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Review

A meta-analysis of serious digital games for healthy lifestyle promotion

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ABSTRACT

Several systematic reviews have described health-promoting effects of serious games but so far no meta-analysis has been reported. This paper presents a meta-analysis of 54 serious digital game studies for healthy lifestyle promotion, in which we investigated the overall effectiveness of serious digital games on healthy lifestyle promotion outcomes and the role of theoretically and clinically important moderators. Findings showed that serious games have small positive effects on healthy lifestyles ($g = 0.252$, 95% CI 0.146; 0.358) and their determinants ($g = 0.334$, 95% CI 0.260; 0.407), especially for knowledge. Effects on clinical outcomes were significant, but much smaller ($g = 0.079$, 95% CI 0.038; 0.120). Long-term effects were maintained for all outcomes except for behavior. Serious games are best individually tailored to both socio-demographic and change need information, and benefit from a strong focus on game theories or a dual theoretical foundation in both behavioral prediction and game theories. They can be effective either as a stand-alone or multi-component programs, and appeal to populations regardless of age and gender. Given that effects of games remain heterogeneous, further explorations of which game features create larger effects are needed. Q16 Q17

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Introduction

Healthy lifestyles comprise an array of potentially modifiable behaviors that can prevent a wide range of diseases, such as some cancers, cardiovascular diseases, stroke, dementia, mental illness, and diabetes (Fratiglioni et al., 2004; Kim et al., 2012; Lopez et al., 2006; Peel et al., 2005). Healthy lifestyle adoption and maintenance, however, are often hindered by motivational issues, lack of time to participate in health promotion programs, and the interventions' low reach into the target group (Baert et al., 2011; McGuire et al., 2013; Toobert et al., 2002). Computer-delivered and computer-tailored interventions have been successfully designed to overcome these obstacles by tailoring to motivational stage, being accessible whenever the individual has time, and ensuring high availability at lower cost (Krebs et al., 2010; Portnoy et al., 2008).

Serious digital games are a type of computer-delivered intervention considered to be both educational and fun. Games differ from computer-delivered interventions by aspiring to be highly enjoyable, attention-captivating and intrinsically motivating (Graesser et al., 2009; Prensky, 2007). Serious games differ from mere entertainment games in their aim to educate or promote behavior change. In the context of health promotion programs, this may be achieved via the provision of health-related information, modeling of positive health behaviors, the creation of opportunities to practice healthy lifestyle skills (Kato, 2010), by changing mediators (e.g. self-regulatory skill development), and by applying change procedures Q18 (e.g. tailoring and goal-setting) (Thompson et al., 2010, 2012). Serious games may furthermore create sustained effects by being intrinsically motivating to play longer and repeatedly (Sitzmann, 2011; Wouters et al., 2013).

Serious games are theorized to derive their learning effects from at least three sources: 1) by creating immersion or transportation, a state in which the player becomes absorbed in the play without disbelief, while creating personally relevant experiences and deep affection for the characters; 2) by establishing flow, a state of high concentration in which the player experiences a balance between skills and challenge; and 3) by meeting the individuals' needs for mastery, autonomy, connectedness, arousal, diversion, fantasy, or challenge (Annetta, 2010; Boyle et al., 2012; Connolly et al., 2012; Kapp, 2012; Lu et al., 2012). Several narrative systematic reviews have described health-promoting effects of serious games. These included health games relating to diverse behaviors and populations, including games for treatment, prevention, and professional education (Rahmani and Boren, 2012). Reviews on healthy lifestyles mostly focused on a single health behavior (e.g. Guy et al, 2011, on obesity prevention) or focused on one specific age group (e.g. Guse et al, 2012, on sexual health among adolescents). An exception was the review of Baranowski et al. which included games for healthy diet, physical activity and illness self-management (Baranowski et al., 2008). All reviews noted large differences between studies, and concluded that reasons for these differences are as yet unclear (Baranowski et al., 2008; DeShazo et al., 2010; Gamberini et al., 2008; Guse et al., 2012; Guy et al., 2011; Kato, 2010; Kharrazi et al., 2012; Lu et al., 2012; Papastergiou, 2009; Primack et al., 2012; Rahmani and Boren, 2012; Wilkinson et al., 2008).

As yet, no meta-analysis of serious games for healthy lifestyle promotion has been reported. Meta-analysis overcomes the problem of small sample sizes in individual studies, which make it hard to determine a treatment's effectiveness. Furthermore, quantifying and comparing heterogeneity across studies by game characteristics permits tests of hypotheses reported in previous reviews (Borenstein et al., 2009). These insights may guide professionals in developing future evidence-based serious games (Ritterfeld et al., 2009).

This meta-analysis of the effectiveness of serious games for healthy lifestyle promotion addressed the following questions: 1) How effective are serious games in changing health behaviors, their determinants and clinical outcomes?; and 2) What is the influence of moderators, such as study characteristics, sample characteristics, theoretical basis, tailoring, and implementation method, on intervention effectiveness?

Methods

Search strategy and study selection

Inclusion and exclusion criteria

Healthy lifestyles were defined as the ability to adapt and self manage mental, social and physical health, in line with a recent conceptualization of health (Huber et al., 2011). Four categories of health behaviors were studied: 1) healthy diet and physical activity, 2) health responsibility/maintenance, 3) social behavior, and 4) mental health promotion. Healthy diet and physical activity/exercise were grouped because they frequently co-occurred in games for health promotion. Examples within this category were drinking water, eating vegetables, low sedentary behavior, and daily step counts. The second category, health responsibility/maintenance, was composed of both general preventive actions and self-management of disease and illness. Examples were good dental care, not smoking, participating in health screening, and asthma self-management. Category 3, social behavior, referred to maintaining positive interpersonal relationships. Examples were not bullying, seeking social support, establishing and maintaining friendships. The fourth category, mental health promotion, included reducing mental health risks, promoting well-being and self-actualization (e.g. personal growth, seeking happiness) and stress management. Examples were monitoring mood, using coping skills, and maintaining cognitive functioning for the elderly. These categories were based on the dimensions in the Health-Promoting Lifestyle Profile (Walker et al., 1987), and can be considered different, yet interrelated, healthy lifestyles. For example, physical activity behaviors may also have mental health promoting effects (Asztalos et al., 2009). Behaviors were thus coded in the category of the closest fit, although they may have also been related to other categories.

Although several commercial off-the-shelf games have been effective in obtaining health benefits (Peng et al., 2011), serious games designed specifically for health promotion provide additional benefits compared to these purely leisure games, for example by providing health-related information (Kato, 2010). We therefore only focused on games made specifically to promote health while also being fun. Exergames (requiring physical activity when played), for example, were only included when developed specifically with a health promotion purpose.

Studies evaluating effects on behavior or its determinants as the primary outcome were included, provided an intervention and control group were

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used. Finally, only studies reported in English were retained. Table 1 provides an overview of inclusion and exclusion criteria.

Search strategy

PubMed (°1966), Web of Science (°1926), CINAHL (°1937) and PsycINFO (°1887) databases were searched for publications since the start of the journal databases until the end of July 2013, with the keywords: ('games' or 'video games' or 'interactive multimedia') and health. Search results were complemented with hand-searching studies reported in the above-mentioned reviews, examining the table of contents of relevant specialized journals and databases (Computers in Human Behavior, Games for Health Journal, CyberPsychology, Behavior and Social Networking, Telemedicine and E-Health, Health Games Research database) and by requesting qualifying manuscripts from the local DiGRA (Digital Games Research Association) chapter. Authors were contacted for more information when data for coding or effect size calculation were lacking.

Coding frame

The coding frame is included in Appendix A.

Primary and secondary outcomes

The primary outcomes were behavior, knowledge, behavioral intentions, perceived barriers, skills, attitudes, subjective norm, and self-efficacy (Bartholomew et al., 2011). Whatever was mentioned by the authors as attitudes, skills, etc. was coded under these outcomes. As a secondary outcome, clinical effects (e.g. weight, depression score) were included, when applicable.

Study characteristics

The following research designs were coded: 1) Pre-test–post-test with control group (randomized on individual level); 2) pre-test–post-test with non-equivalent control group (randomized at group level); 3) post-test only control group design; and 4) non-equivalent post-test only control group design (Portney and Watkins, 2009).

While the pre-test–post-test with control group design offers the highest internal validity, in certain situations randomization at group level (pre-test–post-test with non-equivalent control group) is preferred when individual randomization within existing groups increases social threats to internal validity (i.e. when participants in the control group and intervention group are in contact with each other and may be aware of the other group's circumstances, e.g. in schools) (Portney and Watkins, 2009).

The quality of each study was evaluated using the Effective Public Health Practice Project (EPHPP) assessment tool for public health interventions (http://www.ephpp.ca/tools.html), included in Appendix A. Other study characteristics considered were intervention duration (period during which the game could be played), total actual play time, and time between the last game play and first measurement, or second measurement (if reported). Other indicators of dose–response (e.g. actual frequency of play) were unfortunately so infrequently reported that these could not be included in the coding scheme.

Individual tailoring

Individual tailoring was coded when the game content was adapted to individual user characteristics (e.g. age, gender, sexual preference, motivation). Individual tailoring was categorized as adapting to 1. socio-demographic characteristics, 2. change needs (e.g. risk factors) or stages of adoption (e.g. motivation, attitudes, current level of behavior), or 3. a combination of both. When no tailoring or only group tailoring (Portnoy et al., 2008) was used, this was coded as no individual tailoring.

Theoretical basis

Theories were categorized as behavioral prediction/change theories, game-based learning theories, clinical psychology approaches and theory-based methods, or none reported. Theories on determinants of both risk and healthful behavior and that specified methods to promote change in these determinants were coded as behavioral prediction or change theories (e.g. Health Belief Model, Social Cognitive Theory, Theory of Planned Behavior). Game-based learning theories included those enhancing player motivation, attention and retention of the message by manipulating game characteristics (e.g. Elaboration Likelihood Model, Transportation Theory). While many of these theories are not exclusively used or developed for game-based learning, they are commonly applied in game design to enhance the player's experience (Prensky, 2007). Clinical psychology approaches and theory-based methods which were used to understand the problem behavior, but not to provide levers to change the desired behavior were recorded as 'clinical psychology approaches/theory-based methods' (e.g. Cognitive Behavioral Therapy). Combinations of these theories were entered as such. If no theory was mentioned, this was coded as 'no theoretical foundation reported'.

Implementation method

For each study we recorded whether the game was evaluated as a stand-alone intervention, or as part of a broader multicomponent intervention.

