

Received Date : 18-Jul-2016

Revised Date : 16-Nov-2016

Accepted Date : 14-Dec-2016

Article type : Original

A Systematic Review of Serious Games in Asthma Education

David Drummond^{a,b}, MD, Delphine Monnier^a, MD, Antoine Tesnière^{a,c}, MD, PhD, Alice Hadchouel^{a,b}, MD, PhD

Affiliations: ^aIlumens Simulation Department, Paris Descartes University, 45 rue des Saint Pères, 75006 Paris, France ; ^bPediatric pulmonology, Necker-Enfants Malades Hospital, Assistance Publique-Hôpitaux de Paris, 149 rue de Sèvres, 75015 Paris, France; And ^cSurgical Intensive Care Unit, Cochin Hospital, Assistance Publique-Hôpitaux de Paris, Paris, France

Corresponding author: David Drummond, Ilumens Simulation Department, Paris Descartes University, 45 rue des Saint Pères, 75006 Paris, France, +0033176530100, david.drummond@ilumens.org

Running title: Serious Games in Asthma Education

Funding Source: No funding was secured for this study.

Conflict of Interest: The authors have no conflicts of interest to disclose.

All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

This article contains supplementary materials.

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1111/pai.12690

This article is protected by copyright. All rights reserved.

A Systematic Review of Serious Games in Asthma Education

D. Drummond^{a,b}, MD, D. Monnier^a, MD, A. Tesnière^{a,c}, MD, PhD, A. Hadchouel^{a,b}, MD, PhD

Abstract

Background: Serious games may be useful tools for asthma education. The objectives of this systematic review were to identify the available articles on serious games designed to educate patients and the general public about asthma and to assess their impact on patient's knowledge, behavior and clinical outcomes related to asthma.

Methods: PubMed, Embase, Cochrane Library, PsychInfo, and Web of Science were systematically searched from January 1980 to December 2015 for studies investigating serious games in asthma education. Two investigators independently assessed studies against inclusion criteria and rated those included on indicators of quality. Investigators extracted data on serious games' content and learning objectives, and on outcomes following Kirkpatrick classification.

Results: A total of 12 articles were found to be relevant, describing a total of 10 serious games. All serious games were directed towards children, with eight games for children with asthma and two for school-based intervention. The average Medical Education Research Study Quality Instrument (MERSQI) score was 13.9 of 18, which is high. Most of the serious games were associated with high rates of satisfaction and improvement in children's knowledge. Seven studies evaluated the impact of serious games on clinical outcomes, and found no significant difference relative to control groups.

Conclusions: Although serious games designed for asthma education have evolved with advances in technology, results of their evaluation remained similar across studies, with clear improvements in knowledge but little or no change in behaviors and clinical outcomes.

Keywords: asthma; health education; patient education; pediatrics; video game;

Offprints : David Drummond, Ilumens Simulation Department, Paris Descartes University, 45 rue des Saint Pères, 75006 Paris, France, +0033176530100, david.drummond@ilumens.org

Introduction

Asthma education leads to significant improvement in controlling the disease, and reduces emergency department visits and hospital admissions(1–3). It is recognized to be an essential element in the management of asthmatic patients, and is recommended by national and international guidelines(4,5). However, attendance at asthma education programs is low (6). Barriers that have been identified include difficulty getting time off work, travel costs, psychological factors, and physician resistance(6–8). New approaches are required to reach patients and teach them asthma management.

Serious games (SGs) are theoretically very useful tools for health education in general, and asthma education in particular. According to Bergeron, SGs are interactive computer applications, with or without a hardware component, that (i) have challenging goals, (ii) are fun to play and/or engaging, (iii) incorporate concepts of scoring, (iv) and impart skills, knowledge, or attitudes to the user that can be applied in the real world(9). From an educational perspective, they promote active learning, which is more effective than traditional didactic lectures for both knowledge acquisition and behavioral changes(10–12); they provide feedback, essential for learning(13); they promote deliberate practice by offering repetition of each game level until mastery is reached(14); and they encourage perseverance during the learning process because they are fun. From a healthcare perspective, SGs can teach patients to better understand the pathophysiology of asthma and the objectives of its treatments, to identify rare situations such as asthma attacks, and to practice several skills such as the inhalation technique. Finally, the accessibility of SGs is wider than classic asthma

education programs, and may reach many more patients. For these reasons, SGs can be considered to be new tools for changing patients' behaviors and outcomes regarding their asthma(15).

