016) trained participants to respond to some food items but not to others. Participants in the current study were trained not to respond to food items at all, therefore chances increased that devaluation of specific trained food items generalized to untrained food items of the same category. A generalized devaluation effect could thus explain the equal decrease in evaluation for trained No-Go food items and untrained food items in the *Hit n Run* group. However, this account cannot explain why food items were devaluated equally in the control group as they were in the *Hit n Run* group. The control intervention did not incorporate an inhibition training nor any other evidence based mechanisms directed at a devaluation effect and therefore less or no devaluation of food items would be expected in the control group compared to the *Hit n Run group*.

Yet it is possible that previously unstudied mechanisms in the control intervention (i.e., the informative brochure) may have led to devaluation. Meaning that repeated inhibition of responses was not the only factor that resulted in a devaluation effect, but potentially also the exposure to cautionary information linked to energy-rich foods. Moreover, it is possible that the explicit measurement of picture evaluation gave rise to social desirability bias, which may have overshadowed smaller intervention effects on stimuli devaluation (Hofmann, Gschwendner, Nosek, & Schmitt, 2005). However, another possibility is that the general decline in attractiveness ratings are due to regression to the mean, and therefore do not reflect intervention effects (Chen et al., 2016; Morton & Torgerson, 2005).

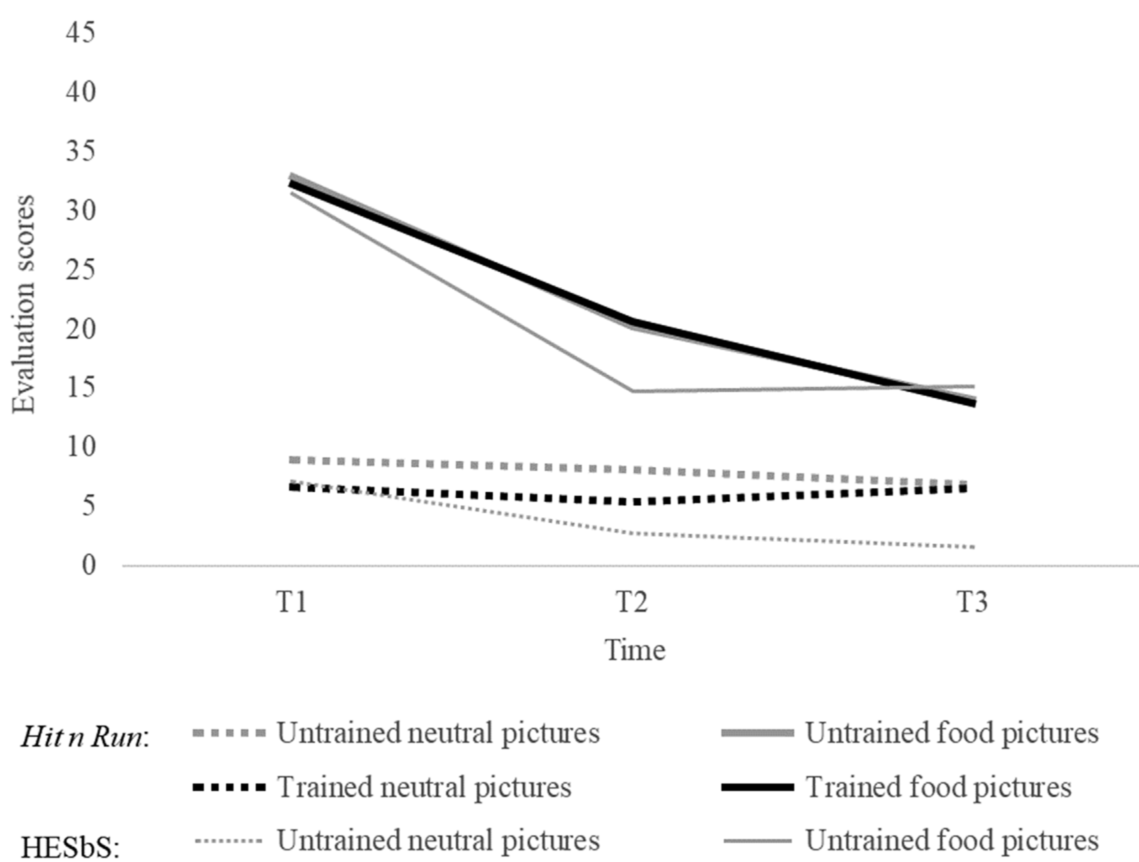

Fig. 3. Unadjusted mean evaluation scores per group over time.

Finally, results revealed no significant intervention effects on caloric intake of healthy or unhealthy food. This finding contradicts earlier studies that did report short-term appetitive behavior change after inhibition training (e.g., Jones et al., 2016). This null finding may be attributed to methodological differences with previous research. For example, typically studies that report appetitive behavior change after inhibition training present participants with a taste test immediately following training (e.g., Houben & Jansen, 2011). Yet, there are also studies that have shown effects of training on caloric intake over a prolonged period of time (e.g. Lawrence et al., 2015). Alternatively null findings may be due to difficulty in obtaining transfer of training for more distal intervention effects (Forman et al., 2017; Perkins & Salomon, 1992). For example, transfer may have been limited by the fact that appetitive food stimuli selected for training were symbolic representations not personalized to the individual (Forman et al., 2017; Guerrieri et al., 2012). Additionally, in our sample a large number of participants were excluded from analyses testing appetitive behavior change due to task awareness; This reduced our power to observe significant change.