Interrater reliability

Two coders (ADS, WVL) independently scored a random selection of one third of the games on all coding dimensions. Both coders had adequate research experience in behavioral science and serious games, and were well-trained in coding game and behavioral change theories and methods. Inter-rater reliability was good (ICC = 0.90). Quality of the studies using the EPHPP criteria was also independently coded by two coders sufficiently experienced in using this tool (ADS, SC), yielding excellent inter-rater reliability (ICC = 0.98).

Meta-analytic procedure

Random-effects Hedges' *g* was applied to indicate effect size, correcting for small sample sizes (Hedges, 1981). A negative Hedges' *g* or a positive Hedges'

Table 1
Inclusion and exclusion criteria.

Inclusion	Definition	Exclusion
Games	Organized play having a set of rules by which to play and a goal, which creates a challenge, provides feedback or shows outcomes, entails interaction and has a topic (Prensky, 2007).	Multimedia programs which are not games (e.g. watching video without any interaction)
Serious games	Made specifically to promote health while also being fun	Commercially available, games only developed for entertainment or leisure purposes (e.g. commercial exergames such as Wii)
Digital game	Includes all games using computer technologies as the delivery media (Mäyrä, 2008)	Games not played on digital media (e.g. board games)
For healthy lifestyle promotion	Health behaviors covered in this review were healthy diet, physical activity, social behavior, health responsibility, stress management and self-actualization, based on the Health-Promoting Lifestyle Profile (Walker et al., 1987). The study's primary outcome focused on healthy lifestyle behavior or one of its determinants.	Games which only target increased skill level, but no lifestyle change (e.g. athletic performance); which are only used in a therapeutic context, with no intent to create a lifestyle change (e.g. treatment support); which are used for professional education
Effect studies	Games evaluated for their effects and that allowed an effect size to be calculated for behavior or its determinants	Studies that only reported usability evaluations, player experiences or case studies; or which only reported effects on clinical outcomes but no healthy lifestyles
Research designs	The following research designs were included: 1) Pre-test–post-test with control group (randomized on individual level); 2) pre-test–post-test with non-equivalent control group (randomized at group level); 3) post-test only control group design; and 4) non-equivalent post-test only control group design (Portney and Watkins, 2009).	The following designs are excluded: 1) One group pre-test–post-test and 2) one group post-test only design.

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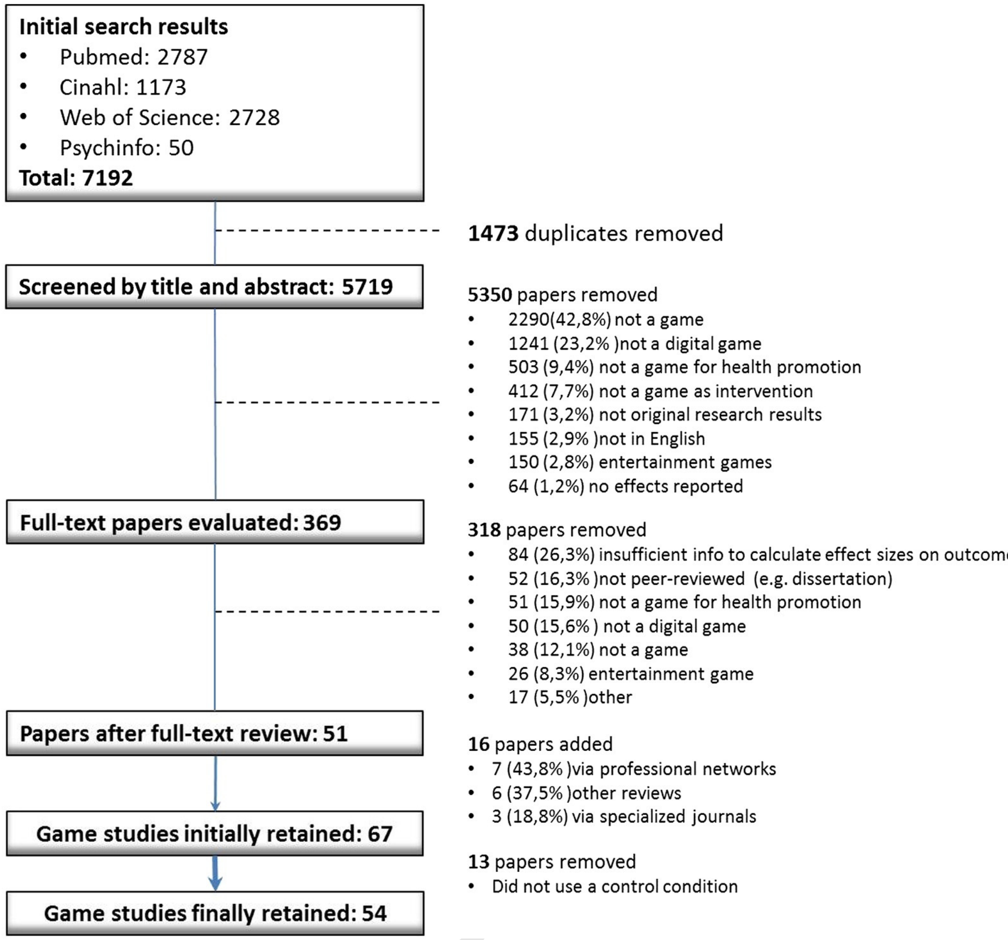

Fig. 1. Flow chart of the study selection process.

g indicated that the serious game respectively reduced or increased adoption of a healthy lifestyle or its determinant. In cases where the intervention targeted a reduction of unhealthy lifestyles, the computed sign of the effect size was reversed so all positive differences reflected an improvement in healthy lifestyles for the treatment group. Moderator analysis was conducted to explain differences in effect sizes. For all moderator analyses, a mixed-effects model was used and Cochran's *Q* test and I^2 (Higgings et al., 2003) were reported to investigate the degree of heterogeneity in effect sizes. Moderator analyses were only conducted when there were at least 3 studies per category. Meta-regression (methods-of-moments procedure) was performed for continuous moderators (Thompson and Higgins, 2002), where the slope (β) and its *p*-value indicated the importance of this moderator in understanding linear changes in effect sizes. To maintain the independence of the data, whenever necessary, effect sizes were averaged across different outcomes. Sensitivity analyses were performed for possible outliers (threshold ± 3SD), for pre-test–post-test correlations set lower (0.20) and higher (0.80) than the standard assumption of 0.50, and for publication bias via a funnel plot and related statistics. All analyses were performed with Comprehensive Meta-Analysis software, version 2.2.050 (Biostat Inc., Englewood, NJ, USA). Effect sizes of ≥0.80 were considered large, ≥0.50 were considered moderate and ≥0.20 were small effects (Cohen, 1988). More information on methods is provided in Appendix A.

Results

The database search yielded 7192 hits, from which 1473 duplicates were removed. Next, 5719 articles were deleted after reading the abstract and title. After reading the full texts, fifty-one games were retained. Sixteen studies were added from other sources, such as a search in specialized journals mentioned above and requests via professional networks, such as the Digital Games Research Association. This resulted in a total of 67 studies. Thirteen studies were removed because they did not include a control condition, resulting in 54 included papers (Fig. 1).

Study and sample characteristics

In the 54 papers, 52 games were assessed in 62 different game evaluations (using independent samples or different study characteristics). A detailed description of these games is shown in Appendix B. Sixty game evaluations involved a first measurement after the intervention (later referred to as ‘first post-test’), fourteen evaluations included a longer follow-up measurement as after this first measurement (later referred to as ‘follow-up test’) and two evaluations only reported the follow-up measurement. Most studies were published in 2010 or later (43.5%), situated in North America (69.4%), or evaluated games for children (61.7%).

Average play duration was 3.9 h over the full duration of the intervention. First measurement on average took place 18.1 days after the intervention. The majority of first effect measurements were conducted on the same day as the intervention. Nearly half of the studies were of strong quality, using a representative sample of the population, reliable and valid measures, adjusting for confounders and reporting low drop-out (Table 2). Moderate designs (one weak scoring) and weak designs (more than one weak scoring) mainly struggled with external validity issues in having high drop-outs at post-intervention measurement (12

Table 2
Study attributes.

Characteristic	*k* studies	%
Publication year		
<2000	6	9.7
2000–2004	15	24.2
2005–2009	14	22.6
2010–2013	27	43.5
Region		
North America (U.S., Canada, Mexico)	43	69.4
Europe	17	27.4
Asia Pacific (incl. Australia, New Zealand)	2	3.2
Africa	0	0
South America	0	0
Study characteristics		
First post-intervention measurement studies	60	
Effects measured on same day (1st post)[a]	30	69.8
Second post-intervention measurement studies	16	
Effects measured on same day (2nd post)	1	10.0
Weak study quality (EPHPP scoring)	10	16.7
Moderate study quality (EPHPP scoring)	21	35.0
Strong study quality (EPHPP scoring)	29	48.3
Sample characteristics[b]		
Targeting children (age ≤ 12 y)	37	61.7
Targeting adolescents (age 13–18 y)	26	43.3
Targeting adults (age 19–65 y)	19	31.7
Targeting elderly (over 65 y)	1	1.6
	M	SD
% female (range 0–100)	52.5	23.2
Age in years (range 5.2–66.3)	16.4	11.8
Days until 1st measurement (range 0–270)	18.1	48.0
Days until 2nd measurement (range 0–186)	82.9	65.5
Average play duration in hours (range 0.08–21.6)	3.9	6.8
Duration of full intervention in days (range 1–365)	51.4	88.0

[a] Information only available for 43 studies at first post-measurement and 10 at second post measurement.
[b] >100% as some games targeted more than one age group.

games, 24.5%) and using a sample not assumed highly representative of the population (10 games, 20.4%).

The majority of games targeted health responsibility/maintenance behavior (29 game evaluations) or healthy diet and physical activity (23 game evaluations). Six were aimed at improving social behavior, while only two were designed to promote mental health. In 37 evaluations, games were studied as stand-alone intervention, whereas 23 were evaluated as part of a multicomponent program.

Effectiveness of games in changing healthy lifestyles

First post-test

For one study (Jantz et al., 2002) the effect size of one outcome exceeded the outlier threshold; this outcome was hence removed from the analyses. All other studies and outcomes were retained.

The average effect size for behavior was positive, but small ($g = 0.252$ (95% CI 0.146; 0.358), $n = 316279$, $k = 22$) (Fig. 2), indicating an improvement in healthy lifestyle after playing the serious games. For behavioral determinants, average effect size was similarly small ($g = 0.334$ (95% CI 0.260; 0.407), $n = 19934$, $k = 50$) (Fig. 3), whereas the average effect size on clinical outcomes was very small, but significant ($g = 0.079$ (95% CI 0.039; 0.120), $n = 9367$, $k = 10$) (Fig. 4).