Previous reviews in the field were published more than 5 years ago(15–19), were not systematic(15–18), did not distinguish SGs from other computer-assisted instructions(18–20), and/or did not focus on asthma education(21,22).

The objectives of this systematic review were to identify the available articles on SGs designed to educate patients and the general public about asthma and to assess their impact on patient's knowledge, behavior and clinical outcomes related to asthma.

Methods

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines(23). To be eligible for inclusion, studies were required to describe or assess SGs created for the purpose of asthma education. The definition of SGs by Bergeron was adopted for this review(9). Asthma education included all the interventions with the following goals: raising awareness that asthma is a serious chronic disease, ensuring the recognition of the triggers and symptoms of asthma, and/or ensuring effective management of asthma(24). Education tools aimed at health professionals were excluded from this review. No age limit for patients was applied.

All types of publications, such as articles, editorials, and conference abstracts, reported in English or French, and published online between January 1st, 1980 and December 31, 2015 were included. Past reviews were not included, but their eligible references were.

A comprehensive literature search of the PubMed, EMBASE, the Cochrane Library, Web of Sciences, and PsychInfo databases was conducted using the following key terms: (serious gam* OR videogame* OR video gam* OR gaming) AND (asthma). These terms were selected using an iterative process guided by pediatric pulmonologists and an expert in serious games on the basis of past systematic reviews(25,26). The returned studies were combined with the references of three relevant reviews(18,20,21). After removal of duplicates, the studies were screened independently and in duplicate by titles and abstract (D.D., D.M.), and studies which were not written in English or French and/or not relevant to asthma education were excluded. For the remaining studies, full-text articles were assessed for eligibility and sorted into the following categories: reviews or learning theory, intended for health professionals, not computer based, not considered to be a game, and relevant studies.

Data extraction was performed independently and in duplicate (D.D., D.M.) on the basis of a data extraction form adapted from Wang *et al.*(26). Methodological quality was also assessed independently and in duplicate using the medical education research study quality instrument (MERSQI)(27). If a study used multiple assessment tools, the tool associated with the primary outcome was chosen. If the primary outcome was not specified by the authors, the tool associated with the highest level of evaluation defined by Kirkpatrick was evaluated(28) (Figure 2).

Primary data was first extracted from the publication. If additional information was necessary, an internet search of the game name, publication title, and author was conducted. An email was sent to the corresponding author if further information was required. If information could not be provided, the field was marked “not specified”. Game genres were categorized according to the nomenclature described by Wolf(29) and adapted by Wang *et al.*(26). Several SGs were assigned to more than one genre because they included different

mini-games, or because of some overlap between genres. Learning objectives of each game were extracted in plain text, and then reorganized into eight categories. Study design, participants, intervention (including duration and frequency of game play), assessment tools, and results were also recorded.

Any disagreements during the categorization of publications, data extraction, or assessment of MERQSI items, were settled by a third reviewer (A.H.).

Statistical Analysis

Data were collected and organized using Microsoft Excel (Microsoft, Redmond, WA) and statistical analysis was performed using PASW Statistics 18 (IBM, Armonk, NY). Cohen κ was used to assess interrater agreement for study selection, data extraction, and methodological quality assessment.

Results

The search identified 12 publications, describing 10 unique SGs, for inclusion (Figure 1). Interrater agreement calculated by Cohen κ was 0.96 for categorizing publications, 0.93 for data extraction, and 0.99 for MERSQI items. The articles associated with two references could not be found and were excluded from the analysis(30,31). The list of included SGs is presented in Table 1, sorted by date of publication of their related article. One SG was discussed only in a thesis which was not accessible(32). Another was found as a conference abstract, and developers of the game provided unpublished data of a randomized trial they conducted(33). The learning objectives of the included SGs are presented in Table 2.

Given the definition of SG chosen, computer-assisted instructions without any fun element were not selected for analysis. All of the ten included SGs were directed towards children and teens. A description of each game is presented in the supplemental material.

Evaluation Data

The results of the evaluation of the included SGs were available for nine of 10. They are presented in Table 3 (a more detailed version of the Table is presented in the supplemental material, Table S1). This section is organized following Kirkpatrick's levels of evaluation: user satisfaction with the SG (level 1), gain of skills and knowledge (level 2), behavioral change (level 3), and improved clinical outcomes (level 4) (28). In the second level, we added the level 2a, described by Mosley *et al.*(34), which relates in this review to the self-efficacy gained after playing the game. Level 2b corresponds to the gain of knowledge and skills as usually described.