To gain a better insight in observed results, in particular the absence of group differences across measures, additional analyses using latent growth curve modeling were performed for the *Hit n Run* group to detect potential heterogeneity in behavior change patterns across gameplay (see supplementary materials). Results revealed no changes in the percentage of correct inhibition of No-Go trials across gameplay sessions for the *Hit n Run* group, nor did results suggest that the lack of group differences could be attributed to heterogeneity in patterns of behavior change across gameplay sessions. It thus appears inhibition was unsuccessfully trained in *Hit n Run*. Below we elaborate which game design elements may have altered training effectiveness.

4.2. Game design limitations and lessons learned

Though we aimed to optimize training effectiveness (e.g., staying close to the design of the original Go/No-Go task, including no more than 25% No-Go trails per session; Chen et al., 2016), several factors may have reduced the effectiveness of *Hit n Run* in unanticipated ways and may explain the consistent lack of group differences. For one, the modification of the traditional Go/No-Go training into an endless runner may have influenced effectiveness (Forman et al., 2017). That is, though we attempted to preserve effective components of the Go/No-Go training as well as utilize several motivating elements of the game format, we may not have been successful. For example, added audiovisual input in *Hit n Run* such as background music and repeated changes in virtual environment may have distracted players from the stimuli to be trained and caused interferences in training effects. Besides, whereas traditional training keeps duration of each trial constant (Lawrence et al., 2015; Veling et al., 2014), *Hit n Run* included a gradual increase in running speed, causing trials to become shorter over time and placing increasingly greater demands on inhibitory control. The resulting increases in difficulty of training may have resulted in suboptimal training of inhibition for players unable to keep up, making the learning curve too steep. Moreover, unlike traditional training *Hit n Run* included the option for alternative responses besides 'Go' or 'No-Go'. Rather than withholding responses to No-Go stimuli, players could opt to avoid stimuli in *Hit n Run* (e.g., moving away from a No-Go stimulus by switching lanes). Therefore, players may have developed different action strategies across gameplay: Instead of inhibiting responses, they may have learned to take action, specifically an avoidant action. Unfortunately, our present data did not allow us to differentiate between such responses.

A final design element of *Hit n Run* that may have impacted on the effectiveness of training is the incorporated feedback- and reward system. Specifically, in contrast to some traditional trainings (Houben & Jansen, 2015; Veling et al., 2008), we did not provide participants with immediate feedback upon each correct non-response, which may be a potential bias. That is, in *Hit n Run*, each correct Go response was rewarded with 100 points, whereas correct No-Go responses were not rewarded to avoid the strengthening of food-reward associations. Though an additional bonus was provided on consecutive correct responses, this bonus turned out to be extremely difficult to maintain. Moreover, both incorrect Go- or No-Go responses resulted in no detraction of points. Therefore, the reward system may have interfered with training as players may have opted to sacrifice potential bonuses and obtain a high score by showing continuous Go responses and forgo inhibition altogether.

Thus, together limitations indicate that future research on in-game data and detection of differential behavioral strategies during game play, as well as on the more fundamental role of reward in inhibition training, is warranted. In particular, we recommend future studies (1) design the back-end of the game to record data that can differentiate between playstyles (e.g., recording if participants consistently respond by moving lanes instead of jumping when seeing a No-Go billboard), and (2) test simple design changes within a traditional training (e.g., to answer the question if speeding up trials results in a different learning curve).

Despite potential drawbacks of game design decisions made, note that these design choices were made to honor entertainment game creation. To overcome common challenges of interventions (e.g., attrition, stigmatization, limited scalability) and capitalize on the motivational benefits of games efforts need to be devoted to designing for an authentic gaming experience that engages people to play on their own volition and can compete with popular commercial games: We argue simply encasing conventional training in a game-shell is unlikely to produce similar motivational benefits. Instead we should aim to design games that combine effective training components with engagement (Boendermaker, Prins, & Wiers, 2015).

As is apparent from the potential design-related drawbacks mentioned above and mere average attractiveness ratings for *Hit n Run* (see supplementary materials) finding the right balance between these objectives can be immensely challenging and complex. We therefore emphasize that incorporating iterative user research and comparative testing early on in the design process is crucial (e.g., see the CeHRes roadmap for practical guidelines; Van Gemert-Pijnen et al., 2011). Based on needs and values of involved stakeholders (e.g., developers, intended users) clear goals need to be formulated prior to the design process. Specified goals can be translated into functional requirements of the game, from which prototypes are created. Iterative user research in the targeted sample will allow one to assess how the intended users connect to and interact with each game prototype, and, more specifically, will allow one to test how each added game element (e.g., increases in speed or the reward system) or instruction (e.g., dosage and duration of play) affects gameplay experience and player enjoyment (e.g., Choi et al., 2016). As a result, prototypes can be refined until ultimately prespecified goals are realized and a user friendly, meaningful product is created that is responsive to user needs.