There was high heterogeneity between games' effects for behavior and behavioral determinants, both at first post-test and at follow-up test, but not for clinical outcomes. There were no significant differences in average effect size on behavior nor on its determinants or clinical outcome by health domain. No significant heterogeneity was observed between games' effects in different health domains.

A sensitivity analysis was conducted for lower (r = 0.20) and higher (r = 0.80) pre-test–post-test correlation values, during which effect sizes largely remained within the 95th percent confidence interval. Since one study had an extremely large sample size, analyses were also run without this study. As for the other sensitivity analyses,

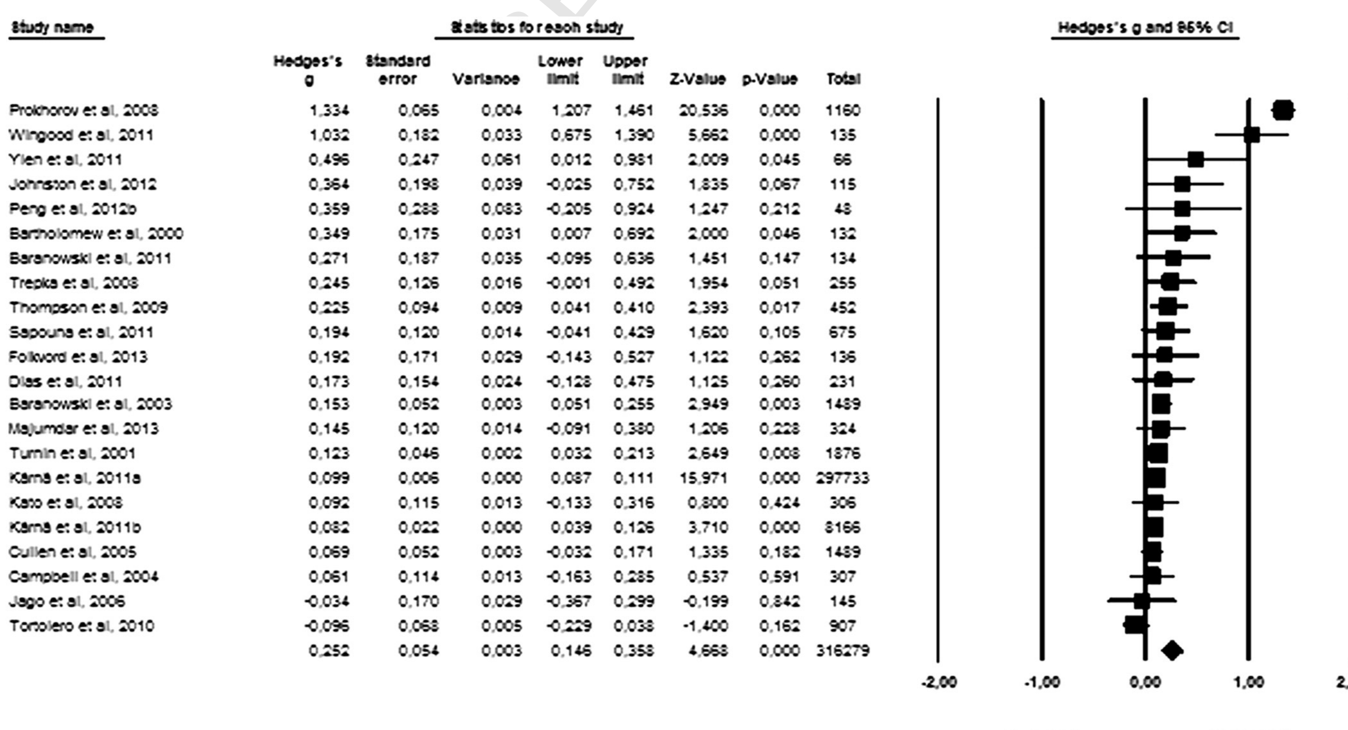

Fig. 2. Forest plot of effect sizes on behavior sorted by size.

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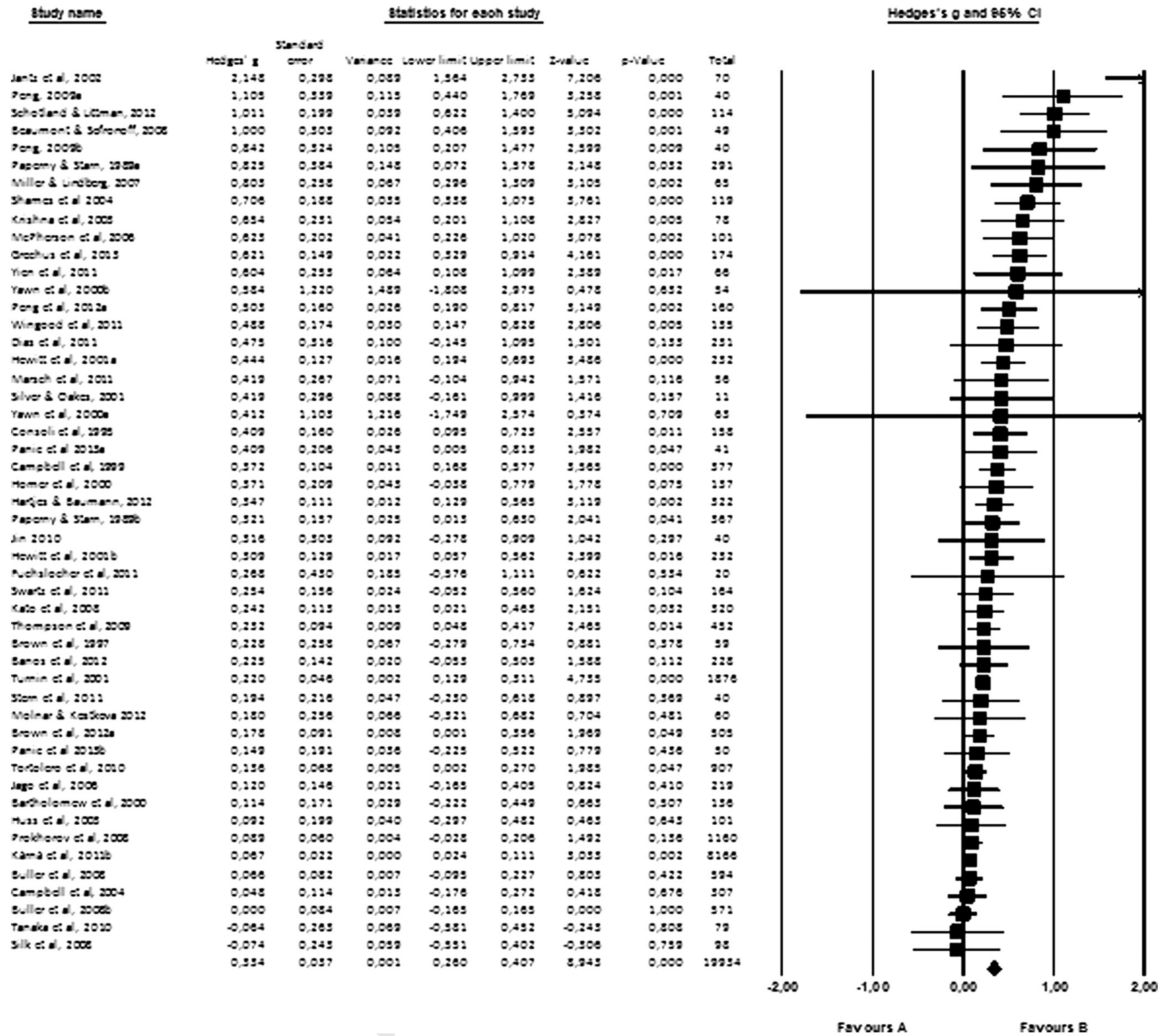

Fig. 3. Forest plot of effect sizes on behavioral determinants sorted by size.

effect size here remained within the 95th percent confidence interval (Table 3).

Funnel plot and Egger's Test (t(48) = 6.042, $p < .001$) indicated that Q26 publication bias could not be ruled out for effects on behavioral determinants with a tendency for smaller published studies to report higher effect sizes. Using Duval's and Tweedie's Trim and Fill approach to impute missing studies to the left of the mean, adjusted average g for behavioral determinants was reduced to $g = 0.179$ (95% CI 0.104; 0.254) but remained significant. For effects on behavior (t(20) = 1.545, $p = 0.06$) and on clinical outcomes (t(8) = 0.762, $p = 0.233$), Egger's Test on publication bias was not significant.

Second post-test

Average effect size for behavior at second post-test measurement was smaller than at first post-intervention measurement and failed to reach significance ($p = .07$). For behavioral determinants and clinical outcomes, average effect size at second post-test measurement was significant and of similar magnitude as at first post-measurement (Table 3).

Influence of study, sample and game characteristics as moderators of game effectiveness

Outcome of interest

Among specific behavioral determinants, the largest effects were found for improvement in knowledge and attitudes; however, all effect sizes were small. Average effect size for subjective norms was non-significant (measured in only one study) (Table 4).

At second post-test, average effect size remained highest for knowledge and approximated a moderate effect size, but average effects were smaller for other behavioral determinants compared to first post-measurement (with the exception of subjective norms, measured in only one study) (Table 4).

Individual tailoring

Individual tailoring was only a significant moderator for the effects on behavioral determinants, but not for behavior or clinical outcomes (Tables 5–7). For behavioral determinants, games tailored only by change needs or stages of adoption had a lower effect size than games

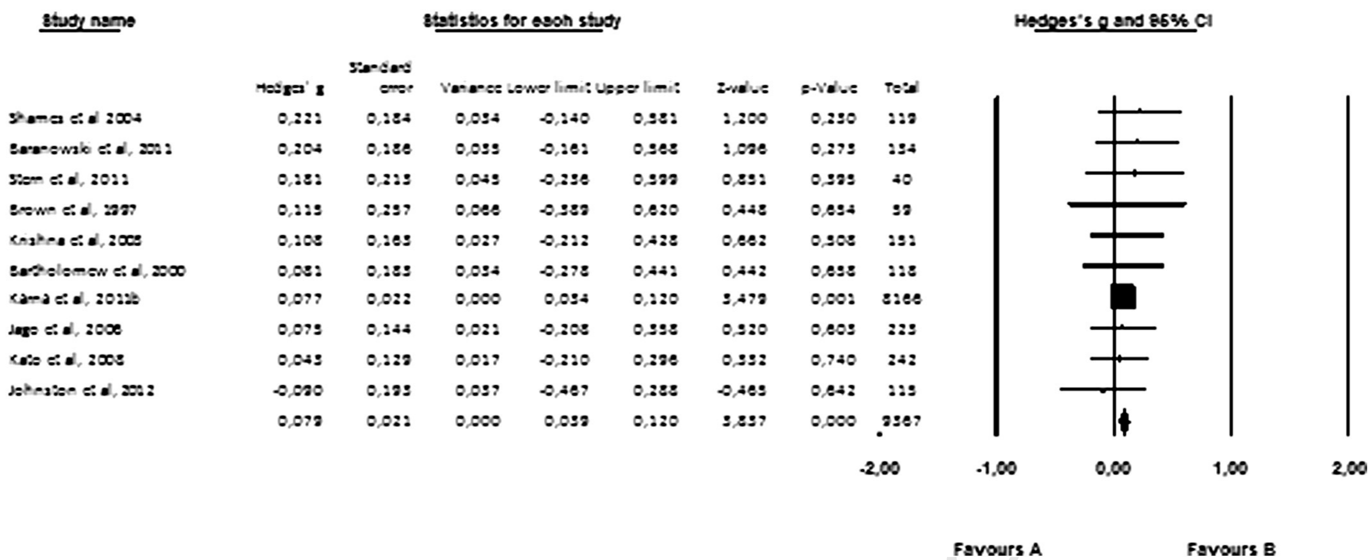

Fig. 4. Forest plot of effect sizes on clinical outcomes sorted by size.

which were not tailored or tailored to both socio-demographics and change needs. Since games tailored only by socio-demographic information were not included in moderator analyses ($k < 3$), it is unclear whether these games would have a significantly higher effect than those tailored only by stages of adoption or change needs (Table 6).