Player Satisfaction (Level 1)

Seven studies covering six SGs reported player satisfaction. Overall, results were highly favorable for satisfaction associated with SGs. More than 90% of children who played the different SGs enjoyed it, and for some games such as *Watch, Discover, Think and Act*, a majority of children found it more fun than their favorite computer game.

Self-efficacy (Level 2a)

Six studies representing six SGs evaluated the modification of self-efficacy induced by playing the games, with mixed results. In a pre/post assessment, the children's self-efficacy improved after playing the game in two studies (33,35) and remained similar in three others (36–38). In randomized controlled trials, one SG was associated with more self-efficacy improvement than in the control group (35), while there was no difference for five others (33,36–39).

Two studies evaluated parent self-efficacy with mixed results. The first used a structured interview on asthma decision-making and behavioral capacity, and showed no difference(38). The second found a higher level of parent self-efficacy in the intervention group(33).

Knowledge acquisition (Level 2b)

Knowledge improvement was the most highly studied outcome, evaluated in all the articles. In a pre/post assessment, the children's knowledge improved after playing the game in all but one study (40). In randomized controlled trials, six SGs were associated with more knowledge improvement than in the control group (33,35,36,39,41,42), while there was no difference for three others (37,38,40).

Parent knowledge was assessed in four studies. There was no difference of parent knowledge in the intervention group compared to the control group in three studies (33,36,39), and a significant difference in favor of parents in the intervention group in one study (41).

Behavior change (Level 3)

Three studies evaluated whether playing the SG led to a change in behavior in real life. In the study from Rubin *et al.* (36), behavior changes were evaluated through a questionnaire on how the child participated in a variety of behaviors related to the management of asthma. Children and parents in the experimental group scored significantly higher for the total score than controls.

Two other studies found no difference in the behavior of the children between the experimental and control groups(33,39).

Clinical outcomes (Level 4)

Seven studies, each evaluating one SG, reported clinical outcomes.

Six studies reported acute visits (33,35,36,38,39,41) and four reported hospital admissions due to asthma (33,35,36,38), with no difference between the intervention and control groups in all these studies. In one of these studies, the difference in terms of hospital admissions became significant in favor of the SG group after adjusting on pre-test assessment, sex and severity(38).

Five studies evaluated patient symptoms (33,38–41). None of these studies demonstrated a difference between the intervention and control groups.

Three studies included lung function tests (Forced expiratory volume in the first second (FEV1) and peak expiratory flow (PEF))(35,40,41). Game play was not associated with any improvement and there was no difference between the intervention and control groups.

Discussion

This study was the first systematic review to evaluate the effectiveness of SGs in asthma education. Overall, most of the SGs included in this review increased children's knowledge of asthma but failed to change behaviors and did not improve clinical outcomes.

The improvements in children's knowledge of asthma after playing various SGs were consistent with findings from other reviews and meta-analysis which studied the effectiveness of SGs used in the fields of medication adherence (43), alcohol and drug use (44), sexual health behaviors(45), and general health promotion(46). However, if basic knowledge of the disease and its management is necessary for behavior change, it is not sufficient (47). Regardless of the learning vector, limited (information only) patient education for adults with asthma is not associated with behavior change or improved clinical outcomes (48). In contrast, self-efficacy, which is strongly associated with behavior change (49), was

rarely improved by the SGs included in this review. This in line with the results of other reviews which also reported unexpectedly small effects of SGs on self-efficacy (46,50).

As a consequence, the few studies which assessed behavior change found little or no change. Changing behaviors through educational interventions is challenging(12,51), and few SGs reached this objective(44–46). An explanation may be that, in several studies included in our review, the SG was not played enough to lead to significant changes. In three studies, the SG was played just once(40,52,53), and in two others children were supposed to play freely at home but many did not(35,41). Future studies of SGs may benefit from testing the dose-effect.

Finally, there was no difference between the SG and control groups in terms of clinical outcomes, when results were not adjusted on covariates. Clinical outcomes are rarely evaluated in studies evaluating the effectiveness of SGs in the field of preventive medicine(43,44,46,54,55). The absence of difference observed in our review may be the consequence of the very limited impact that the SGs had on behavior change. However, two other explanations need to be discussed. A first explanation may be a lack of power. Several studies reported a trend towards an improvement of clinical outcomes in the intervention group relative to control groups, but all failed to reached statistical significance. A second explanation may be that these interventions were directed towards children, and not their parents. Parents are the primary care providers for their children with asthma, and educational intervention should also be directed towards them.