Moreover, running consecutive, comparative tests against traditional trainings straight from the start will allow one to monitor alterations in training effectiveness and detect crucial training components, and most importantly allow for data-informed game design. For example, if compared to traditional training within subjects Go/No-Go performance decreases after adding a reward element or extra auditory input to the intervention game, game design can be adapted to ensure equal or increased performance to traditional training.

However, we note that when applied games are developed within the research context, more often than not little time or money is allocated to incorporating suggested alterations that emerge from prototype testing. In practice, user research and comparative testing requires sufficient resources, time, and expertise. We therefore recommend future researchers to be conscious of their resource constraints while goal setting allowing for a realistic timeline and ample resources to overcome unforeseen setbacks in game design.

4.3. Methodological limitations and future directions

Notwithstanding the rigorous two-armed RCT design employed in the current study and the relatively large sample size, some methodological limitations should be noted. First, although findings suggested better (general) inhibitory control efficiency and decreased perceived attractiveness of calorie-dense foods for both groups after intervention, it is unclear whether these changes are due to intervention effects or due to general learning effects and social desirability, respectively. Future research could therefore include a passive control group and/or both explicit and implicit measures of stimulus evaluation. Furthermore, though the informative brochure control group in the current study was specifically selected for three reasons: (1) Self-help materials like informative brochures are one of most widely used interventions for overweight and obesity (e.g., see Hartmann-Boyce, Fletcher, & Aveyard, 2015), thus allowing a comparison to a current practice; (2) The brochure provides an active control intervention, which ensures that effects found for *Hit n Run* are not due to non-specific factors of receiving an intervention (e.g., Crum & Phillips, 2015); and (3) The brochure includes no inhibition training elements and therefore reduces the risk of finding false negative results in a proof-of-principal phase. This control group, nonetheless, did not allow for direct comparison between *Hit n Run* and traditional Go/No-Go training. It will be valuable for future studies to assess whether similar response inhibition patterns are found for *Hit n Run* and traditional training (identical in both content and dosage to the game intervention) or whether specific design-related differences reduced effectiveness. If feasible, we would encourage future studies to compare *Hit n Run* or another game-based inhibition training to both a traditional training control as well as the informative brochure control, so that the impact of design-related differences can be tested as well as effects of the game in comparison to a common practice intervention that does not train inhibition skills. Finally, the current study examined effects of *Hit n Run* in a target population of young adults who reported disinhibited eating, but who were not necessarily overweight. Despite moderately high scores on symptoms of food addiction, disinhibited eating, and restrained eating, associated with inhibitory deficits in previous studies (e.g., Nederkoorn, Van Eijs, & Jansen, 2004) our lack in results may be due to improper selection criteria. Indeed, our selection criteria were similar to Lawrence et al. (2015), yet Lawrence and colleagues included significantly more overweight and obese individuals (78.0% in Lawrence et al. versus 29.8% in the current study), and in contrast to the current study did find positive effects of inhibition training. It could therefore be argued that positive effects of inhibition training are limited to overweight populations and future studies may need to ensure to include participants who are both overweight and show inhibitory deficits.

Even though, multiple studies have demonstrated effects of inhibition training in a normative sample, including effects on caloric intake and picture evaluation (Chen et al., 2017; Houben & Jansen, 2011; Veling et al., 2008), we recommend that future studies examine effectiveness of inhibition training among individuals with a high BMI as they may benefit more from training. Moreover, if prevention of overweight is the aim, it may be valuable to target disinhibited eaters who have recently shown a weight gain, indicating that their lack of inhibition is putting them at immediate risk for becoming overweight. Furthermore, future studies could screen for deficiencies in food-specific inhibitory control using a Go/No-Go task.

Finally, though Bayesian inferential analyses (see supplementary materials) demonstrated that results overall corresponded with the reported null findings, support for a few null effects could be considered mere anecdotal. Thereby, alluding to limited statistical power and increased likelihood for false-negatives (type II erros; Munafò et al., 2017). To advance the field more well-powered studies are needed.

4.4. Conclusion

In conclusion, the current study revealed similar effects of *Hit n Run* and HESbS. Neither intervention improved inhibitory control accuracy and both reduced perceived attractiveness of calorie-dense food cues. Although the absence of an advantageous effect of *Hit n Run* may have resulted from limitations (e.g., discrepancies between *Hit n Run* and traditional Go/No-Go training), the current study provides multiple implications for successful design of future intervention games. Future studies will need to carefully investigate factors that promote effective inhibition training within video game formats for the motivational benefits of video game-based intervention remain promising. Moreover, further fundamental research is required to gain a more coherent understanding of psychological mechanisms underlying behavioral effects of inhibition training in order to facilitate the development of inhibition games.

Declarations

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Declaration of interest

Hit n Run has not been commercialized and there are no plans on doing so. Thus, there are no competing financial interests. The authors declare no conflicts of interest.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.appet.2018.06.039.

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