Theoretical basis

The type of theoretical foundation significantly affected effectiveness for behavioral determinants, but not for behavior or clinical outcomes (Tables 5–7). Games based purely on behavioral prediction theories had the lowest average effect size. Their effects were however still significant (Table 6).

Table 3
Average effect sizes for behavior, determinants and clinical outcomes.

Outcome	*n*	*k*	Hedges' *g* (95% CI)	*p*	Q	*p*	I^2 index
Behavior							
Mean effect size 1st measurement	316279	22	0.252 [0.146; 0.358]	<.001	408.07	<.001	95%
Without Kärnä et al. (2011a) (large sample)	18547	21	0.269 [0.115; 0.423]	<.01	387.34	<.001	95%
–At r = 0.20	316279	22	0.232 [0.127; 0.337]	<.001	400.03	<.001	95%
–At r = 0.80	316279	22	0.305 [0.195; 0.415]	<.001	443.05	<.001	95%
Health domain	316279	22			*4.11*	*0.128*	
Health responsibility/maintenance	2640	5	0.541 [−0.164; 1.246]	.133	258.86	<.001	98%
Diet & physical activity	7067	14	0.138 [0.091; 0.185]	<.001	9.67	0.720	0%
Social behavior	306573	3	0.098 [0.086; 0.109]	<.001	1.16	0.559	0%
Mental health	0	0	NA		NA		
Mean effect size 2nd measurement							
Behavior	11565	10	0.110 [−0.009; 0.228]	0.070	36.29	<.001	75%
Behavioral determinants							
Mean effect size 1st measurement	19934	50	0.334 [0.260; 0.407]	<.001	183.24	<.001	73%
–At r = 0.20	19934	50	0.300 [0.231; 0.369]	<.001	159.78	<.001	69%
–At r = 0.80	19934	50	0.416 [0.331; 0.501]	<.001	258.11	<.001	81%
Health domain	19854	48			*2.98*	*0.226*	
Health responsibility/maintenance	7147	29	0.294 [0.211; 0.377]	<.001	61.59	<.001	55%
Diet & physical activity	4184	14	0.460 [0.290; 0.630]	<.001	71.64	<.001	80%
Social behavior	8305	4	0.298 [−0.097; 0.694]	0.139	11.08	<.05	73%
Mental health	80	2	0.235 [−0.110; 0.580]	0.182	0.11	0.744	0%
Mean effect size 2nd measurement							
Behavioral determinants	10919	12	0.262 [0.139; 0.384]	<.001	40.50	<.001	73%
Clinical outcomes							
Mean effect size 1st measurement	9367	10	0. 079 [0.039; 0.120]	<.001	2.18	0.988	0%
–At r = 0.20	9367	10	0.063 [0.023; 0.104]	<.01	1.62	0.996	0%
–At r = 0.80	9367	10	0.123 [0.083; 0.164]	<.001	4.14	0.902	0%
Health domain	1161	9			*0.07*	*0.793*	
Health responsibility/maintenance	689	5	0.101 [−0.049; 0.250]	0.187	0.64	0.958	0%
Diet & physical activity	249	3	0.068 [−0.124; 0.260]	0.487	1.21	0.547	0%
Social behavior	8166	1	0.077 [0.034; 0.120]	<.01	NA		
Mental health	40	1	0.181 [−0.236; 0.599]	0.395	NA		
Mean effect size 2nd measurement							
Clinical outcomes	8928	7	0.101 [0.060; 0.143]	<.001	0.80	0.997	0%

n = combined sample size; k = number of studies; Hedges' g (random effects); CI = confidence interval; Q = homogeneity statistic (mixed effects); I^2 = inconsistency, a second measure of heterogeneity; NA: not applicable.

Table 4
Average effect sizes for behavioral determinants.

Mean effect size 1st measurement	19934	50	0. 334 [0.260; 0.407]	<.001	183.24	<.001	73%
Knowledge	8221	32	0.407 [0.311; 0.504]	<.001	100.77	<.001	69%
Attitudes	10023	8	0.386 [0.159; 0.614]	<.01	61.10	<.001	89%
Self-efficacy	13120	20	0.212 [0.091; 0.333]	<.01	113.91	<.001	83%
Skills	9561	7	0.352 [0.075; 0.628]	<.05	65.05	<.001	91%
Subjective norms	907	1	−0.086 [−0.220; 0.048]	0.207	NA		
Perceived barriers	452	1	0.198 [0.014; 0.383]	<.05	NA		
Behavioral intentions	1497	6	0.308 [0.072; 0.545]	<.05	15.60	<.01	68%
Mean effect size 2nd measurement	10919	12	0.262 [0.139; 0.384]	<.001	40.50	<.001	73%
Knowledge	2075	8	0.464 [0.289; 0.639]	<.001	20.38	<.01	66%
Attitudes	9237	3	0.070 [0.029; 0.111]	<.01	1.06	0.590	0%
Self-efficacy	10580	8	0.101 [0.044; 0.159]	<.01	8.07	0.327	13%
Skills	8206	2	0.050 [0.006; 0.093]	<.05	0.19	0.663	0%
Subjective norms	907	1	0.186 [0.052; 0.320]	<.01	NA		
Perceived barriers	442	1	−0.002 [−0.188; 0.184]	0.986	NA		
Behavioral intentions	1071	2	0.129 [0.006; 0.251]	<.05	0.42	0.520	0%

n = combined sample size; k = number of studies; Hedges' g (random effects); CI = confidence Interval; Q = homogeneity statistic (mixed effects); I^2 = inconsistency, a second measure of heterogeneity; NA: not applicable.

Implementation method

Implementation method was not a significant moderator of game effectiveness for either behavior, determinants or clinical outcomes (Tables 5–7). Both forms of implementation had significant average effect sizes for behavioral determinants and clinical outcomes. Average effects on behavior of stand-alone games however showed only a trend to significance.

Sample characteristics

Neither the average age of participants nor the percentage of women in the sample was a significant moderator on game effectiveness on behavior, determinants or clinical outcomes (note: only one game for the elderly was included) (Table 8).

Study characteristics

The quality of the study did not significantly affect the effectiveness for behavior, determinants or clinical outcomes (Tables 5–7). For behavior, games evaluated in a post-test only control group design had a lower average effect size than games evaluated in other study designs (Table 5).

The elapsed time between the last time the game was played and when the outcome was measured, was a significant moderator in the games' effects, but only for behavior. More specifically, the greater the amount of time between the last game play and first post-test for behavior, the larger the effect size (Table 8).

This was, however, the opposite at second post-test: here the greater the time elapsed until post-test measurement, the smaller the effect size for behavior, suggesting a curvilinear relation, in which a minimal time is needed to practice the behavior at first post-test to have effects, but where a longer follow-up time showed smaller effects on behavior. This inverse relation between time and effect was also true for behavioral determinants (Table 8). None of the other study characteristics were significant moderators in the average effects on behavior, determinants or clinical outcomes.

Table 5
Moderator analyses on behavior (first post-test).

Moderator	n	k	Hedges' g (95% CI)	p	Q	p	I^2 index
EPHPP study quality	314403	21			*0.02*	*0.890*	
Weak	1876	1	0.123 [0.032; 0.213]	<.01	NA		
Moderate	1245	5	0.267 [0.129; 0.404]	<.001	1.50	0.827	0%
Strong	316279	16	0.253 [0.123; 0.383]	<.001	401.41	<.001	96%
Study design	314403	21			*6.13*	*<.05*	
Non-equivalent post-test only	1876	1	0.123 [0.032; 0.213]	<.01	NA		
Non-equivalent pre-test–post-test control group	14872	10	0.255 [0.001; 0.510]	.050	359.49	<.001	97%
Post-test only control group	298100	3	0.099 [0.087; 0.111]	<.001	0.53	0.767	0.000
Pre-test–post-test control group	1432	8	0.325 [0.121; 0.529]	<.01	23.79	<.01	71%
Tailoring	8684	17			*0.35*	*0.552*	
No tailoring	3925	10	0.234 [0.101; 0.368]	<.01	27.79	<.01	68%
Tailoring by socio-demo	675	1	0.194 [−0.041; 0.429]	0.105	NA		
Tailoring by stages/needs	4759	7	0.374 [−0.066; 0.813]	0.095	278.92	<.001	98%
Tailoring by socio-demo & stages/needs	907	1	−0.096 [−0.229; 0.038]	0.162	NA		
Theoretical foundation	315539	20			*2.85*	*0.240*	
None mentioned	2243	3	0.131 [0.047; 0.215]	<.01	0.23	0.890	0%
Only behavioral prediction theory	308852	7	0.270 [0.061; 0.480]	<.05	370.17	<.001	98%
Only game theory	66	1	0.496 [0.012; 0.981]	<.05	NA		
Game and clinical psychology approaches/theory-based methods	675	1	0.194 [−0.041; 0.429]	0.105	NA		
Both behavioral and game theory	4444	10	0.244 [0.109; 0.378]	<.001	31.17	<.001	71%
Implementation method	316279	22			*1.25*	*0.263*	
Stand-alone	5517	12	0.307 [−0.004; 0.618]	0.053	271.61	<.001	96%
Multi-component	310762	10	0.126 [0.059; 0.193]	<.001	42.55	<.001	79%

n = combined sample size; k = number of studies; Hedges' g (random effects); CI = confidence interval; Q = homogeneity statistic (mixed effects); I^2 = inconsistency, a second measure of heterogeneity; NA: not applicable.