The SGs included in this systematic review were all computer or web based. Mobile phone applications may be more appropriate to educate children and adolescents: a survey among children and adolescents in Europe and Japan aged 9 to 16 years old found that, on average, 69% used a mobile phone, which was a smartphone in two-thirds of the cases(57). The easy

accessibility of serious games integrated in mobile applications on smartphones may enhance their effectiveness as educational tools, but to our knowledge, the three educational games developed on mobile applications for children with asthma were not evaluated(58). This approach is nevertheless supported by the demonstration that an app which associated reminders and positive reinforcement, although not being a SG, was effective in improving adherence and asthma control among underserved minority adolescents(59).

Thus, this systematic review has three main implications for the development of future SGs in asthma education. First, because it was shown that patient education limited to the delivery of information was not sufficient to lead to behavior change and improved clinical outcomes (48), we think that future SGs should not be limited to the delivery of information through quizzes or mini-games. Rather, developers should consider involving more game genres such as management or training simulation which are more likely to promote behavior change. Second, all the actors involved in pediatric asthma management should be targeted by educational interventions and the parents of children with asthma should not be left aside. To our knowledge, no SG was developed specifically for these parents, while parent education through interactive media seems possible and effective (60). Third, the effectiveness of SGs may be enhanced if they were integrated in mobile applications, and such applications should also be scientifically evaluated.

This systematic review has some limitations. First, we included only games that were described in the scientific literature, while other games for asthma education were developed. Second, conclusions were drawn on a small number of game studies. However, the average MERSQI score was 13.9 out of 18, reflecting the overall good evaluation methodology of these studies. This score is well above the average of 9.95 calculated by Reed *et al.*, who applied the scale to 210 medical education research studies(27). Third, in multicomponent interventions, the effect of the game component could not be analyzed separately from the

other intervention components. Fourth, knowledge and self-efficacy measurements relied on questionnaires which were often developed by the authors of the studies, and were not reproducible across studies. Lastly, the heterogeneity in the design of the studies, which evaluated different types of SGs, involved different uses, different control groups, and different primary outcomes, precluded the performance of a meta-analysis.

In conclusion, SGs for asthma education allow children to effectively learn while having fun. However, no significant difference could be shown for clinical outcomes despite most of the trends favoring the SG group.

References

1. Coffman JM, Cabana MD, Halpin HA et al. Effects of asthma education on children's use of acute care services: a meta-analysis. *Pediatrics* 2008; **121**:575–586.
2. Guevara JP, Wolf FM, Grum CM et al. Effects of educational interventions for self management of asthma in children and adolescents: systematic review and meta-analysis. *BMJ* 2003; **326**:1308–1309.
3. Boyd M, Lasserson TJ, McKean MC et al. Interventions for educating children who are at risk of asthma-related emergency department attendance. *Cochrane Database Syst Rev* 2009; :CD001290.
4. From the Global Strategy for Asthma Management and Prevention, Global Initiative for Asthma (GINA). GINA Report, Global Strategy for Asthma Management and Prevention. 2015.<http://www.ginasthma.org/> (accessed 7 Sep2015).
5. Haute Autorité de Santé. Education thérapeutique de l'enfant asthmatique - Synthèse des recommandations. 2002.http://www.has-sante.fr/portail/upload/docs/application/pdf/education_asthmatique_enfant_version_finale_du_22_10_02_synthese.pdf (accessed 9 Sep2015).
6. Direction générale de la santé. Etats des lieux des écoles de l'asthme. 2006.<http://www.sante.gouv.fr/pour-connaître-les-résultats-de-l'étude-sur-les-écoles-de-l-asthme.html> (accessed 1 Nov2015).
7. FitzGerald JM. Psychosocial barriers to asthma education. *Chest* 1994; **106**:260S–263S.
8. Yoon R, McKenzie DK, Miles DA et al. Characteristics of attenders and non-attenders at an asthma education programme. *Thorax* 1991; **46**:886–890.
9. Bergeron B. Developing Serious Games. 1 edition. Hingham, Mass: Charles River Media 2006