Table 6
Moderator analyses on behavioral determinants.

Moderator	*n*	*k*	Hedges' *g* (95% CI)	*p*	Q	*p*	I^2 index
EPHPP study quality	19934	50			*0.24*	*0.886*	
Weak	3172	10	0.317 [0.192; 0.442]	<.001	13.61	0.137	34%
Moderate	3750	17	0.357 [0.223; 0.490]	<.001	50.04	<.001	68%
Strong	13012	23	0.317 [0.206; 0.429]	<.001	97.66	<.001	77%
Study design	18058	49			*3.30*	*0.192*	
Non-equivalent post-test only	1876	1	0.220 [0.129; 0.311]	<.001	NA		
Non-equivalent pre-test–post-test control group	13952	17	0.278 [0.161; 0.395]	<.001	83.87	<.001	81%
Post-test only control group	440	5	0.223 [0.009; 0.438]	<.05	3.11	0.540	0%
Pre-test–post-test control group	3666	27	0.391 [0.297; 0.485]	<.001	47.96	<.01	46%
Tailoring	11654	48			*11.79*	*<.01*	
No tailoring	7228	36	0.381 [0.293; 0.468]	<.001	81.03	<.001	57%
Tailoring by socio-demo	114	1	1.011 [0.622; 1.400]	<.001	NA		
Tailoring by stages/needs	3440	9	0.146 [0.037; 0.255]	<.01	16.47	<.05	15%
Tailoring by socio-demo & stages/needs	987	3	0.634 [−0.042; 1.310]	0.066	11.92	<.01	83%
Theoretical foundation	19934	50			*17.73*	*<.01*	
None mentioned	3150	10	0.403 [0.272; 0.534]	<.001	14.53	0.105	38%
Clinical psychology approaches/theory-based methods	168	3	0.354 [−0.214; 0.921]	0.222	7.49	<.05	73%
Only behavioral prediction theory	12691	12	0.149 [0.068; 0.230]	<.001	26.45	<.01	58%
Only game theory	1112	9	0.432 [0.193; 0.671]	<.001	16.12	<.05	50%
Both behavioral and game theory	2813	16	0.417 [0.260; 0.574]	<.001	58.54	<.001	74%
Implementation method	19934	50			*1.06*	*0303*	
Stand-alone	7444	31	0.371 [0.263; 0.480]	<.001	106.04	<.001	72%
Multi-component	12491	19	0.293 [0.192; 0.395]	<.001	62.17	<.001	71%

n = combined sample size; *k* = number of studies; Hedges' *g* (random effects); CI = confidence interval; Q = homogeneity statistic (mixed effects); I^2 = inconsistency, a second measure of heterogeneity; NA: not applicable.

Discussion

This was the first article to conduct a meta-analysis of serious games for healthy lifestyle promotion. Overall, serious games increased healthy lifestyle adoption ($g = 0.252$, 95% CI 0.146; 0.358) and improved antecedents that determine adoption ($g = 0.334$, 95% CI 0.260; 0.407), and this applied across the several included health domains.

Overall, effect sizes were small. The effect sizes on behavior were however in line with findings of two meta-analyses on computer-delivered interventions (range between 0.13 and 0.22 (Krebs et al., 2010); and range between 0.04 and 0.35 (Portnoy et al., 2008)). Hence, serious games for the promotion of healthy lifestyles may be considered as effective as other computer-delivered interventions. The
Q27 effects on clinical outcomes ($g = 0.08$ at first measurement and $g = 0.10$ at second measurement in our meta-analysis) were also comparable to the available literature (d = 0.10 in Portnoy et al., 2008). Health professionals and policy makers may therefore consider serious games as an alternative to other computer-delivered interventions. Further insights on time-efficiency and cost-effectiveness of these methods for health promotion may also be needed to inform this choice. This information is, to our knowledge, not yet available for healthy lifestyle promotion. An educational game showed that, possibly, more time may be needed to create learning effects via game-based learning than with traditional methods (Huizenga et al., 2009). Players of educational games, however, also appeared to be willing to spend more learning time on games than on learning via traditional methods, provided that Q28
the challenge in the game was feasible (Bourgonjon et al., 2010; Squire, 2005).

Table 7
Moderator analyses on clinical outcomes.

Moderator	*n*	*k*	Hedges' *g* (95% CI)	*p*	Q	*p*	I^2 Index
EPHPP study quality	9367	10			*0.07*	*0.794*	
Weak	0	0	NA				
Moderate	499	5	0.102 [−0.070; 0.273]	0.246	1.43	0.838	0%
Strong	8868	5	0.078 [0.036; 0.120]	<.001	0.68	0.954	0%
Study design	9367	10			*NA*		
Non-equivalent pre-test–post-test control group	8389	2	0.077 [0.034; 0.120]	<.001	0.00	0.989	0%
Pre-test–post-test control group	978	8	0.099 [−0.025; 0.223]	0.117	2.07	0.956	0%
Tailoring	1086	8			*NA*		
No tailoring	834	6	0.106 [−0.029; 0.241]	0.123	0.80	0.977	0%
Tailoring by socio-demo	0	0	NA				
Tailoring by stages/needs	252	2	0.142 [−0.114; 0.398]	0.278	0.22	0.639	0%
Tailoring by socio-demo & stages/needs	0	0	NA				
Theoretical foundation	9367	10			*NA*		
None mentioned	119	1	0.221 [−0.140; 0.581]	0.230	NA		
Clinical psychology approaches/theory-based methods	40	1	0.181 [−0.236; 0.599]	0.395	NA		
Only behavioral prediction theory	8317	2	0.078 [0.035; 0.121]	<.001	0.04	0.851	0%
Only game theory	0	0	NA				
Both behavioral and game theory	891	6	0.066 [−0.070; 0.202]	0.339	1.28	0.937	0%
Implementation method	9367	10			*0.15*	*0.700*	
Stand-alone	475	4	0.113 [−0.062; 0.287]	0.206	0.64	0.888	0%
Multi-component	8892	6	0.077 [0.036; 0.119]	<.001	1.40	0.925	0%

n = combined sample size; *k* = number of studies; Hedges' *g* (random effects); CI = confidence interval; Q = homogeneity statistic (mixed effects); I^2 = inconsistency, a second measure of heterogeneity; NA: not applicable.

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Table 8
Meta-regression analyses.

Moderators	*n*	*k*	β (95% CI)	*p*
Behavior				
Time until 1st measurement	7792	15	0.005 [0.002; 0.008]	<.01
Duration of intervention	8045	16	0.001 [−0.001; 0.002]	0.324
Time until follow-up	2492	8	−0.003 [−0.006; −0.001]	<.01
Publication year	316279	22	0.009 [−0.022; 0.039]	0.573
Mean age	316279	22	0.013 [−0.004; 0.030]	0.124
% female	315119	21	0.001 [−0.001; 0.004]	0.247
Play duration (h)	7734	14	−0.005 [−0.033; 0.023]	0.709
Determinants				
Time until 1st measurement	7668	35	−0.001 [−0.003; 0.001]	0.539
Duration of intervention	9005	44	−0.001 [−0.002; 0.000]	0.156
Time until follow-up	1391	6	−0.002 [−0.004; −0.000]	<.05
Publication year	19934	50	−0.005 [−0.018; 0.008]	0.468
Mean age	19667	46	−0.001 [−0.007; 0.005]	0.823
% female	18199	44	0.002 [−0.001; 0.005]	0.231
Play duration (h)	7975	39	−0.011 [−0.026; 0.005]	0.165
Clinical outcomes				
Time until 1st measurement	754	5	−0.002 [−0.013; 0.008]	0.647
Duration of intervention	1067	8	0.000 [−0.002; 0.002]	0.830
Time until follow-up	433	4	−0.000 [−0.004; 0.003]	0.878
Publication year	9367	10	−0.004 [−0.022; 0.015]	0.686
Mean age	9157	8	0.001 [−0.006; 0.008]	0.795
% female	9367	10	0.001 [−0.004; 0.006]	0.767
Play duration (h)	741	6	0.004 [−0.011; 0.012]	0.593

β = regression point estimate; *n* = combined sample size; *k* = number of studies.

Furthermore, strategies recommended to overcome low reach and adoption of computer-tailored interventions, such as higher interactivity and visual attractiveness (Crutzen et al., 2008, 2011), are inherent in serious games. Coupled with their intrinsically motivating fun aspect (Ritterfeld et al., 2009), serious games may prove a better medium than other computer-delivered interventions to reach the target audience in a large scale implementation. This hypothesis, however, awaits further corroboration.

Our meta-analysis revealed a large heterogeneity between studies, which warrants the investigation of putative moderators. We were able to identify some moderators.

First, effect sizes varied as a function of type of outcome. The effects were largest on knowledge, which approximated a moderate effect size at follow-up. This is consistent with findings from general health promotion and computer-delivered interventions, that knowledge is easier to influence than other outcomes (Portnoy et al., 2008). Regrettably, this is often not the most relevant determinant since the causal relationship between knowledge and behavior change is weak (Bartholomew et al., 2011). The effect on the intention to change health behavior, which is often a strong predictor of behavior, is more promising. Unfortunately, the effect on behavioral intention at follow-up measurement was substantially reduced, as was the case for self-efficacy, which is another determinant with a strong association with behavior change (Bartholomew et al., 2011). Games are thought to provide a good medium for increasing self-efficacy as they offer the opportunity for enactive experience in a safe environment, without real-life consequences to making wrong decisions (Peng, 2008; Prensky, 2007). In our review, effects on self-efficacy were unexpectedly small. A review of computer-tailored interventions also reported limited effects on self-efficacy (Lustria et al., 2009). Possibly, self-efficacy may have been unrealistically high at the start of the intervention, known as optimistic bias. This may have been corrected when more information and experience became available (Schwarzer, 1998).

For computer-tailored interventions, the use of self-regulation theories has been recommended to improve effectiveness (Lustria et al., 2009). The few ($n = 5$, $k = 1071$) game evaluations in our review using these theories and measuring self-efficacy outcomes nevertheless did not show significantly higher effects than games without this theoretical foundation ($Q = 0.711$, $p = 0.399$).

Although effects at follow-up measurement were significant and positive for most outcomes, they were smaller than at the immediate post-measurement, and failed to reach significance for behavior. Methods used in non-game healthy lifestyle interventions to maintain a long-term effect on behavior were providing reinforcement throughout follow-up, having booster sessions, sending tailored reminders, using self-regulation and anticipatory coping techniques to deal with potential relapse, integrating Motivational Interviewing techniques and creating healthy-behavior-facilitating changes in the environment via multi-level programs (Jacobs et al., 2004; Lustria et al., 2009; Martins and McNeil, 2009; Norris et al., 2001; Orleans, 2000).