- Accepted Article
10. Freeman S, Eddy SL, McDonough M et al. Active learning increases student performance in science, engineering, and mathematics. *Proc Natl Acad Sci* 2014; **111**:8410–8415.
 11. Prince M. Does active learning work? A review of the research. *J Eng Educ-Wash-* 2004; **93**:223–232.
 12. Davis D, O'Brien M, Freemantle N et al. Impact of formal continuing medical education: Do conferences, workshops, rounds, and other traditional continuing education activities change physician behavior or health care outcomes? *JAMA* 1999; **282**:867–874.
 13. Kirschner PA, Sweller J, Clark RE. Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educ Psychol* 2006; **41**:75–86.
 14. Ericsson KA. Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. *Acad Med J Assoc Am Med Coll* 2004; **79**:S70–81.
 15. Lieberman, D.A. Interactive video games for health promotion: Effects on knowledge, self-efficacy, social support, and health. In: R.L. Street, W.R. Gold, & T. Manning (Eds.), *Health promotion and interactive technology: Theoretical applications and future directions*. Mahwah, NJ: R.L. Street, W.R. Gold, & T. Manning 1997
 16. Papastergiou M. Exploring the potential of computer and video games for health and physical education: A literature review. *Comput Educ* 2009; **53**:603–622.
 17. Lieberman DA. Management of chronic pediatric diseases with interactive health games: Theory and research findings. *J Ambulatory Care Manage* 2001; **24**:26–38.
 18. Clark NM, Mitchell HE, Rand CS. Effectiveness of educational and behavioral asthma interventions. *Pediatrics* 2009; **123 Suppl 3**:S185–192.
 19. Sanders DL, Aronsky D. Biomedical informatics applications for asthma care: a systematic review. *J Am Med Inform Assoc JAMIA* 2006; **13**:418–427.
 20. Nabors LA, Kockritz JL, Ludke RL et al. Enhancing school-based asthma education efforts using computer-based education for children. *J Asthma Off J Assoc Care Asthma* 2012; **49**:209–212.
 21. Hieftje K, Edelman EJ, Camenga DR et al. Electronic media-based health interventions promoting behavior change in youth: a systematic review. *JAMA Pediatr* 2013; **167**:574–580.
 22. Parisod H, Pakarinen A, Kauhanen L et al. Promoting Children's Health with Digital Games: A Review of Reviews. *Games Health J* 2014; **3**:145–156.
 23. Shamseer L, Moher D, Clarke M et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation. *BMJ* 2015; **349**:g7647.

24. National Heart, Lung, and Blood Institute. National Asthma Education and Prevention Program (NAEPP). https://www.nhlbi.nih.gov/about/org/naepp/naep_pd
25. Graafland M, Schraagen JM, Schijven MP. Systematic review of serious games for medical education and surgical skills training. *Br J Surg* 2012; **99**:1322–1330.
26. Wang R, DeMaria S, Goldberg A et al. A Systematic Review of Serious Games in Training Health Care Professionals. *Simul Healthc J Soc Simul Healthc* Published Online First: 3 November 2015. doi:10.1097/SIH.0000000000000118
27. Reed DA, Cook DA, Beckman TJ et al. Association between funding and quality of published medical education research. *JAMA* 2007; **298**:1002–1009.
28. Kirkpatrick DL. *Evaluating Training Programs: The Four Levels*. San Francisco : Emeryville, CA: Berrett-Koehler 1994
29. Wolf MJP. Genre and the Video Game. 2000.<http://www.robinlionheart.com/gamedev/genres.xhtml> (accessed 29 Jan2016).
30. Huss K, Winkelstein ML, Crosbie K et al. ‘Backpack adventures in asthma’: Interactive multimedia computer game piques childrens’ interest in asthma. In: *Journal of Allergy and Clinical Immunology*. Mosby, Inc 11830 Westline Industrial Dr, St Louis, MO 63146-3318 USA 2001: S71–S71.
31. Sadock R, Rubin D. Development of a computer-video educational game for management of asthma. In: *Clinical Research*. Slack Inc 6900 Groe RD, Thorofare, NJ 08086 1984: A228–A228.
32. Howell K. ‘Quest for the Code’: A study of a computer based education program for children with asthma. *Psychol - Diss* Published Online First: 1 January 2005.http://surface.syr.edu/psy_etd/32
33. Schroeder, Susan; Swartz, Lynne; Gau, Jeff; Ary, Dennis V. A randomized, controlled trial of Lungtropolis™: An internet asthma game for children and companion website for parents. Unpubl. Manuscr.
34. Mosley C, Dewhurst C, Molloy S et al. What is the impact of structured resuscitation training on healthcare practitioners, their clients and the wider service? A BEME systematic review: BEME Guide No. 20. *Med Teach* 2012; **34**:e349-385.
35. McPherson AC, Glazebrook C, Forster D et al. A randomized, controlled trial of an interactive educational computer package for children with asthma. *Pediatrics* 2006; **117**:1046–1054.
36. Rubin DH, Leventhal JM, Sadock RT et al. Educational intervention by computer in childhood asthma: a randomized clinical trial testing the use of a new teaching intervention in childhood asthma. *Pediatrics* 1986; **77**:1–10.
37. Shegog R, Bartholomew LK, Parcel GS et al. Impact of a computer-assisted education program on factors related to asthma self-management behavior. *J Am Med Inform Assoc JAMIA* 2001; **8**:49–61.