Second, individual tailoring related significantly to the games' effects on determinants, but not on behavior or clinical outcome. It appeared insufficient to tailor games only to behavioral change needs, instead games are best tailored by both socio-demographic information (e.g. age, gender, body frame) and behavioral change needs (e.g. current level of lifestyle adoption, already acquired knowledge, stages of change, or motivation). Similarly, in computer-tailored interventions, tailoring showed the strongest effects when based on both theoretical concepts (e.g. stages of change, decisional balance, attitudes) and user characteristics (Noar et al., 2007) and performed via dynamic tailoring, in which tailoring is continuously adjusted during the intervention (Krebs et al., 2010). For games, dynamic tailoring has been recommended based on the difficulty level the player can master (e.g. via providing hints when the challenge is too hard), to ensure flow and to provide all players with an optimal level of challenge (Charles et al., 2005; Wilson et al., 2009). In games, not only the educational content but also game rules and environment need to be learned by players. Games with highly immersive features designed to increase game enjoyment were found to increase cognitive load and decrease the performance on the educational task: players were focusing on mastering the game requirements, which competed with the cognitive resources available to grasp the educational content (Schrader and Bastiaens, 2012). It may thus be advisable to tailor the game also to the player's prior gaming experience and adjust this continuously based on their game play proficiency. Only two games in our review used dynamic tailoring. Further experimental research is needed to clarify the benefits of dynamic tailoring in serious games for health promotion.

Third, as hypothesized, the theories used for game development are a significant element in the serious game's effectiveness, but only on behavioral determinants and not on behavior or clinical outcomes. A strong focus on game-based learning theories (e.g. Transportation Theory) alone or combined with behavioral prediction theories (e.g. Social Cognitive Theory) related to higher game effectiveness than games founded only on behavioral prediction theories. This finding supports hypotheses from previous articles suggesting that a good theoretical blending of the ‘fun’ and ‘educational’ element is critical in game effectiveness (Baranowski et al., 2011a,b; Deshazo et al., 2010; Kato, 2012; Kharrazi et al., 2012; Papastergiou, 2009). While serious games share some characteristics with computer-tailored programs, the importance of game-based learning theories underlines the specificity of serious games as an intervention mode. Merely using behavioral prediction theories was associated with the smallest effects in our meta-analysis, whereas reviews on computer-tailored interventions have reported moderate effects for programs only based on behavioral prediction theories (Webb et al., 2010). Often game studies briefly mentioned which theoretical foundation was used, but not how theoretical techniques were applied to address the target outcome. Interpretation and application of theories may therefore have been different across game studies. Other studies have indeed reported that the terminology of theories is not used in a consistent manner across interventions and that one term may be used to represent different techniques, as well as that different labels may be used for the same technique (Michie et al., 2011a). More detailed process descriptions on how theory guided change in specific target outcomes, e.g. using the Intervention Mapping

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Protocol (Bartholomew et al., 2011) or the Behavior Change Wheel (Michie et al., 2011b), are needed.

Some moderators did not explain heterogeneity in the games' effects. The duration of the full intervention did not relate to a different effectiveness, in contrast with the finding of Primack et al. (2012). They reported that interventions lasting fewer than 12 weeks more often achieved their objectives than interventions lasting longer. This result was mostly influenced by the solidly positive effects of one-time interventions (Primack et al., 2012). Since they did not assess the time between the intervention and measurement, length of intervention and time between intervention and measurement may be confounded here, as effects of one-time interventions were likely to be measured immediately afterwards. These were coded separately in our meta-analyses, singling out the effect of intervention duration versus duration until measurement. While this seems counter-intuitive, a meta-analysis on computer-delivered interventions for health promotion also revealed that the dose of the intervention (ranging from 1 h for stand-alone interventions to 4–8 h per component in multi-component programs) did not significantly relate to the average intervention effect (Portnoy et al., 2008).

Similarly, game play duration was, contrary to expectations, not significantly related to effectiveness. Game duration in general was low, with a total average of 4 h, while leisure games are played 7 h per week on average (Boyle et al., 2012). Insufficient playing time was previously mentioned as a potential reason for the lack of effectiveness (Rahmani and Boren, 2012), but this was not supported by our findings. Possibly a floor effect was at play here.

Both games evaluated as part of a multi-component program and as stand-alone games were effective, although the effects on behavior of stand-alone games were only borderline significant ($p = 0.053$), despite a higher average effect size than games that were part of multi-component programs. Effect sizes of stand-alone games showed significant heterogeneity. Many other game characteristics (e.g. use of a narrative, challenge in the game, co-design, scaffolding levels) (Kapp, 2012; Lu et al., 2012) may influence game effectiveness and may be applied differently in stand-alone or multi-component games. Future investigations into these game features are needed to further explore the high heterogeneity within stand-alone and multi-component games.

Differences in effect size were also not found for mean age or gender, confirming earlier findings that serious games can work in various populations (Primack et al., 2012), when their preferences are taken into account (Brox et al., 2011).

Future studies should aim to strengthen the evidence base for interventions with a dual theoretical foundation in game and behavioral prediction theories, clearly describing theoretical frameworks allowing to discern how key features were applied, using rigorous designs with high external validity, longer play durations, tailoring dynamically throughout the game and including a follow-up measurement and techniques on how to maintain the effect in the longer term.

Limitations

Some limitations to this meta-analysis need to be noted. First, 'no evidence for an effect' does not equal 'evidence for no effect'. In some areas, analyses were likely statistically underpowered (e.g. mental health, social behavior, clinical outcomes). Second, other factors (e.g. game features), may partially explain the high heterogeneity which indicates results should be treated with caution. These features were not included here. Third, publication bias is always a concern: reported effect sizes may be overestimated (e.g. behavioral determinants). The analyses were furthermore limited by the information available in the manuscripts and that additionally obtained from the researchers. More detailed descriptions of the games themselves and of the development process are needed to make empirical advances in this field. Lastly, this review included various types of health behaviors, which may be difficult to compare. There was, however, no significant heterogeneity related to the various health domains which were included. Decreasing risky behavior may be harder to achieve than increasing health-promoting behavior (Adriaanse et al., 2011). Our meta-analysis did not distinguish between reducing unhealthy behavior or increasing healthy actions. Future meta-analysis may wish to include these differences and also take into account the health status of the target group.

Conclusions

Findings indicated that serious games had positive effects on healthy lifestyles and their determinants, especially for knowledge, and on clinical outcomes. Long-term effects were maintained for knowledge, but not for behavior. Serious games were best individually tailored to both socio-demographic and change need information and benefited from a theoretical foundation in both behavioral prediction and game theories. They were effective either as a stand-alone or multi-component program and appealed to a variety of populations regardless of age and gender. Given that effects of games remain heterogeneous, further explorations of which game features create larger effects are needed.

Conflict of interest statement

The authors declare that there are no conflicts of interests. Q32

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.ypmed.2014.08.026.

References

Adriaanse, M.A., Vinkers, C.D.W., De Ridder, D.T.D., Hox, J.J., De Wit, J.B.F., 2011. Do implementation intentions help to eat a healthy diet? A systematic review and meta-analysis of the empirical evidence. Appetite 56, 183–193.

Annetta, L.A., 2010. The I's have it: a framework for serious educational game design. Rev. Gen. Psychol. 14 (2), 105–112.

Asztalos, M., De Bourdeaudhuij, I., Cardon, G., 2009. The relationship between physical activity and mental health varies across activity intensity levels and dimensions of mental health among women and men. Public Health Nutr. 13 (8), 1207–1214.

Baert, V., Gorus, E., Mets, T., Geerts, C., Bautmans, I., 2011. Motivators and barriers for physical activity in the oldest old: a systematic review. Ageing Res. Rev. 10, 464–474.

Baranowski, T., Buday, R., Thompson, D., Baranowski, J., 2008. Playing for real. Video games and stories for health-related behavior change. Am. J. Prev. Med. 34 (1), 74–82.

Baranowski, T., Baranowski, J., Thompson, D., Buday, R., 2011a. Behavioral science in video games for children's diet and physical activity change: key research needs. J. Diabetes Sci. Technol. 5 (2), 229–233.

Bartholomew, L.K., Parcel, G.S., Kok, G., Gottlieb, N.H., Fernàndez, M.E., 2011. Planning health promotion programs, An Intervention Mapping Approach3rd edition. Jossey Bass.

Borenstein, M., Hedges, L.V., Higgins, J.P.T., Rothstein, H.R., 2009. Introduction to Meta-analysis. Wiley, West Sussex.

Bourgonjon, J., Valcke, M., Soetaert, R., Schellens, T., 2010. Students' perceptions about the use of video games in the classroom. Comput. Educ. 54, 1145–1156.

Boyle, E.A., Connolly, T.M., Hainey, T., Boyle, J.M., 2012. Engagement in digital entertainment games: a systematic review. Comput. Hum. Behav. 28, 771–780.

Brox, E., Fernandez-Luque, L., Tøllefsen, T., 2011. Healthy gaming — video game design to promote health. Appl. Clin. Infect. 2, 128–142.

Charles, D., Kerr, A., Mcneill, M., et al., 2005. Player-centred game design: player modelling and adaptive digital games, In: Digital Games Research Association Digra (Ed.), DiGRA 2005 Conference: Changing Views — Worlds in Play, 285 ed. (Vancouver, British Columbia, Canada).

Cohen, J., 1988. Statistical Power Analysis for the Behavioral Sciences. Lawrence Erlbaum Associates, Hillsdale, New Jersey.

Connolly, T.M., Boyle, E., Macarthur, E., Hainey, T., Boyle, J.M., 2012. A systematic literature review of empirical evidence on computer games and serious games. Comput. Educ. 59, 661–686.

Crutzen, R., De Nooijer, J., Brouwer, W., Oenema, A., Brug, J., De Vries, N.K., 2008. Internet-delivered interventions aimed at adolescents: a Delphi study on dissemination and exposure. Health Educ. Res. 23 (3), 427–439.