38. Bartholomew LK, Gold RS, Parcel GS et al. Watch, Discover, Think, and Act: evaluation of computer-assisted instruction to improve asthma self-management in inner-city children. *Patient Educ Couns* 2000; **39**:269–280.
39. Homer C, Susskind O, Alpert HR et al. An evaluation of an innovative multimedia educational software program for asthma management: report of a randomized, controlled trial. *Pediatrics* 2000; **106**:210–215.
40. Huss K, Winkelstein M, Nanda J et al. Computer game for inner-city children does not improve asthma outcomes. *J Pediatr Health Care Off Publ Natl Assoc Pediatr Nurse Assoc Pract* 2003; **17**:72–78.
41. Shames RS, Sharek P, Mayer M et al. Effectiveness of a multicomponent self-management program in at-risk, school-aged children with asthma. *Ann Allergy Asthma Immunol Off Publ Am Coll Allergy Asthma Immunol* 2004; **92**:611–618.
42. Yawn BP, Algatt-Bergstrom PJ, Yawn RA et al. An in-school CD-ROM asthma education program. *J Sch Health* 2000; **70**:153–159.
43. Kato PM, Cole SW, Bradlyn AS et al. A Video Game Improves Behavioral Outcomes in Adolescents and Young Adults With Cancer: A Randomized Trial. *Pediatrics* 2008; **122**:e305–e317.
44. Rodriguez DM, Teesson M, Newton NC. A systematic review of computerised serious educational games about alcohol and other drugs for adolescents. *Drug Alcohol Rev* 2014; **33**:129–135.
45. DeSmet A, Shegog R, Van Ryckeghem D et al. A Systematic Review and Meta-analysis of Interventions for Sexual Health Promotion Involving Serious Digital Games. *Games Health J* 2015; **4**:78–90.
46. DeSmet A, Van Ryckeghem D, Compennolle S et al. A meta-analysis of serious digital games for healthy lifestyle promotion. *Prev Med* 2014; **69C**:95–107.
47. Thompson D. Designing serious video games for health behavior change: current status and future directions. *J Diabetes Sci Technol* 2012; **6**:807–811.
48. Gibson PG, Powell H, Coughlan J et al. Limited (information only) patient education programs for adults with asthma. *Cochrane Database Syst Rev* 2002; :CD001005.
49. Bartholomew LK, Parcel GS, Kok G et al. Planning health promotion programs: an intervention mapping approach. 2006. *San Franc CA Jossey-Bass Second Google Sch*
50. Lustria MLA, Cortese J, Noar SM et al. Computer-tailored health interventions delivered over the Web: review and analysis of key components. *Patient Educ Couns* 2009; **74**:156–173.
51. Goossens E, Fieuws S, Van Deyk K et al. Effectiveness of structured education on knowledge and health behaviors in patients with congenital heart disease. *J Pediatr* 2015; **166**:1370–1376.e1.

52. Kaufman D, Sauve L, Renaud L. Enhancing Learning through an Online Secondary School Educational Game. *J Educ Comput Res* 2011; **44**:409–428.
53. McPherson A, Forster D, Glazebrook C et al. The asthma files: evaluation of a multimedia package for children's asthma education. *Paediatr Nurs* 2002; **14**:32–35.
54. Primack BA, Carroll MV, McNamara M et al. Role of video games in improving health-related outcomes: a systematic review. *Am J Prev Med* 2012; **42**:630–638.
55. Charlier N, Zupancic N, Fieuws S et al. Serious Games for improving knowledge and self-management in young people with chronic conditions: A systematic review and meta-analysis. *J Am Med Inform Assoc JAMIA* Published Online First: 17 July 2015. doi:10.1093/jamia/ocv100
56. Orrell-Valente JK, Jarlsberg LG, Hill LG et al. At what age do children start taking daily asthma medicines on their own? *Pediatrics* 2008; **122**:e1186-1192.
57. GSMA and the Mobile Society Research. Children's use of mobile phones - A special report. 2015 http://www.gsma.com/publicpolicy/wp-content/uploads/2012/03/GSMA_Childrens_use_of_mobile_phones_2014.pdf (accessed 10 Nov2016).
58. Wu AC, Carpenter JF, Himes BE. Mobile health applications for asthma. *J Allergy Clin Immunol Pract* 2015; **3**:446–448.e16.
59. Mosnaim G, Li H, Martin M et al. A tailored mobile health intervention to improve adherence and asthma control in minority adolescents. *J Allergy Clin Immunol Pract* 2015; **3**:288–290.e1.
60. Annaim A, Lassiter M, Viera AJ et al. Interactive media for parental education on managing children chronic condition: a systematic review of the literature. *BMC Pediatr* 2015; **15**:201.
61. Quest for the Code <http://asthma.starlight.org/> (Accessed: 15th March 2016). <http://asthma.starlight.org/> (accessed 14 Mar2016).
62. Asthme: 1, 2, 3... Respirez! Available at <http://www.savie.qc.ca/CarrefourJeux2/Site/Jeux/Parchesi/infoParchesi.Asp?NoPartie=270> (Accessed: 15th March 2016). <http://www.savie.qc.ca/CarrefourJeux2/Site/Jeux/Parchesi/infoParchesi.Asp?NoPartie=270> (accessed 15 Mar2016).
63. Lungtropolis. Available at: <http://www.lungtropolis.com/> (Accessed: 15th March 2016).

Figure 1: Flowchart of systematic review and categorization

Figure 2: Classification of outcomes related to educational interventions based on Kirkpatrick model (28) adapted by Mosley (34)

Table 1: Overview of Included Serious Games

Table 2: Learning goals of Serious Games published in journal articles

Table 3: Outcome data for identified trials.

Table 1: Overview of Included Serious Games

Authors	Game	Audience	Game Genre	Platform	Development Team	Publication	Represented online?
Rubin et al (1986)(36)	Asthma Command	Asthmatic children 7-12 years	Management simulation	Computer	Not specified	Journal article	No
Bartholomew et al (2000)(38), Shegog et al (2001)(37)	Watch, Discover, Think and Act	Asthmatic children in elementary and middle school.	Training simulation	Computer	Medical experts, Programmers/game designers, Educationalists	Journal article	No
Yawn et al (2000)(42)	Air Academy: The quest for Airtopia	School children 6-12 years	Adventure	Computer	Medical experts, Programmers/game designers, Educationalists, Psychologists	Journal article	No
Homer et al (2000)(39)	Asthma control	Asthmatic children 3-12 years	Adventure, Platform	Computer	Medical experts, Programmers/game designers, Educationalists	Journal article	No
McPherson et al (2002)(53), McPherson et al (2006)(35)	The Asthma Files	Asthmatic children 7-14 years	Mini games, Quiz	Computer	Medical experts, Programmers/game designers, Psychologists	Journal article	No
Huss et al (2003)(40)	Wee Willie Wheezie	Asthmatic children 7-12 years	Platform	Computer	Medical expert	Journal article	No
Shames et al (2004)(41)	Bronkie's Asthma Adventure	Asthmatic children 5-12 years	Adventure	Super Nintendo	Medical experts, Programmers/game designers, Educationalists	Journal article	No
Howell (2005)(32)	Quest for the code	Asthmatic and school children 8-11 years	Mini games, Quiz, Adventure	Computer and web-based	Not specified	Thesis abstract	Yes(61)
Kaufman et al (2011)(52)	Asthma: 1,2,3 . . . Breath!	School Teens 14-18 years	Boardgame	Web-based	Medical experts, Programmers/game designers, Educationalists	Journal article	Yes(62)
Schroeder (2012)(33)	Lungtropolis	Asthmatic children 5-10 years	Mini games, Quiz, Puzzle	Web-based	Not specified	Conference abstract + Unpublished data	Yes(63)