Crutzen, R., De Nooijer, J., Brouwer, W., Oenema, A., Brug, J., De Vries, N.K., 2011. Strategies to facilitate exposure to internet-delivered health behavior change interventions aimed at adolescents or young adults: a systematic review. Health Educ. Behav. 38 (1), 49–62.
Deshazo, J., Harris, L., Pratt, W., 2010. Effective intervention or child's play? A review of video games for diabetes education. Diabetes Technol. Ther. 12 (10), 815–822.
Fratiglioni, L., Paillard-Borg, S., Winblad, B., 2004. An active and socially integrated lifestyle in late life might protect against dementia. Lancet Neurol. 3, 343–353.
Gamberini, L., Barresi, G., Majer, A., Scarpetta, F., 2008. A game a day keeps the doctor away: a short review of computer games in mental healthcare. J. Cyberther. Rehabil. 1 (2), 127–145.
Graesser, A., Chipman, P., Leeming, F., Biedenbach, S., 2009. Deep learning and emotion in serious games. In: Ritterfeld, U., Cody, M., Vorderer, P. (Eds.), Serious Games, Mechanisms and Effects. Routledge, New York and London.
Guse, K., Levine, D., Martins, S., et al., 2012. Interventions using new digital media to improve adolescent sexual health: a systematic review. J. Adolesc. Health 51, 535–543.
Guy, S., Ratzki-Leewing, A., Gwadry-Sridhar, F., 2011. Moving beyond the stigma: systematic review of video games and their potential to combat obesity. Int. J. Hypertens. 1–13.
Hedges, L., 1981. Distribution theory for glass's estimator of effect size and related estimators. J. Educ. Stat. 6 (107), 128.
Higgings, J.P.T., Thompson, S.G., Deeks, J.J., Altman, D.G., 2003. Measuring inconsistency in meta-analyses. Br. Med. J. 327, 557–560.
Huber, M., Knottnerus, J.A., Green, L., et al., 2011. How should we define health? BMJ 343 (6), d4163.
Huizenga, J., Admiraal, W., Akkerman, S., Ten Dam, G., 2009. Mobile game-based learning in secondary education: engagement, motivation and learning in a mobile city game. J. Comput. Assist. Learn. 25, 332–344.
Jacobs, A.D., Ammerman, A.S., Ennett, S.T., et al., 2004. Effects of a tailored follow-up intervention on health behaviors, beliefs, and attitudes. J. Women's Health 13 (5), 557–568.
Jantz, C., Anderson, J., Gould, S.M., 2002. Using computer-based assessments to evaluate interactive multimedia nutrition education among low-income predominantly Hispanic participants. J. Nutr. Educ. Behav. 34 (5), 252–260.
Kapp, K.M., 2012. The Gamification of Learning and Instruction: Game-based Methods and Strategies for Training and Education. John Wiley & Sons, San Francisco, CA.
Kato, P.M., 2010. Video games in health care: closing the gap. Rev. Gen. Psychol. 14 (2), 113–121.
Kato, P.M., 2012. Evaluating efficacy and validating games for health. Games Health J. 1 (1), 74–76.
Kharrazi, H., Lu, A.S., Gharghabi, F., Coleman, W., 2012. A scoping review of health game research: past, present and future. Games Health J. 1 (2), 153–164.
Kim, Y.S., Park, Y.S., Allegrante, J.P., et al., 2012. Relationship between physical activity and general mental health. Prev. Med. 55, 458–463.
Krebs, P., Prochaska, J.O., Rossi, J.S., 2010. A meta-analysis of computer-tailored interventions for health behavior change. Prev. Med. 51, 214–221.
Lopez, A.D., Mathers, C.D., Ezzati, M., Jamison, D.T., Murray, C.J.L., 2006. Global and regional burden of disease and risk factors, 2001: systematic analysis of population health data. Lancet 367, 1747–1757.
Lu, A.S., Baranowski, T., Thompson, D., Buday, R., 2012. Story immersion of videogames for youth health promotion: a review of literature. Games Health J. 1 (3), 199–204.
Lustria, M.L.A., Cortese, J., Noar, S.M., Glueckauf, R.L., 2009. Computer-tailored health interventions delivered over the web: review and analysis of key components. Patient Educ. Couns. 74, 156–173.
Martins, R.K., Mcneil, D.W., 2009. Review of motivational interviewing in promoting health behaviors. Clin. Psychol. Rev. 29, 283–293.
Mäyrä, F., 2008. An introduction to game studies. Games in CultureSage Publications, London.
Mcguire, A.M., Anderson, D.J., Fulbrook, P., 2013. Perceived barriers to healthy lifestyle activities in midlife and older Australian women with type 2 diabetes. Collegian (ahead of print).
Michie, S., Ashford, S., Sniehotta, F.F., Dombrowski, S.U., Bishop, A., French, D.P., 2011a. A refined taxonomy of behaviour change techniques to help people change their physical activity and healthy eating behaviours: the CALORE taxonomy. Psychol. Health 26 (11), 1479–1498.
Michie, S., Van Stralen, M.M., West, R., 2011b. The behaviour change wheel: a new method for characterising and designing behaviour change interventions. Implement. Sci. 6 (42), 1–11.
Noar, S.M., Benac, C.N., Harris, M.S., 2007. Does tailoring matter? Meta-analytic review of tailored print health behavior change interventions. Psychol. Bull. 133 (4), 673–693.
Norris, S.L., Engelgau, M.M., Venkat Narayan, K.M., 2001. Effectiveness of self-management training in type 2 diabetes. A systematic review of randomized controlled trials. Diabetes Care 24 (3), 561–587.
Orleans, C.T., 2000. Promoting the maintenance of health behavior change: recommendations for next generations of research and practice. Health Psychol. 19 (1 Suppl.), 76–83.
Papastergiou, M., 2009. Exploring the potential of computer and video games for health and physical education: a literature review. Comput. Educ. 53, 603–622.
Peel, N.M., McClure, R.J., Bartlett, H.P., 2005. Behavioral determinants of healthy aging. Am. J. Prev. Med. 28 (3), 298–304.
Peng, W., 2008. The mediational role of identification in the relationship between experience mode and self-efficacy: enactive role-playing versus passive observation. Cyberpsychol. Behav. 11 (6), 649–652.
Peng, W., Lin, J.-H., Crouse, J., 2011. Is playing exergames really exercising? A meta-analysis of energy expenditure in active video games. Cyberpsychol. Behav. Soc. Netw. 14 (11), 681–688.
Portney, L.G., Watkins, M.P., 2009. Foundations of clinical research, Applications to Practice3rd edition. Pearson Prentice Hall, New Jersey.
Portnoy, D.B., Scott-Sheldon, L.A., Johnson, B.T., Carey, M.P., 2008. Computer-delivered interventions for health promotion and behavioral risk reduction: a meta-analysis of 75 randomized controlled trials, 1988–2007. Prev. Med. 47, 3–16.
Prensky, M., 2007. Digital Game-based Learning: Practical Ideas for the Application of Digital Game-based Learning, Edition 2007 ed. Paragon House, St. Paul, MN.
Primack, B.A., Carroll, M.V., Mcnamara, M., et al., 2012. Role of video games in improving health-related outcomes. A systematic review. Am. J. Prev. Med. 42 (6), 630–638.
Rahmani, E., Boren, S.A., 2012. Videogames and health improvement: a literature review of randomized controlled trials. Games Health J. 1 (5), 331–341.
Ritterfeld, U., Cody, M., Vorderer, P., 2009. Introduction. In: Ritterfeld, U., Cody, M., Vorderer, P. (Eds.), Serious GamesMechanisms and Effects. Routledge, London and New York.
Schrader, C., Bastiaens, T.J., 2012. The influence of virtual presence: effects on experienced cognitive load and learning outcomes in educational computer games. Comput. Hum. Behav. 28, 648–658.
Schwarzer, R., 1998. Optimism, goals, and threats: how to conceptualize self-regulatory processes in the adoption and maintenance of health behaviors. Psychol. Health 13 (4), 759–766.
Sitzmann, T., 2011. A meta-analytic examination of the instructional effectiveness of computer-based simulation games. Pers. Psychol. 64, 489–528.
Squire, K., 2005. Changing the game: what happens when video games enter the classroom? http://website.education.wisc.edu/~kdsquire/tenure-files/26-innovate.pdf.
Thompson, S.G., Higgins, J.P.T., 2002. How should meta-regression analyses be undertaken and interpreted? Stat. Med. 21, 1559–1573.
Thompson, D., Baranowski, T., Buday, R., et al., 2010. Serious video games for health: how behavioral science guided the development of a serious video game. Simul. Gaming 41 (4), 587–606.
Thompson, D., Bhatt, R., Lazarus, M., Cullen, K., Baranowski, J., Baranowski, T., 2012. A serious video game to increase fruit and vegetable consumption among elementary aged youth (Squire's Quest! II): rationale, design, and methods. JMIR Res. Protoc. 1 (2), e19.
Toobert, T.J., Strycker, L.A., Glasgow, R.E., Bagdade, J.E., 2002. If you build it, will they come? Reach and adoption associated with a comprehensive lifestyle management program for women with type 2 diabetes. Patient Educ. Couns. 48, 99–105.
Walker, S.N., Sechrist, K.R., Pender, N.J., 1987. The Health-Promoting Lifestyle Profile: development and psychometric characteristics. Nurs. Res. 36 (2), 76–81.
Webb, T.L., Joseph, J., Yardley, L., Michie, S., 2010. Using the internet to promote health behavior change: a systematic review and meta-analysis of the impact of theoretical basis, use of behavior change techniques, and of mode of delivery on efficacy. J. Med. Internet Res. 12 (1), e4–e29.
Wilkinson, N., Ang, R.P., Goh, D.H., 2008. Online video game therapy for mental health concerns: a review. Int. J. Soc. Psychiatry 54 (4), 370–382.
Wilson, K.A., Bedwell, W.L., Lazzara, E.H., et al., 2009. Relationships between game attributes and learning outcomes: review and research proposals. Simul. Gaming 40, 217–266.
Wouters, P., Van Nimwegen, C., Van Oostendorp, H., Van Der Spek, E.D., 2013. A meta-analysis of the cognitive and motivational effects of serious games. J. Educ. Psychol. 105 (2), 249–265.

References of included articles

Baños, R.M., Cebolla, A., Oliver, E., Alcañiz, M., Botella, C., 2013. Efficacy and acceptability of an internet platform to improve the learning of nutritional knowledge in children: the ETIOBE mates. Health Educ. Res. 28 (2), 234–248.
Baranowski, T., Baranowski, J., Cullen, K., et al., 2003. Squire's Quest! Dietary outcome evaluation of a multimedia game. Am. J. Prev. Med. 24 (1), 52–61.
Baranowski, T., Baranowski, J., Thompson, D., et al., 2011b. Video game play, child diet, and physical activity behavior change. A randomized controlled trial. Am. J. Prev. Med. 40 (1), 33–38.
Bartholomew, L.K., Gold, R.S., Parcel, G.S., et al., 2000. Watch, discover, think, and act: evaluation of computer-assisted instruction to improve asthma self-management in inner-city children. Patient Educ. Couns. 39, 269–280.
Beaumont, R., Sofronoff, K., 2008. A multi-component social skills intervention for children with Asperger syndrome: the Junior Detective Training Program. J. Child Psychol. Psychiatry 49 (7), 743–753.
Brown, S.J., Lieberman, D.A., Gemeny, B.A., Fan, Y.C., Wilson, D.M., Pasta, D.J., 1997. Educational video game for juvenile diabetes: results of a controlled trial. Med. Inform. 22 (1), 77–89.
Brown, K., Newby, K., Bayley, J., Joshi, P., Judd, B., Baxter, A., 2012. Development and Evaluation of a Serious Game for Relationships and Sex Education using Intervention Mapping. Coventry University.
Buller, M.K., Kane, I.L., Martin, R.C., et al., 2008. Randomized trial evaluating computer-based sun safety education for children in elementary school. J. Cancer Educ. 23, 74–79.
Campbell, M.K., Honess-Morreale, L., Farrell, D., Carbone, E., Brasure, M., 1999. A tailored multimedia nutrition education pilot program for low-income women receiving food assistance. Health Educ. Res. 14 (2), 257–267.
Campbell, M.K., Carbone, E., Honess-Morreale, L., Heisler-Mackinnon, J., Demissie, S., Farrell, D., 2004. Randomized trial of a tailored nutrition education CD-ROM program for women receiving food assistance. J. Nutr. Educ. Behav. 36 (2), 58–66.
Consoli, S.M., Ben Said, M., Jean, J., Menard, J., Plouin, P.-F., Chatelier, G., 1995. Benefits of a computer-assisted education program for hypertensive patients compared with standard education tools. Patient Educ. Couns. 26, 343–347.

Cullen, K., Watson, K., Baranowski, T., Baranowski, J., Zakeri, I., 2005. Squire's Quest: intervention changes occurred at lunch and snack meals. Appetite 45, 148–151.

Dias, M., Agante, L., 2011. Can advergames boost children's healthier eating habits? A comparison between healthy and non-healthy food. J. Consum. Behav. 10, 152–160.

Folkvord, F., Anschütz, D.J., Buijzen, M., Valkenburg, P.M., 2013. The effect of playing advergames that promote energy-dense snacks or fruit on actual food intake among children. Am. J. Clin. Nutr. 97, 239–245.

Fuchslocher, A., Niesenhaus, J., Krämer, N., 2011. Serious games for health: an empirical study of the game “balance” for teenagers with diabetes mellitus. Entertain. Comput. 2, 97–101.

Grechus, M., Brown, J., 2013. Comparison of individualized computer game reinforcement versus peer-interactive board game reinforcement on retention of nutrition label knowledge. J. Health Educ. 31 (3), 138–142.

Hartjes, L.B., Baumann, L.C., 2012. Evaluation of a Web-based malaria risk reduction game for study abroad students. J. Am. Coll. Health 60 (5), 403–414.

Hewitt, M., Denman, S., Hayes, L., Pearson, J., Wallbanks, C., 2001. Evaluation of ‘Sun-safe’: a health education resource for primary schools. Health Educ. Res. 16 (5), 623–633.

Homer, B.D., Hayward, E.O., Frye, J., Plass, J.L., 2012. Gender and player characteristics in video game play of preadolescents. Comput. Hum. Behav. 28, 1782–1789.

Huss, K., Winkelstein, M., Nanda, J., Naumann, P.L., Sloand, E.D., Huss, R.W., 2003. Computer game for inner-city children does not improve asthma outcomes. J. Pediatr. Health Care 17, 72–78.

Jago, R., Baranowski, T., Baranowski, J., et al., 2006. Fit for Life Boy Scout badge: outcome evaluation of a troop and internet intervention. Prev. Med. 42, 181–187.

Jin, S.-A.A., 2010. The effects of incorporating a virtual agent in a computer-aided test designed for stress management education: the mediating role of enjoyment. Comput. Hum. Behav. 26, 251–443.

Johnston, J.D., Massey, A.P., Marker-Hoffman, R.L., 2012. Using an alternate reality game to increase physical activity and decrease obesity risk of college students. J. Diabetes Sci. Technol. 6 (4), 828–838.

Kärnä, A., Voeten, M., Little, T.D., Poskiparta, E., Alanen, E., Salmivalli, C., 2011a. Going to scale: a nonrandomized nationwide trial of the KiVa antibullying program for grades 1–9. J. Consult. Clin. Psychol. 79 (6), 796–805.

Kärnä, A., Voeten, M., Little, T.D., Poskiparta, E., Kaljonen, A., Salmivalli, C., 2011b. A large-scale evaluation of the KiVa antibullying program: grades 4–6. Child Dev. 82 (1), 311–330.

Kato, P.M., Cole, S.W., Bradlyn, A.S., Pollock, B.H., 2008. A video game improves behavioral outcomes in adolescents and young adults with cancer: a randomized trial. Pediatrics 122, e305–e317.

Krishna, S., Francisco, B.D., Balas, A., König, P., Graff, G.R., Madsen, R.W., 2003. Internet-enabled interactive multimedia asthma education program: a randomized trial. Pediatrics 111, 503–510.

Majumdar, D., Koch, P.A., Lee, H., Contento, I.R., De Lourdes Islas-Ramos, A., Fu, D., 2013. “Creature-101”: a serious game to promote energy balance-related behaviors among middle school adolescents. Games Health J. 2 (5), 280–290.

Marsch, L.A., Grabinski, M.J., Bickel, W.K., et al., 2011. Computer-assisted HIV prevention for youth with substance use disorders. Subst. Use Misuse 46 (1), 46–56.

Mcpherson, A.C., Glazebrook, C., Forster, D., James, C., Smyth, A., 2006. A randomized, controlled trial of an interactive educational computer package for children with asthma. Pediatrics 117, 1046–1054.

Miller, C.K., Lindberg, D.V., 2007. Evaluation of a computer-based game about the glycemic index among college-aged students. Top. Clin. Nutr. 22 (3), 299–306.

Molnar, A., Kostkova, P. On Effective Integration of Educational Content in Serious Games, In Proceedings of 13th IEEE International Conference on Advanced Learning Technologies, pp. 15–18.

Panic, K., Cauberghe, V., De Pelsmacker, P., 2013. Promoting dental hygiene to children: comparing traditional and interactive media following threat appeals. J. Health Commun. 1–16 (ahead of print).

Paperny, D.M., Starn, J.R., 1989. Adolescent pregnancy prevention by health education computer games: computer-assisted instruction of knowledge and attitudes. Pediatrics 83, 742–752.

Peng, W., 2009. Design and evaluation of a computer game to promote a healthy diet for young adults. Health Commun. 24, 115–127.

Peng, W., Lin, J.-H., Pfeiffer, K.A., Winn, B., 2012. Need satisfaction supportive game features as motivational determinants: an experimental study of a self-determination theory guided exergame. Media Psychol. 15, 175–196.

Peng, W., Pfeiffer, K.A., Lin, J.-H., Winn, B., Suton, D., 2013. Promoting physical activity through an active videogame among young adults. In International Communication Association, Annual Meeting 2013, London.

Prokhorov, A.V., Kelder, S.H., Shegog, R., et al., 2008. Impact of a Smoking Prevention Interactive Experience (ASPIRE), an interactive, multimedia smoking prevention and cessation curriculum for culturally diverse high-school students. Nicotine Tob. Res. 10 (9), 1477–1485.

Sapouna, M., Wolke, D., Vannini, N., et al., 2010. Virtual learning intervention to reduce bullying victimization in primary school: a controlled trial. J. Child Psychol. Psychiatry 51 (1), 104–112.

Schotland, M., Littman, K., 2012. Using a computer game to teach young children about their brains. Games Health J. 1 (6), 442–448.

Shames, R.S., Sharek, P., Mayer, M., et al., 2004. Effectiveness of a multicomponent self-management program in at-risk, school-aged children with asthma. Ann. Allergy Asthma Immunol. 92, 611–618.

Silk, K.J., Sherry, J., Winn, B., Keesecker, N., Horodynski, M.A., Sayir, A., 2008. Increasing nutrition literacy: testing the effectiveness of print, web site, and game modalities. J. Nutr. Educ. Behav. 40, 3–10.

Silver, M., Oakes, P., 2001. Evaluation of a new computer intervention to teach people with autism or Asperger syndrome to recognize and predict emotions in others. Autism 5, 299–316.

Stern, Y., Blumen, H.M., Rich, L.W., Richards, A., Herzberg, G., Gopher, D., 2011. Space fortress game training and executive control in older adults: a pilot intervention. Aging Neuropsychol. Cognit. 18 (6), 653–677.

Swartz, L.H.G., Sherman, C.A., Harvey, S.M., Blanchard, J., Vawter, F., Gau, J., 2011. Midlife women online: evaluation of an internet-based program to prevent unintended pregnancy & STIs. J. Women Aging 23 (4), 342–359.

Tanaka, J.W., Wolf, J.M., Klaiman, C., et al., 2010. Using computerized games to teach face recognition skills to children with autism spectrum disorder: the let's face it program. J. Child Psychol. Psychiatry 51 (8), 944–952.

Thompson, D., Baranowski, T., Baranowski, J., et al., 2009. Boy Scout 5-a-Day badge: outcome results of a troop and internet intervention. Prev. Med. 49, 518–526.

Tortolero, S.R., Markham, C.M., Peskin, F.M., et al., 2010. It's your game: keep it real: delaying sexual behavior with an effective middle school program. J. Adolesc. Health 46, 169–179.

Trepka, M.J., Newman, F.L., Davila, E.P., Matthew, K.J., Dixon, Z., Huffman, F.G., 2008. Randomized controlled trial to determine the effectiveness of an interactive multimedia food safety education program for clients of the special supplemental nutrition program for women, infants and children. J. Am. Diet. Assoc. 108 (6), 978–984.

Turnin, M.C., Tauber, M.T., Couvaras, O., et al., 2001. Evaluation of microcomputer nutritional teaching games in 1,876 children at school. Diabetes Metab. 27, 459–464.

Wingood, G.M., Card, J.F., Er, D., et al., 2011. Preliminary efficacy of a computer-based HIV intervention for African-American women. Psychol. Health 26 (2), 223–234.

Yawn, B.P., Algatt-Bergstrom, P.J., Yawn, R.A., et al., 2000. An in-school CD-ROM asthma education program. J. Sch. Health 70 (4), 153–159.

Yien, J.-M., Hung, C.-M., Hwang, G.-J., Lin, Y.-C., 2011. A game-based learning approach to improving students' learning achievements in a nutrition course. Turk. Online J. Educ. Technol. 10 (2), 1–10.

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