Authors	Game	Pathophysiology of asthma	Recognition of triggers	Recognition of symptoms	Inhalation technique	Appropriate use of medications	Therapeutic compliance	Appropriate use of health services	Maintenance of normal activity (school attendance)
Rubin (1986)(36)	Asthma Command		X	X		X	X	X	X
Bartholomew (2000)(38), Shegog (2001)(37)	Watch, Discover, Think and Act		X	X		X	X	X	
Yawn (2000)(42)	Air Academy: The quest for Airtopia	X	X	X		X	X		
Homer (2000)(39)	Asthma control		X	X		X		X	X
McPherson (2002)(53), McPherson (2006)(35)	The Asthma Files		X	X		X		X	
Huss (2003)(40)	Wee Willie Wheezie		X	X		X			
Shames (2004)(41)	Bronkie's Asthma Adventure		X	X	X	X	X	X	
Howell (2005)(32)	Quest for the code	X	X	X		X		X	
Kaufman (2011)(52)	Asthma: 1,2,3 . . . Breath!		X	X		X			
Schroeder (2013)(33)	Lungtropolis	X	X	X		X		X	

Table 2: Learning goals of Serious Games published in journal articles.

Table 3: Outcome data for identified trials.

Authors	Study participants	Results	MERSQI Score (of 18)
Rubin et al (1986)(36)	65 asthmatic children 7-12 years	- K/SE: Higher improvement in children knowledge in the I group. No diff. for parent knowledge. No diff. in SE. - B: Improved behavior related to the management of asthma in children. No difference for parent behavior (questionnaire) - CO: No difference in the number of EV, hospital days, and school days absent.	18
Bartholomew et al (2000)(38)	133 asthmatic children 7-17 years	- K/SE: No difference between groups for child knowledge and SE. - CO: No difference on symptoms, functional status, HA, and EV when results were not adjusted on covariates. Decreased HA number when adjusted on baseline, sex and severity.	14.4
Yawn et al (2000)(42)	87 children 9-10 years	- K: Higher post-test knowledge scores in the I groups than in the C group*	12.5
Homer et al (2000)(39)	137 asthmatic children 3-12 years	- K: Higher child knowledge in the I group; No difference in parent knowledge - B: No difference on children behavior (questionnaire) - CO: No difference in asthma severity, functional status, mean number of EV* and acute office visits*	16.2
Shegog et al (2001)(37)	71 asthmatic children 8-13	- SE/K: No difference in self-efficacy, attribution, knowledge of asthma self-management (questionnaires)	13.5
McPherson et al (2002)(53)	10 asthmatic children 7-14 years	- K: Improvement pre/post on the Child Knowledge and Appraisal Questionnaire scores*	10
Huss et al (2003)(40)	101 asthmatic children 7-12 years	- K: No difference on the Pediatric Asthma Quality of Life Questionnaire, Air Control Questionnaire (on management strategy), Asthma knowledge test (on signs, symptoms, and cause of asthma) - CO: No difference on asthma symptoms*, lung function tests.	14.5
Shames et al (2004)(41)	119 asthmatic children 5-12 years	- K: Child knowledge: Higher score for the I group at W8 but not at W32 and W52. Parental knowledge: No difference at W8 but higher score for the I group at W32 and W52. - CO: No difference in asthma symptoms, lung function and acute visits.	15.6
McPherson et al (2006)(35)	101 asthmatic children 7-14 years	- K: Higher knowledge* scores in the I group at 1 month. - SE: Higher CALOC (Children's asthma locus of control) scores in the I group at 1 month. - CO: No difference on lung function, EV, HA, and steroid use at one month. Improved CO on steroids use and school absence at the 6-month follow-up but not significant in the intention-to-treat analysis.	16.5
Kaufman (2011)(52)	133 teens 14-18 years	- K: Significant improvement pre/post in knowledge*	10.5
Schroeder (2013)(33)	622 asthmatic children 5-10 years with their parents	- K/SE: Higher knowledge scores in children, not in parents. Higher self-efficacy scores in parents, not in children - B: No difference on medication adherence (questionnaire) - CO: No difference in attitudes, behavior, asthma control, EV and HA (data not shown for EV and HA)	11.5

I: intervention group; C: control group. SE: self-efficacy; K: Knowledge; B: Behavior; CO: Clinical outcomes.

EV: emergency visits. HA: hospital admissions. W: week. Asterixis (*) indicate the primary outcome for each study when defined by the authors.

A more detailed version of the table is presented in the supplemental material (Table S1)



